



Gastrointestinal nematode infection and feeding behaviour of goats in a heterogeneous vegetation: No evidence of therapeutic self-medication

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ABSTRACT

The aim of this study was to identify modifications in the feeding behaviour of goats browsing a tropical deciduous forest (TDF) when natural gastrointestinal nematode (GIN) infection was suppressed. Continuous bite monitoring through direct observation was implemented in 12 Criollo goats (adults, non-pregnant) foraging for 4 h per day during the rainy season. In the first Period (P1, one observation point) all goats were maintained with natural GIN infection. In the second Period (P2, three observation points), goats were equally distributed into 2 groups: i) moxidectin treated group (TG) used in a suppressive scheme; and ii) naturally infected group (IG). For each observation point, goats were monitored at three timepoints per day (80 min each), for three consecutive days, to estimate their intake of dry matter (DM), condensed tannins (CT), crude protein, metabolizable energy and digestible DM. Live weight (LW), faecal samples and blood samples were obtained every 28 days to determine LW change, faecal egg counts (FEC) and packed cell volume (PCV). During P1 and P2, the TG and IG had similar LW change and PCV. During both periods, the intake of DM, CT and all macronutrients were similar for TG and IG. The suppression of GIN infection did not modify the feeding behaviour of goats. Therefore, a therapeutic self-meditative behaviour was not identified in Criollo goats browsing a TDF.

1. Introduction

In patchy heterogeneous vegetation, goats may demonstrate flexible feeding behaviour, *i.e.* goats can shift from grazing to browsing and vice versa when moved to different grazing sites (Sanon et al., 2007; Ventura-Cordero et al., 2018). A change in feeding behaviour was associated with plant availability and nutritional imbalances of macronutrients (Ventura-Cordero et al., 2018), or the consumption of plant secondary compounds (PSC) (Rogosic et al., 2008). Furthermore, shifts in feeding behaviour were associated with certain breeds of goats (Aharon et al., 2007). There is a growing interest in identifying the capacity of animals to change their feeding behaviour as a strategy to alleviate disease (self-medication). It was hypothesized that small ruminants learn to increase their intake of PSC-containing feeds when experiencing a gastrointestinal parasitic infection and decrease the intake when the parasitic load was eliminated (Villalba et al., 2010). Previous studies suggested that small ruminants ingest a higher quantity of PSC, such as condensed tannins (CT), as a response to higher levels of gastrointestinal nematode (GIN) infection. This was confirmed

for sheep consuming alfalfa (*Medicago sativa*) + 10% quebracho tannin (*Schinopsis quebracho-colorado*) (Villalba et al., 2010) or beet pulp + 8% quebracho tannins (Juhnke et al., 2012), and for goats consuming *Lysiloma latifolium* (Martínez-Ortiz-de-Montellano et al., 2010) or *Pistachia lentiscus* (Amit et al., 2013). Such behaviour might be considered self-medication because the modification in terms of a higher CT consumption might be a response to parasitism (Singer et al., 2009). However, other recent studies including a field study using lambs grazing pastures of sainfoin (*Onobrychis viciifolia*) (Villalba et al., 2013), a pen study with lambs fed sainfoin pellets (Costes-Thiré et al., 2018), and a cafeteria study performed with Criollo goats naturally infected with GIN consuming four tropical plants (Ventura-Cordero et al., 2017) reported that GIN infection failed to modify the feeding behaviour of small ruminants.

To the best of our knowledge, no field study evaluating the effect of GIN suppression on goat feeding behaviour under a heterogeneous vegetation such as a tropical deciduous forest (TDF) has been reported. A study of feeding behaviour in heterogeneous vegetation should consider a wide range of opportunities to select feeds under high plant

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diversity. Continuous bite monitoring through direct observation method has been implemented in a TDF resulting in a grid of bite categories (BC) adapted to the conditions of this forest (González-Pech et al., 2014). This has enabled a detailed quantification of the different plants and plant parts or BC consumed by sheep and goats (González-Pech et al., 2015; Ventura-Cordero et al., 2019). This protocol can be used to study feeding behaviour, including macronutrient and CT intake, and whether goat feeding behaviour changes when animals are exposed to a suppressive anthelmintic (AH) treatment with moxidectin. The moxidectin treatment scheme was selected because it has a 28-day persistent effect against GIN in goats (Torres-Acosta and Jacobs, 1999). Such AH management has been used in previous field studies with kids in a TDF to maintain them free of GIN infection (Torres-Acosta et al., 2004; Torres-Acosta et al., 2006). Therefore, this study aimed to identify modifications in the feeding behaviour of goats browsing a TDF when natural gastrointestinal nematode infection was suppressed.

2. Materials and methods

2.1. Study site

This study was performed from June to September during the rainy season in Mérida, Yucatán, México (20 52'7.14"N, 89 37'24.04"W). The climate of the study area was warm and humid with summer rain. The mean maximum and minimum temperatures reported throughout the months of the study were 36.2 °C and 24.0 °C respectively, with a cumulative rainfall of 695.8 mm. The grazing areas included 2.8 ha of native vegetation corresponding to a TDF (Flores et al., 2006) and included different species of plants corresponding to different habits (creeper/climbers, dicot herbaceous, grasses and shrubs) (Ventura-Cordero et al., 2019).

2.2. Animals and experimental conditions

The study farm of the Faculty of Veterinary Medicine, Universidad Autónoma de Yucatán, Mexico (FMVZ-UADY) had a mixed flock of 30 adult Pelibuey/Blackbelly hair sheep and 70 adult Criollo goats with many years of browsing experience in the TDF. Twelve female goats were selected from the goat herd according to the following criteria: a) good dental and locomotive system condition; b) non-dominant members of the flock; c) non-pregnant; d) 7 ± 2 years old; and e) live weight (LW) of 36.3 ± 4 kg. The experiment was divided into two experimental periods. Period 1 (P1) lasted for 28 days and included one observation point (Fig. 1). In that period all twelve goats were kept with their natural GIN infection. Animals were divided into two groups of six goats balanced according to age, LW, parturition number and faecal egg count (FEC) (groups TG and IG). Period 2 (P2) lasted for 84 days and included three observation points (Fig. 1). Goats in the treated group (TG) were dewormed with moxidectin (0.3 mg/kg LW sub-cutaneously) every 28 days from the beginning of P2. This protocol aimed to maintain goats without GIN infection while browsing the TDF as

reported by Torres-Acosta et al. (2004, 2006). The infected group (IG) maintained their natural GIN infection throughout the experimental period. The number of animals included in each experimental group was higher than the minimum number required for grazing behaviour studies (Penning et al., 1993), preference studies (Parsons et al., 2018) and co-grazing studies with sheep and goats (Yiakoulaki et al., 2009).

Experimental goats browsed alongside the complete sheep and goat flock for 4 h per day (7:00 am–11:00 am). After returning to their pens, animals were separated and maintained in individual cages with water *ad libitum* and supplemented with 0.5% of LW with sorghum meal. The LW of the animals was measured every 28 days.

2.3. Intake estimations through continuous bite monitoring by direct observation

Continuous bite monitoring using the direct observation method (Agreil and Meuret, 2004) was implemented on the TDF. The independence of observations, as well as a good power for the comparisons of dry matter intake was reported for this methodology in a TDF (González-Pech et al., 2015). Briefly, the procedure included: (a) a familiarization period to habituate animals to the presence of human observers, and *vice-versa* (González-pech et al., 2018); (b) the use of a coding grid of BC adapted to the conditions of a TDF (González-Pech et al., 2014); (c) the coding grid was coupled with manual harvest simulations to estimate the weight for every BC of every plant species consumed (gram of dry matter, g DM) (Ventura-Cordero et al., 2019); (d) audio recording of BC codes for all observed plants consumed by goats; and (e) capturing audio data and statistical analyses of all BC for every plant species.

For the present study, intake observations were arranged using a Latin rectangle square design on 3 consecutive days and 3 goats for 3 schedules of 80 min (focal sampling; Altman, 1974) and four observers in total. This design enabled the observation of 12 experimental goats once per month (25 days between observations) and accounted for variability associated with grazing area, environmental conditions, observers and shearers. As mentioned above, four observations points were used, one observation point during P1 and three observations points during P2. Each observer could identify each observed goat, but the observers were blinded to which group each experimental goat was assigned to.

2.4. Macronutrient and condensed tannin consumption

Plant samples were collected, and plant species were identified in the FMVZ-UADY herbarium. The DMI was estimated for each plant species by adding the total number of observed bites for every BC. Then, the sum of the DMI from all plant species was used to calculate the total DMI for each goat. Plants that were consumed > 1% of the DMI were identified. The crude protein intake (CPI), metabolizable energy intake (MEI), digestible DM intake (DDMI) and CT intake (CTI) were estimated as a product of the DMI and the chemical values [crude

Experimental days		0	14	28	42	56	70	84	98	112
Habituation Period		Period 1		Period 2						
		Observation point 1		Observation point 2	Observation point 3		Observation point 4			
Treated group (TG) n=6		Naturally infected		Dewormed	Dewormed		Dewormed			
Infected group (IG) N=6		Naturally infected		Naturally infected	Naturally infected		Naturally infected			
Faecal samples	FEC	FEC		FEC		FEC		FEC		
Blood samples	PCV	PCV		PCV		PCV		PCV		
Weight	LW	LW		LW		LW		LW		

Fig. 1. Experimental design used to identify changes in the feeding behaviour of Criollo goats browsing heterogeneous vegetation when gastrointestinal nematode infection is suppressed.

protein (CP), metabolizable energy (ME), *in vitro* dry matter digestibility (IVDMD) and CT] of forages consumed at > 1% of the DMI, as reported previously in a contemporary study (Ventura-Cordero et al., 2019).

For the present study, plants consumed at > 1% of the DMI and with a CT content > 5% were considered as tannin rich plants (TRPs). The latter were in accord with studies on temperate forages, where 5.5% CT was the threshold value to classify plants as tannin rich (Min et al., 2003; Waghorn and McNabb, 2003).

2.5. GIN infection level and packed cell volume

The GIN infection level was monitored every 28 days from faecal samples gathered directly from the rectum of individual animals. The FEC was estimated during three consecutive days using the McMaster technique. Subsequently, faecal cultures were generated following the Corticelli and Lai (1963) technique, and the genera of GIN L₃ larvae were identified according to the keys of identification reported by Bowman and Lynn (1999). Every 28 days, blood samples were obtained from the jugular vein before the foraging activity of goats. Blood samples were preserved by refrigeration at 4 °C until the packed cell volume (PCV) was determined using the microhematocrit method (Hansen and Perry, 1994).

2.6. Data and statistical analysis

Data from bites, DMI, CTI, CPI, MEI, DDMI, PCV, LW, and the intake of *Gymnopodium floribundum*, *Leucaena leucocephala*, *Mimosa bahamensis*, *Neomillspaughia emarginata*, and *Eragrostis amabilis* as well as the FEC (egg per gramme of faeces, EPG) were assessed using respective linear mixed models. The normality of residuals and the respective homogeneity of variances for each variable were confirmed. Therefore, when the residuals showed a normal distribution, PROC MIXED was selected, and when residuals did not show a normal distribution, PROC GLIMMIX was used.

PROC MIXED used the REPEATED statement to define the variance structure for repeated measurements. The autoregressive covariance structure was used to account for measurements being made at successive observation points (1–4). The MODEL statement was similar for each dependent variable (DMI, CPI, bites, PCV, LW). The fixed effects were treatment (TG, IG), observation point (1–4) and treatment × observation point interactions. The SUBJECT statement referred to goats nested within treatments, defined as the variable on which repeated measurements were obtained. Goats were considered a random factor (Costes-Thiré et al., 2018).

PROC GLIMMIX used the compound symmetry type covariance structure to consider measurements repeated over time in the same goat. The MODEL statement included dependent variables (CTI, MEI, DDMI, EPG, and intake of *G. floribundum*, *L. leucocephala*, *M. bahamensis*, *N. emarginata* and *E. amabilis*), and fixed effects including treatment (TG, IG), observation point (1–4) and treatment × observation point interaction. The SUBJECT statement referred to goats nested within treatments, and goats were considered a random effect (Bueso-Ródenas et al., 2014). The observation point was the only fixed effect included in the MODEL for the FEC dependent variable. All reported values are the least square means.

3. Results

3.1. Plant species consumed by goats

A total of 35 plant species were consumed by goats, of which 28 were consumed at < 1% of the daily DMI and 7 plant species were consumed at > 1% of the daily DMI (Table 1). A total of 31 plant species as well as fallen leaves and pods had < 5% CT content. The leaves from 4 plant species, *G. floribundum*, *L. leucocephala*, *M.*

bahamensis and *N. emarginata*, were considered TRP as they provided > 5% CT. Considering the habit of consumed plant species, the contribution to the daily DMI of goats during all experimental periods was 6.3% creeper/climbers, 2.4% dicot herbaceous, 63.3% grass, 27.8% shrubs and 0.2% from fallen leaves or pods.

3.2. Feeding behaviour and macronutrient intake

A total of 76,000 bites were recorded during the whole study. The mean number of bites/day/goat was affected by the observation point ($P = 0.002$), while the treatment and treatment × observation point interactions were not significant ($P > 0.05$). At the first observation point, there was a mean of 1652 bites/day/goat. During the second observation point, there was an increased number of bites, 2254 bites/day/goat ($P < 0.05$). However, there were significantly reduced numbers of bites at points 3 and 4 (1424 and 1312 bites/day/goat, respectively; $P < 0.05$).

The *E. amabilis* grass was the only plant material consumed in different quantities during the study periods: $92.44 < 454.26 = 386.19 > 201.59$ g/DM at observation points 1, 2, 3 and 4, respectively ($P < 0.001$).

Goats in the IG and TG had a similar consumption of macronutrients at all observation points (Table 2). The observation point effect was significant for DMI, CTI, MEI and DDMI ($P < 0.05$). The DMI, MEI and DDMI were lower at observation points 1 and 4 compared with observation point 2 ($P < 0.05$), whereas the CTI at observation point 1 was higher than that of the other 3 observation points.

3.3. Condensed tannin consumption obtained from tannin rich plants

Table 3 shows the consumption of CT from TRP by experimental goats browsing heterogeneous vegetation. The effect of moxidectin suppressive treatment was not significant. Consequently, goats in the IG and TG harvested similar amounts of CT from TRPs ($P > 0.05$).

3.4. GIN infection level, faecal cultures, packed cell volume and live weight

The AH treatment effect was not significant for the PCV ($P = 0.398$) or LW change ($P = 0.741$). No significant effect was observed for the interaction between treatment × observation points for the variables PCV ($P = 0.599$) and LW change ($P = 0.293$).

The evolution of the FEC and PCV for the treated (TG) and infected (IG) groups throughout the observation points is shown in Fig. 2. During all experimental points, the IG had a similar EPG ($P > 0.05$, Fig. 2). In the second period, the suppression of GIN infection was verified in the TG (EPG = 0) (Fig. 2).

Observation point had a significant effect on the PCV and LW change variables ($P < 0.05$). During observation points 1, 2 and 3, the PCV was similar (23.33%, 24.50% and 22.75%, respectively; $P > 0.05$). However, at the last observation point, the PCV was increased to 24.75% ($P < 0.05$).

The initial LW of Criollo goats was 36.31 kg, which was reduced to 35.55 kg LW at the second observation point ($P < 0.05$) but increased to 37.56 and 39.43 kg LW at observation points 3 and 4, respectively ($P < 0.05$).

Faecal cultures obtained from experimental goats showed a mixed natural infection during P1. Faeces from the IG group contained 40.98% *Haemonchus* spp, 39.03% *Trichostrongylus* spp and 19.98% *Oesophagostomum* spp. In the same period, faeces from the TG group contained 52.38% *Haemonchus* spp, 33.33% *Trichostrongylus* spp and 14.29% *Oesophagostomum* spp. During the four observation points, the natural GIN infection of IG goats consisted of 15.38% *Haemonchus* spp, 46.15% *Trichostrongylus* spp and 38.46% *Oesophagostomum* spp.

Table 1
Plant species consumed by infected and dewormed goats browsing a tropical deciduous forest.

Habit of plants	Plant species
Creeper/Climber	<i>Cardiospermum halicacabum</i> , <i>Ipomoea crinicalyx</i> [*] , <i>Ipomoea nill</i> , <i>Morinda royoc</i> , <i>Passiflora foetida</i>
Dicot herbaceous	<i>Alternanthera flavescens</i> , <i>Blechum pyramidatum</i> , <i>Bourreria pulchra</i> , <i>Cnidioscolus aconitifolius</i> , <i>Gymnopodium floribundum</i> [*] , <i>Lantana Cámara</i> , <i>Parthenium hysterophorus</i> , <i>Sida acuta</i> , <i>Tetramerium nervosum</i> , <i>Waltheria indica</i> [*]
Grass	<i>Lasiacis divaricata</i> , <i>Chloris inflata</i> , <i>Eragrostis amabilis</i> [*] , <i>Eragrostis ciliaris</i>
Shrubs	<i>Acacia collinsi</i> , <i>Acacia pennatula</i> , <i>Caesalpinia gaumeri</i> , <i>Leucaena leucocephala</i> [*] , <i>Lysiloma latisiliquum</i> , <i>Mimosa bahamensis</i> [*] , <i>Senegalia gaumeri</i> , <i>Bahinia divaricata</i> , <i>Bunchosia swartziana</i> , <i>Cordia alliodora</i> , <i>Diospyros anisandra</i> , <i>Neomillspaughia emarginata</i> [*] , <i>Piscidia piscipula</i> , <i>Randia aculeata</i> , <i>Solanum trydanum</i> , <i>Viguiera dentata</i>
Various	Mixture of dry leaves, Mixture of pods

* Plant species consumed at 1% of daily dry matter intake or higher.

4. Discussion

The ability of animals to change their feeding behaviour to alleviate disease (i.e. self-medication) has been the focus of recent research. Therefore, this study aimed to identify modifications of feeding behaviour of goats browsing a TDF when natural GIN infection was suppressed.

4.1. Plant species consumed by goats

The plant species consumed by infected and dewormed goats in the TDF were consistent with previous studies performed in similar types of vegetation during the rainy and dry season (Flores and Bautista, 2012; González-Pech et al., 2015; Ventura-Cordero et al., 2019). This is the first study to identify the consumption of the herb *Lantana camara* in goats grazing the TDF. Of note, *L. camara* was toxic to ruminants causing hepatic lesions and photosensitivity (Bath and De Wet, 2000). However, it was reported that cattle and goats in Zimbabwean rangeland readily consumed *L. camara* without toxicity (Gusha et al., 2016). In our study, *L. camara* consumption represented less than 1% of the DMI. Therefore, goats might have not crossed the *L. camara* intake threshold to cause toxicity or clinical signs.

The proportion of grass species included in the diet of goats was twice the quantity of shrubs consumed by goats. Such a high proportion of grass in the diet can be considered a behavioural adaptation of goats to the TDF, which is an environment characterized by a high CP contribution from many plant species that are included in the diet of these animals (González-Pech et al., 2015). Under such conditions, goats need to ingest plant species with a low protein content to balance the protein:energy consumption. Furthermore, a previous field feeding behaviour study reported that the inclusion of grass as a source of dietary energy might be a means to complement the nutritional characteristics of shrubs species (Revell et al., 2013). This type of behaviour (high consumption of grass) was only possible because the study was performed during the rainy season when grass species are abundant in the

TDF. Other field studies performed in dessert rangelands or during the dry season in the TDF of México, showed that browsing Criollo goats consumed less grass (7.8%) than shrubs (92.1%) (Allegretti et al., 2012). In addition, Criollo goats browsing the TDF during the dry season only consumed 5.5% of grass, 36.3% of shrubs and 41.4% of fallen pods and leaves (González-Pech et al., 2015). In these studies, goats might have been exposed to very low grass availability. Therefore, Criollo goats could not increase the consumption of grass materials to balance their protein:energy requirement.

4.2. Feeding behaviour and macronutrient intake

During the first period of this study when goats in the two groups had a natural infection, there was no difference in their feeding behaviour, as demonstrated by a similar number of bites and DMI for animals in the IG and TG. Furthermore, the suppression of natural GIN infection in the TG was not enough to trigger changes in the feeding behaviour of goats. The shift from naturally infected to non-infected status in the TG did not promote an adjustment in the feeding behaviour expressed as the number of bites, DMI, CPI, DDMI and MEI. This indicated that the whole macronutrient intake pattern may be better explained as an adjustment by animals to meet nutrient requirements, rather than coping with the GIN infection. The present study observed that macronutrient consumption changed at the different points of observation (from 1 to 4), except for the CPI which might have already been in excess of the animals' requirements (Ventura-Cordero et al., 2019). These findings suggest that goats adjust their intake to meet their nutrient requirements and is not associated with parasitic status. Although the present study did not measure the plant biomass throughout the experimental periods, and therefore cannot confirm the role of plant availability on intake, recent studies showed that plant availability, including that of TRP, is neither limiting the consumption nor the selection of goats (Ventura-Cordero et al., 2018).

Table 2
Daily dry matter and macronutrient intake by infected and dewormed goats browsing a tropical deciduous forest.

	Observation point 1		Observation point 2		Observation point 3		Observation point 4		SEM	Treatment effect	Point effect	T × P
	IG	TG	IG	TG	IG	TG	IG	TG				
DMI (g DM)	329.89	336.10	617.98	708.60	548.52	487.56	322.30	548.56	97.277	0.367	0.014	0.492
CTI (g CT/ kg DM)	76.91	55.47	19.18	37.70	14.39	12.19	17.91	22.93	9.038	0.997	0.001	0.129
CPI (g CP/ kg DM)	45.54	49.09	66.82	78.56	59.21	58.99	43.46	53.47	11.046	0.420	0.097	0.964
MEI (Mcal/ kg DM)	0.33	0.42	1.18	1.30	1.06	0.93	0.57	0.66	0.184	0.725	0.001	0.909
DDMI (g DDM/ kg DM)	90.14	114.34	305.1	336.63	272.9	241.95	150.0	172.37	47.489	0.715	0.001	0.911

DMI = dry matter intake, CTI = condensed tannin intake, CPI = crude protein intake, MEI = metabolizable energy intake, DDMI = digestible dry matter intake. IG = infected group, TG = treated group. SEM = standard error of the mean.

Table 3

Condensed tannin consumption (g/day) from tannin rich plants by infected and dewormed goats browsing a tropical deciduous forest.

Intake (g CT/day)	Observation point 1		Observation point 2		Observation point 3		Observation point 4		SEM	Treatment effect	Point effect	T × P
	IG	TG	IG	TG	IG	TG	IG	TG				
<i>Gymnopodium floribundum</i>	30.87	26.1	7.42	11.76	3.38	2.71	5.79	7.17	3.678	0.984	0.001	0.552
<i>Leucaena leucocephala</i>	3.56	4.99	5.02	8.86	3.53	4.52	4.60	7.15	1.850	0.287	0.152	0.751
<i>Mimosa bahamensis</i>	6.44	5.88	5.90	11.36	2.79	2.33	5.21	4.60	2.344	0.622	0.071	0.446
<i>Neomillspaughia emarginata</i>	35.59	17.79	0.29	5.20	4.24	2.12	1.91	3.58	5.984	0.410	0.001	0.279

IG = infected group, TG = treated group, SEM = standard error of the mean.

4.3. Condensed tannin consumption from tannin rich plants

In the present study we explored the consumption of TRP by goats and how this consumption was affected by their GIN infection status. We asked why adult Criollo goats free to graze the TDF did not increase or decrease CTI according to their GIN infection status? We hypothesized that the low GIN burden (measured as FEC) did not provoke any signs of infection that could be alleviated by the intake of CT-rich feeds. Earlier studies by Lisonbee et al. (2009) reported that infected lambs consumed more grape pomace plus quebracho tannin (70:30%) when they had higher infections compared with non-infected lambs. However, the consumption of a CT rich supplement was reduced when the parasitic burden was decreased. Furthermore, a direct relationship between GIN infection and a preference for CT-rich feeds, in the form of medicinal feed, was also suggested in a sheep pen trial (Juhnke et al., 2012). In our study, naturally infected goats (IG) showed a similar CTI pattern to that of dewormed goats (TG) indicating that parasitic status was irrelevant. The CTI was higher at observation point 1 for both experimental groups compared with observation points 2, 3 and 4. The same pattern was observed for the intake of the 2 TRP with the highest CT content (*G. floribundum* and *N. emarginata*; Table 3). Therefore, goats substituted these TRPs for a higher intake of *E. amabilis* grass, characterized by a null CT content (Ventura-Cordero et al., 2019). The latter is in agreement with a previous study indicating that animals aimed to balance the protein:energy ratio in a heterogeneous vegetation environment (Ventura-Cordero et al., 2018), while possibly reducing any negative impact of CT, even when any possible AH effect is lost in the naturally infected group (IG) (Trade-off) (Méndez-Ortiz, 2018).

4.4. GIN infection level, faecal cultures, packed cell volume and live weight

The FEC displayed by goats in the IG was low and similar during all experimental observation points (Fig. 2). This low level of GIN infection is common in goats browsing native vegetation in Yucatan (Torres-Acosta et al., 2014). The foliage consumed from plant species in the

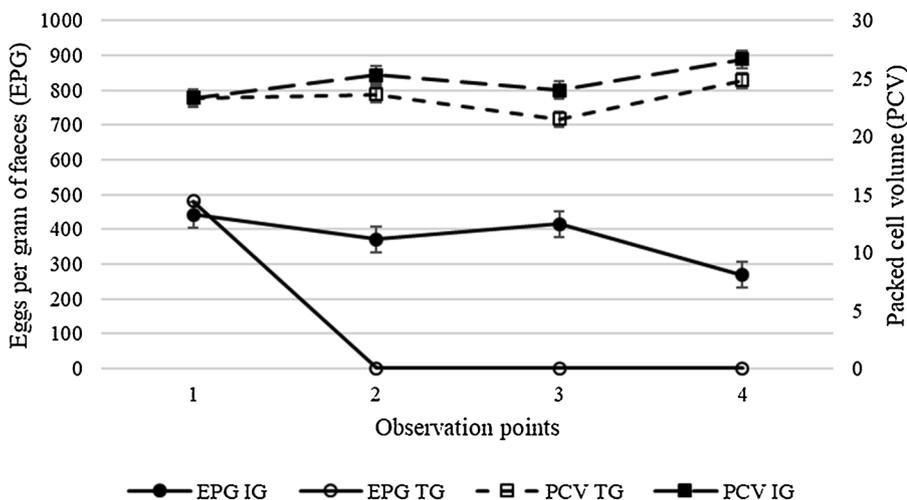


Fig. 2. Evolution of faecal egg count and packed cell volume of treated (TG) and infected (IG) groups at all observation points during the experimental period. The solid lines represent the faecal egg count of the Infected group (black circles) and Treated group (open circles). The dashed lines represent the packed cell volume of the Infected group (black squares) and the Treated group (open squares).

TDF did not further reduce the FEC of infected goats (IG) at all observation points. Therefore, a therapeutic self-medicative behaviour was not identified in Criollo goats browsing a TDF. However, the goats maintained a low FEC throughout the observation points during the rainy season (~500 EPG) (Fig. 2). This low GIN infection level might be related to: i) a low infectivity of the TDF (~3000 L₃/kg DMI; Jaimez-Rodríguez et al., submitted); ii) adult goats may have a strong immunity against GIN, which causes a low infection; and iii) the PSC from many different plant species consumed by goats in the TDF, many of which have *in vitro* AH activity against GIN (Castañeda-Ramírez et al., 2017; Castañeda-Ramírez et al., 2018). The AH activity of CT has been widely investigated for many temperate and tropical plant species (Hoste et al., 2012). As a result, the present trial focused on identifying the potential behavioural modification of goats towards TRPs. Here, we confirmed that goats did not modify their behaviour.

Recent studies showed an important interaction between the CT and other secondary compounds leading to higher or lower AH activity, at least under *in vitro* conditions. For example, Castañeda-Ramírez et al. (2017) reported that extracts from the foliage of *L. leucocephala*, *P. piscipula*, *L. latisiliquum*, *A. pennatula* and *B. swartziana* incubated with polyvinylpyrrolidone (PVPP), used as a tannin blocking agent, increased the AH activity against *H. contortus* eggs. These and other plant species with *in vitro* AH activity were consumed by goats grazing the TDF in our study. Therefore, interactions of PSC must also consider the phytochemical profile of each plant. A qualitative phytochemical analysis from the extracts of *L. leucocephala*, *P. piscipula*, *L. latisiliquum*, *A. pennatula* and *B. swartziana* resulted in the positive identification of saponins, alkaloids, and terpenes (Mancilla, 2018). All these PSCs can act alone, together or even as an antagonist of their AH activity (Katiki et al., 2017). In such a complex environment, once the animal detects plants that provide nutrients, and which might promote beneficial effects (such as AH activity), there might be no motivation to change their feeding behaviour unless a negative consequence appears (i.e. toxicity, antagonist effects). However, a recent study in the TDF suggest that the feeding behaviour of goats is dynamic and depends on the nutritional

context of the grazing site in the heterogeneous vegetation (Ventura-Cordero et al., 2018).

The PCV values displayed by the IG and TG were similar. Therefore, natural GIN infection in IG animals did not disturb their homeostasis (anaemia). This result also supports the absence of motivation to change their feeding behaviour. In contrast, the work by Amit et al. (2013) showed that parasitized Mamber goats had a lower PCV than non-parasitized goats, and that these clinically affected parasitized goats consumed more TRP. The difference between studies suggests that the presence or absence of a change in feeding behaviour depends on the parasitic infection level. This was confirmed by the similar LWC between experimental groups. A recent meta-analysis study showed that > 2,500 adult parasites are necessary to observe a significant negative impact on the LW change in lambs (Méndez-Ortíz et al., 2019).

5. Conclusion

The suppression of natural GIN infection did not modify the feeding behaviour of goats browsing a TDF. Criollo goats naturally infected with GIN (IG) or treated with moxidectin (TG) had similar DMI, CTI, CPI, MEI and DDMI. The suppression of GIN infection did not affect LW change or PCV in Criollo goats. The latter suggests the GIN infection was insufficient to trigger a change in the feeding behaviour of goats. Therefore, therapeutic self-medicative behaviour was not identified in Criollo goats browsing a TDF.

Criollo goats obtain nutrients from the TDF but its high CP content leads goats to search for low protein feedstuffs such as grass despite the greater risk of GIN infection. This study suggests the existence of prophylactic self-medication that might be driven towards balancing the energy:protein ratio of harvested plant materials. This information might aid the design of supplementation strategies to help browsing animals achieve optimal productivity. Animals with an enhanced nutritional status will require less AH treatment with commercial drugs, which might help delay the development of AH resistant worms.

Ethical statement

All procedures performed in studies involving animals were in accordance with the ethical standards of the institution at which the studies were conducted.

Conflict of interest statement

The authors declare that they have no conflict of interest that could have direct or potential influence or impart bias on the work included in this paper

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