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Comparing body condition score and FAMACHA© to identify hair-sheep ewes with high faecal egg counts of gastrointestinal nematodes in farms under hot tropical conditions

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ABSTRACT

Data from a targeted selective treatment (TST) survey in three sheep farms was used to compare body condition scores (BCS) ≤ 2 and FAMACHA© scores ≥4 or ≥3 as criteria to identify ewes with ≥ 750 eggs per gram of faeces (EPG), and to confirm whether that EPG threshold allowed maintaining a large proportion of animals with no anthelmintic (AH) treatment. The survey included monthly data from all grazing adult ewes in three commercial farms. Farms 1 and 3 were surveyed for 11 months, and Farm 2 for 6 months, with a total of 7342 events recorded. Mean monthly population consisted of 330 ewes (Farm 1), 129 ewes (Farm 2) and 265 ewes (Farm 3). The FAMACHA© scores and BCS of adult ewes were recorded monthly. Ewes with FAMACHA© ≥ 4 or BCS ≤ 2 were faecal sampled to determine faecal egg counts (FEC) (2788 events). Ewes with ≥ 750 EPG were treated with an AH (658 events). The TST survey showed that BCS ≤ 2 was the best criteria to find ewes with FEC ≥ 750 EPG, with 1.1% false negatives. Meanwhile, FAMACHA© ≥4 or ≥3 failed to identify half of the events with ≥ 750 EPG (50–55% false negatives). Thus, the TST scheme could focus on screening ewes with BCS ≤ 2, and the FEC of those animals can avoid unnecessary AH treatments. The TST scheme was easier to implement at the farm with largest ratio of ewes with BCS > 2, as fewer ewes were sampled and treated, compared to farms where many ewes had BCS ≤ 2. In the surveyed farms a threshold of ≥ 750 EPG resulted in 63.5% of all ewes maintained with no AH treatment for the duration of the survey.

1. Introduction

Control of gastrointestinal nematode (GIN) populations is becoming a difficult task in many countries around the world due to the widespread existence of worm populations with resistance against two or more anthelmintic (AH) classes (Torres-Acosta et al., 2012). In tropical México, the presence of resistance against two or three AH classes is a common feature in many sheep farms (Herrera-Manzanilla et al., 2017; Sepúlveda-Vázquez et al., 2017). As the situation of AH resistance worsens, it is necessary to seek for new management practices to delay further development of resistant GIN isolates. One way to reduce AH drug use is to implement targeted selective treatment (TST) schemes aiming to treat only those animals within the flock that need treatment rather than treating the whole herd (Cabaret, 2003; Van Wyk et al., 2006; Berrag et al., 2009). At present, the faecal egg count (FEC) of GIN eggs is the sole variable strongly correlated to the number of GIN inside sheep and goats (Cabaret et al., 1998; Cringoli et al., 2008). However, the use FEC in a TST scheme is impractical and unprofitable for commercial farms as it claims a great deal of time, effort and cost to obtain individual FEC (Stafford et al., 2009). Many other TST methodologies have proposed treating animals according to other criteria including the FAMACHA© card to identify anaemia (Molento et al., 2009), weight gain (Busin et al., 2014), milk production (Hoste et al., 2002), body condition score (BCS) (Honhold et al., 1993; Cornelius et al., 2014), breech soiling (Busin et al., 2014) and the diarrhea score (Cabaret et al., 2006). However, those TST tools cannot ensure that signs or criteria are truly or solely associated to high GIN infections. Consequently, Torres-Acosta et al. (2014) proposed a combined TST scheme in which a faecal

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[1] Rest in peace.

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sample is obtained from animals with FAMACHA© scores ≥ 4 or BCS ≤ 2, and the AH is dosed only to those animals crossing a FEC threshold in naturally infected animals at farm level. Such TST scheme was built and validated for sheep and goats under hot humid tropical conditions of México using a threshold ≥ 750 eggs per gram of faeces (EPG), and such TST scheme avoided unnecessary AH treatments for > 70% of sampled adult hair-sheep (Medina-Pérez et al., 2015). However, recording FAMACHA© and BCS of all grazing ewes on a monthly basis represents a great work burden for farmers. Thus, it is necessary to investigate whether both criteria are equally necessary to select animals to be faecal sampled, or whether either of those criteria could be preferred to reduce the workload at the farm without causing unwanted health problems due to false negative events with high EPG but not detected by screening tools such as BCS or FAMACHA©. Data from a survey using a TST scheme in three sheep farms was used to compare BCS ≤ 2 and FAMACHA© scores ≥ 4 or ≥ 3, as criteria to identify ewes with FEC ≥ 750 EPG, and to confirm whether that EPG threshold allowed maintaining a large proportion of ewes without AH treatment.

2. Material and methods

2.1. Features of surveyed farms

The survey was carried out in three commercial sheep farms between the years 2011 and 2012. The farms were located in the municipalities of Poxilá (Farm 1: 20°49′ N, 89°48′ W), Yaxcabá (Farm 2: 20°36′ N, 88°49′ W) and Umán (Farm 3: 20°50′ N, 89°44′ W) in Yucatán state, México. Data from the different farms surveyed included eleven months of records on Farms 1 and 3, and six months of records at Farm 2 as the owner closed its premises due to administration problems. The study commenced with three months of the dry season (March, April and May) and continued with six rainy season months (June–November), and the last two months (December and January) were also considered dry season according to Flores-Guido and Espejel-Carvajal (1994). Climatological data recorded for each month of the survey in the study region were obtained from the meteorological service CINVESTAV-México, and included the minimum and maximum mean ambient temperatures (ºC), relative humidity (%) and monthly rainfall (mm) (CINVESTAV, 2017).

Adult animal population in each farm varied from 221 to 361 adult ewes (mean of 330 ewes) for Farm 1, from 66 to 173 adult ewes (mean of 129 ewes) for Farm 2, and from 205 to 291 adult ewes (mean of 265 ewes) for Farm 3. All farms had adult hair-sheep breeds mainly Pelibuey and Katahdin with some ewes crossed with Blackbelly or Dorper. Feeding of ewes was based on diurnal grazing during approximately 8 h per day, and after that animals were kept indoors overnight. The grazing paddocks in the surveyed farms included a high proportion of introduced grass species (mainly *Cynodon plectostachyus* and *Brachiaria brizantha*) and some shrubs typical of the tropical deciduous forest (i.e. *Leucaena leucocephala*). Paddocks were not used under any rotation scheme.

Dietary supplementation was provided daily inside the pen to all adult females. The supplementary feeding used in the three farms included a concentrate feed and freshly chopped *Pennisetum purpureum* grass. Each farmer decided the quantity of supplements offered to their ewes every day. When possible, farmers tried to increase the quantity of concentrate feed during late pregnancy and lactation in an attempt to supply sufficient food to match the requirements of their animals. The farms had similar reproductive programmes, with ewes lambing every 8–9 months without any reproductive seasonality. Thus, the study included groups of ewes on different reproductive physiological stages. The three farms had veterinary supervision. Prior to the survey, GIN control was based solely on the frequent use of AH drugs, and frequency varied according to farmers' perceptions.

2.2. FAMACHA© and body condition score (BCS)

Farms were visited once every 30 days. All adult ewes present at each farm on the day of the visit were individually explored to determine their FAMACHA© score using the original card as described by van Wyk and Bath (2002), with a 64.3% sensitivity and 91.3% specificity to detect anaemic sheep (packed cell volume ≤ 19%) when using FAMACHA© ≥ 4 (Kaplan et al., 2004). The same two trained persons recorded the colour of the conjunctiva of the lower eyelids of both eyes of all ewes throughout the survey. Both researchers used the correct technique to manipulate the eyelids of sheep and used the original FAMACHA© card to evaluate all the animals.

The BCS of each animal was also determined following the protocol described by Russel (1984), where 1 corresponded to emaciated animals, and 5 to overfed animals. Animal identification, FAMACHA© score and BCS were recorded for every animal on each monthly visit.

2.3. Criteria to obtain a faecal sample and estimation of faecal egg counts

Ewes showing FAMACHA© scores ≥ 4, BCS ≤ 2, or both criteria, were sampled directly from the rectum to obtain faeces that were used to determine FEC as previously described for tropical goats (Torres-Acosta et al., 2014), and for hair sheep (Medina-Pérez et al., 2015). Faeces were placed in new plastic bags clearly labeled with respective animal numbers and were taken to the Parasitology Laboratory at the Veterinary Faculty, Universidad Autónoma de Yucatán, for processing. Faecal samples were processed with a modified McMaster technique, with a sensitivity of 50 EPG of GIN using 2 g of faeces per animal as described by Bauer et al. (2010). The individual FEC of all sampled animals was added to the database containing animal identification, FAMACHA© scores and BCS. The McMaster technique allowed counting *Eimeria* spp. oocysts as well as eggs of *Trichuris* spp. and *Moniezia* spp., but those parasites were scarce in all surveyed animals. As confirmed by previous studies using tracers to evaluate pasture infectivity in the north of the Yucatán peninsula (Torres-Acosta et al., 2004, 2006), the presence of *Fasciola hepatica* was not expected because there are no superficial rivers or lakes. Hence, faecal samples were not submitted to sedimentation tests.

2.4. Criteria to treat animals with an anthelmintic drug

On each monthly visit, all the sampled ewes with FEC ≥ 750 EPG received an AH treatment. The choice of AH class used was based on prior evaluation of drug efficacy in each surveyed farm before the study commenced. Farms 1 and 2 were treated with levamisole at 7.5 mg kg^{-1} by subcutaneous route. Animals at Farm 3 were treated with albendazole at 5.0 mg kg^{-1}. Sampled animals with FEC < 750 EPG were not treated with AH. These activities were included in the record of each farm. Same management was repeated every month of the survey.

2.5. Statistical analysis

Every adult sheep assessed within the TST scheme provided an event for that respective month and farm. Every ewe included in the survey provided at least one event, and a maximum of eleven events for each farm. Each event was considered an independent value as it was obtained with at least 30 days difference from any other recorded event, time in which that ewe could change its physiological status (mating, pregnancy or lactation) or changed grazing conditions on different months and different seasons (dry or wet season). Databases of each farm included all the events of the month with BCS (from 1 to 5), FAMACHA© scores (from 1 to 5), individual EPG, and whether animals were treated with an AH or not. Events recorded in each farm were used to determine: (i) total number of events, which included all the animals in the surveyed farms, (ii) sampled events, which included all events with a faecal sample, and (iii) events treated with AH, which included all events treated with AH. Those three indicators from each farm were used to generate respective 2 × 2 contingency tables to compare the proportions of events with a faecal sample, and the proportions of events receiving an AH treatment. Comparisons between farms were made with Chi-square using the Statgraphics® Centurion XVI software, version 16.1.11. (StatPoint Technologies, Inc., Warrenton, Virginia, USA).

2.5.1. Comparing the ratio of ewes with BCS > 2 and BCS ≤ 2 between surveyed farms

Due to the difficulty of comparing the quality and quantity of nutrients ingested by the individual animals in the surveyed farms during the study period, a ratio of animals with BCS > 2 for every ewe with BCS ≤ 2 was used as an indirect comparison of the nutritional level between surveyed farms. The ratio was built with the total number of events in the surveyed farms recorded with BCS > 2 and BCS ≤ 2, and the ratios were expressed in decimals. Respective 2 × 2 contingency tables were used to identify significant differences between farms in the proportion of ewes with BCS > 2. Comparisons were also made with Chi-square using the Statgraphics® Centurion XVI software, version 16.1.11. (StatPoint Technologies, Inc., Warrenton, Virginia, USA).

2.5.2. Using BCS or FAMACHA© to identify ewes with ≥ 750 EPG

Further 2 × 2 contingency tables were used to estimate respective odds ratios (OR) and 95% confidence intervals (95%CI) to identify animals with ≥ 750 EPG comparing the following proportions:

(a) Events with BCS ≤ 2 vs. events with BCS > 2,
(b) Events with FAMACHA© score ≥ 4 vs. events with FAMACHA© score ≤ 3, and
(c) Events with FAMACHA© scores ≥ 3 *vs*. events with FAMACHA© ≤ 2.

The FAMACHA scores ≥ 4 or ≥ 3 were both tested as suggested in previous trials using those two cut-off points to identify anaemic animals (Kaplan et al., 2004; Torres-Acosta et al., 2014).

The contingency tables also generated the sensitivity, specificity, percentage of false positive cases (FP%) and percentage of false negative cases (FN%) for the FAMACHA© scores (either ≥ 4 or ≥ 3) as criteria to detect ewes with EPG ≥ 750. The same was also calculated for BCS ≤ 2 as criteria to detect individuals with EPG ≥ 750 using Win Episcope 2.0 (Thrusfield et al., 2001).

2.5.3. Distribution of EPG data from all the sampled ewes

The EPG data of all events sampled in each farm were used to determine the median, the third quartile (75%), as well as the minimum and maximum EPG counts. Data from each farm were also used to determine the proportion of events with ≥ 750 EPG and ≥ 1000 EPG.

2.5.4. Number of AH treatments administered to each ewe in surveyed farms

All the ewes present at least three months during the entire survey in each farm were identified and grouped according to the number of AH treatments received as follows: (i) with no AH treatment, (ii) treated once, (iii) treated twice, and (iv) treated three times or more. That information was presented as total number of ewes and as a proportion of ewes in each farm.

3. Results

3.1. Environmental conditions prevailing during the study

Fig. 1 shows the mean ambient temperatures (maximum and minimum) (°C) as well as the relative humidity (RH) (%) and the monthly rainfall recorded by the meteorological service in the study region during the 11-month survey. The mean monthly maximum temperatures varied from 31.7 to 40.8 °C, being March, April, May and June the hottest months. The mean monthly minimum temperatures varied from 14.6 to 22.9 °C with means < 20 °C from October to March. The monthly rainfall varied from 0 mm to 181.6 mm being June, July, August and September the months with more rainfall while no rain was recorded on April and May. January was unusually wet with a rainfall of 72.9 mm. The monthly RH varied from 67.3% to 86.8% during the eleven months of study, being April and March the months with the lower RH (67.3% and 68%, respectively).

3.2. Comparing the ratio of ewes with BCS > 2 and BCS ≤ 2 between surveyed farms

Surveyed farms showed different ratios of ewes with BCS > 2. Farm 3 had the highest ratio of animals with BCS > 2 (2.59 animals for every ewe with BCS ≤ 2) compared to the other two farms ($P < 0.05$). Meanwhile, Farm 2 had a better ratio of animals with BCS > 2 compared to Farm 1 (1.14 vs. 0.96; $P < 0.05$).

3.3. Comparing the proportion of events sampled or treated between farms

Fig. 2 shows the number of ewes present at each farm on each month of the study, together with the number of sampled ewes and the number of animals treated with an AH. There was no tendency to increase the number of sampled or treated animals during the wet season months (June–November). That figure also shows that many ewes were sampled every month, but the number of ewes receiving an AH treatment was clearly smaller.

Table 1 shows the total number of events, proportion of events needing a faecal sample and the proportion of events treated with an AH for the entire duration of the survey. The proportion of events needing a faecal sample or an AH treatment was similar between Farms 1 and 2 ($P > 0.05$), and both were significantly higher than the proportions at Farm 3 ($P < 0.05$).

The BCS and FAMACHA© scores of the animal events treated with an AH are also shown in Table 1. Not a single ewe with BCS > 2 was sampled or treated when showing FAMACHA© scores ≤ 3. Most events needing AH treatment were recorded with BCS ≤ 2 and FAMACHA© ≤ 3. Only one farm had a few ewes needing AH treatment when classified with BCS > 2 and FAMACHA© 4,5.

3.4. Using BCS or FAMACHA© to identify ewes with ≥ 750 EPG

Ewes with BCS ≤ 2 were at a higher risk of crossing the treatment threshold (≥ 750 EPG), compared to ewes with BCS > 2 (22.0% *vs*. 1.7% respectively; OR = 16.7, 95%CI = 7.86–35.36; see Table 2). Animals with FAMACHA© scores ≥ 4 also showed a higher risk of crossing the treatment threshold (≥ 750 EPG) compared to animals with FAMACHA© ≤ 3 (44.4% vs. 20.9%, respectively; OR = 3.0, 95% IC = 2.1–4.2; Table 2). When using FAMACHA© scores ≥ 3, the risk of crossing the EPG threshold was still significantly higher compared to ewes with FAMACHA© ≤ 2 (30.3% vs. 17.5%, respectively; OR = 2.1, 95%CI = 1.72–2.44; Table 2).

Table 2 also includes the sensitivity (%), specificity (%), false positives (%) and false negatives (%), with their respective 95% confidence intervals (95% CI) for the use of BCS ≤ 2, or FAMACHA© scores ≥ 4, or FAMACHA© scores ≥ 3 as the criteria to identify adult hair-sheep ewes with faecal excretions ≥ 750 EPG of GIN in the surveyed farms. The use of BCS ≤ 2 resulted in a great sensitivity (98.9%) and poor specificity (15.2%), which represented 84.8% of false positives ewes (ewes with BCS ≤ 2 and < 750 EPG) but only 1.1% of false negatives ewes (ewes with BCS > 2 but with ≥ 750 EPG). Meanwhile, FAMACHA© ≥ 4 resulted in a low sensitivity (44.4%) and moderate specificity (79.1%), representing 20.9% of false positives ewes (ewes with FAMACHA© ≥ 4 and < 750 EPG), and more than 55.6% of the ewes classified as false negatives (ewes with FAMACHA© ≤ 3 and ≥

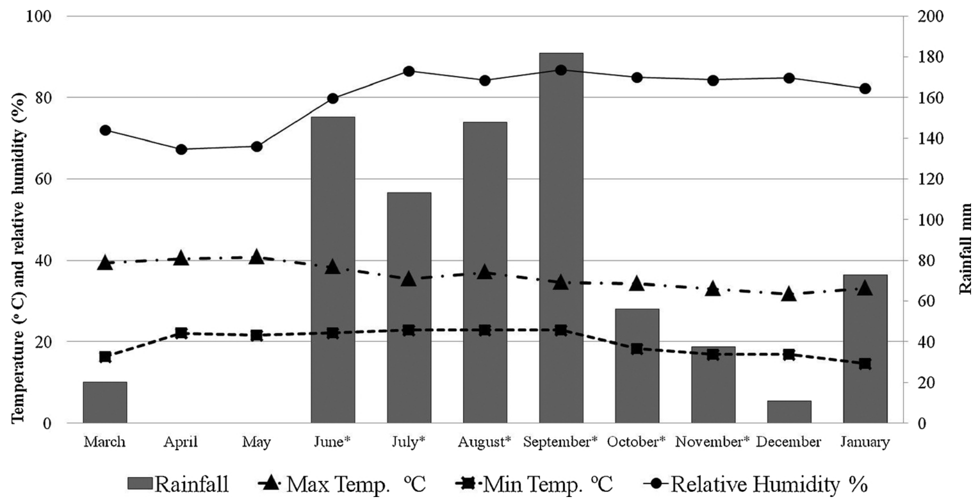

Fig. 1. Mean, maximum and minimum ambient temperatures (°C) per month, relative humidity (%) and accumulated monthly rainfall (mm) recorded throughout the eleven months of the survey in the hot humid tropics of Yucatán, México where the three study farms were surveyed.

750 EPG). A similar situation was found for the FAMACHA© ≥ 3, with a low sensitivity (49.4%) and moderate specificity (67.8%), increasing the proportion of false positives to 32.2%, while the false negatives events were maintained (50.6%).

3.5. Distribution of EPG data from all the sampled ewes

Table 3 shows the FEC data distribution of sampled events including the median EPG (50% of the population), the third quartile (75% of population), the minimum and maximum EPG. It also includes the proportion of sampled ewes that had ≥ 750 EPG or ≥ 1000 EPG. Half of the events sampled had < 150 EPG in all farms and the third quartile varied from 400 to 750 EPG in different farms. Thus, by choosing a threshold of ≥ 750 EPG for AH treatment, the proportion of events treated with AH treatment varied from 19.5% to 28.1% of all sampled events (Table 3). Meanwhile, a threshold of ≥ 1000 EPG would have resulted in 13.8%–16.8% of events treated with AH from the total events sampled.

3.6. Number of AH treatments administered to each ewe in surveyed farms

Table 4 shows the number of ewes that were present at least during three months of the survey grouped according to the number of AH treatments received in each flock throughout the survey. Farm 3 had the highest proportion of individual sheep without any AH treatment (79.8%), with only 14.4% of the ewes with single treatment (14.4%), leaving only 5.9% of animals with 2 or more AH treatments during the study period. The other two farms also tended to have more animals with no AH treatments, and most ewes receiving only one AH treatment, and few needing two or more treatments (19.0% in Farm 1 and 14.3% in Farm 2).

4. Discussion

4.1. Environmental conditions prevailing during the study

The environmental conditions, ambient temperatures, relative humidity and rainfall recorded during the survey were considered common for the climatic conditions of the tropical forest in the north of the Yucatán peninsula of México, with the sole exception of a slightly wetter January than usual (Flores-Guido and Espejel-Carvajal, 1994). The TST scheme was easy to implement in the three farms during the dry and rainy season months.

4.2. Comparing the ratio of ewes with BCS > 2 and BCS ≤ 2 between surveyed farms

The three commercial hair-sheep farms showed different ratios of ewes with BCS > 2, with Farm 3 showing more animals with BCS > 2 than the other two farms ($P < 0.05$). The later suggested that farms differed in their nutritional status either in quantitative or qualitative terms. In spite of the difference in the ratio of animals with BCS > 2, the TST scheme was viable in all surveyed farms and allowed to maintain a considerable proportion of ewes without any AH treatment for the duration of the survey. Those ewes kept without AH treatment did not show any clinical signs compatible with high GIN infections.

4.3. Comparing the proportion of events sampled or treated between farms

Fig. 2 shows that the number of sampled animals on each month was higher than the number of animals treated on that same month, suggesting that many sampled ewes did not reach the FEC threshold (≥ 750 EPG). Thus, it was evident that other aspects besides GIN infection were causing ewes to have either BCS ≤ 2 or FAMACHA© ≥ 4, i.e. insufficient quality or quantity of food to match the requirements for reproduction, milk production or even maintenance. The latter justify the need to include a FEC in the TST scheme as proposed by Torres-Acosta et al. (2014).

Farm 3 had the least ewes sampled and treated compared to Farms 1 and 2 ($P < .0.05$) (Table 1). It is important to underline that Farm 3 had the highest ratio of ewes with BCS > 2 (2.59 for every animal with BCS ≤ 2) compared to the other farms (1.14 and 0.96 for Farm 2 and Farm 1, respectively). As it has been reported in previous TST surveys with hair-sheep ewes, farms with more ewes with BCS ≤ 2 end up with an increased likelihood of AH treatments while farms with a higher proportion of ewes with BCS > 2 have fewer sampled events, consequently reducing the number of animals crossing the FEC threshold ≥ 750 EPG (Medina-Pérez et al., 2015).

4.4. Using BCS or FAMACHA© to identify ewes with ≥ 750 EPG

The importance of BCS to identify animals crossing the FEC threshold was clear in the present survey. Animals with BCS ≤ 2 significantly increased their risk of being treated with AH compared to animals with BCS > 2 (Table 2). The protective role of BCS > 2 must be highlighted as very few ewes with BCS > 2 received an AH treatment, and those few were found for their FAMACHA© ≥ 4 (see Table 1). Previous studies evaluating the combined TST scheme in goats

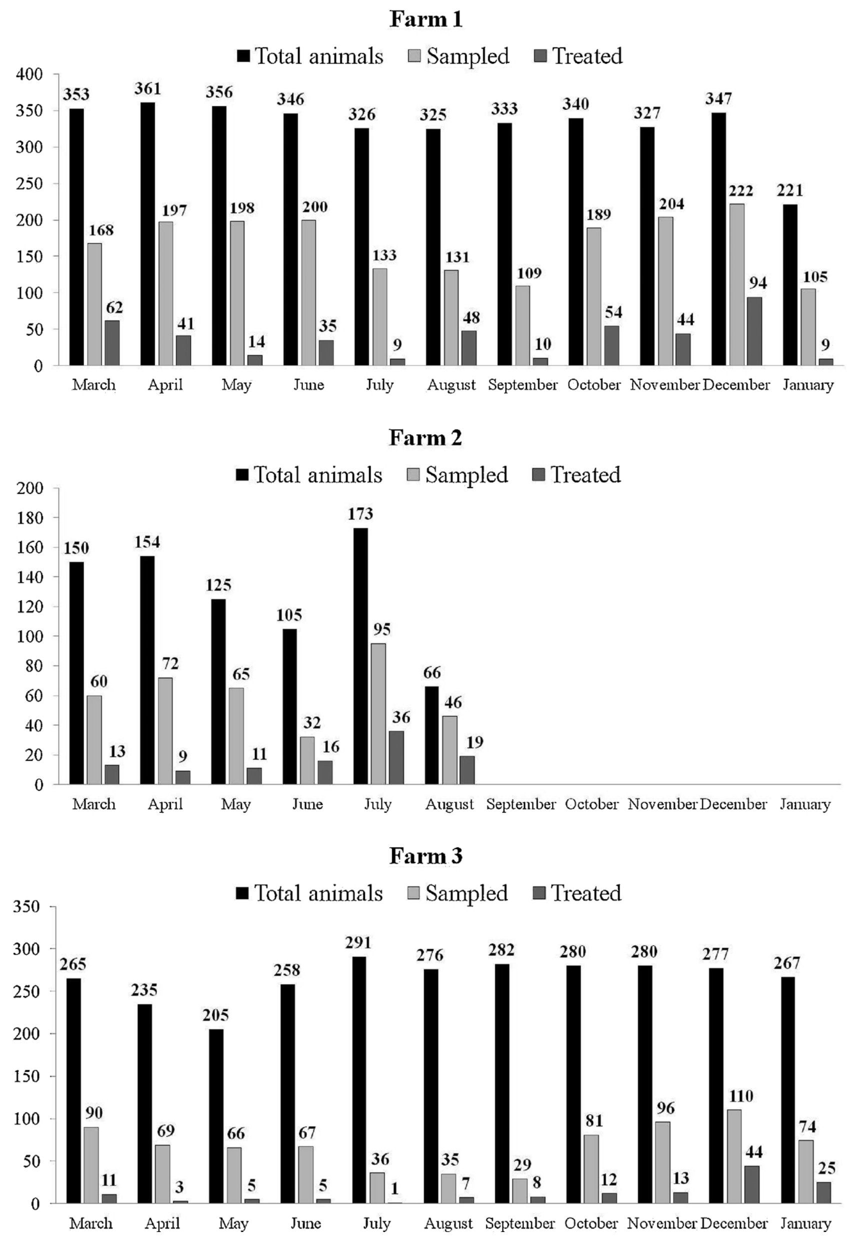

Fig. 2. Total population of adult ewes present in the three experimental farms on each month of the survey with the respective number of ewes sampled and treated with an anthelmintic according to the criteria used for the combined targeted selective treatment scheme by Torres-Acosta et al. (2014).

Table 1
Number and proportion of sheep events, number of events sampled and treated with an anthelmintic (AH) for the control gastrointestinal nematodes according to the combined target selective treatment scheme in three sheep farms under hot humid tropical conditions in Yucatán, México. The number and proportion of events receiving AH treatment were also classified according to their body condition score (BCS) and FAMACHA© scores.

Farms	Total number of events per farm	Events sampled	Events treated with AH	Number and proportion of events treated according to FAMACHA© scores and body condition scores					
				FAMACHA© 4, 5		FAMACHA© 3		FAMACHA© 1, 2	
				BCS 1, 2	BCS > 2	BCS 1, 2	BCS > 2	BCS 1,2	BCS > 2
Farm 1	3635	1729 (47.6 %)a	420 (11.6 %)a	23 (5.5 %)	2 (0.5 %)	40 (9.5%)	NS	355 (84.5%)	NS
Farm 2	773	370 (47.9 %)a	104 (13.4 %)a	31 (29.9 %)	4 (3.8 %)	38 (36.5%)	NS	31 (29.8%)	NS
Farm 3	2934	689 (23.5 %)b	134 (4.5%)b	4 (3.0 %)	1 (0.8 %)	58 (43.2%)	NS	71 (53.0%)	NS
All Farms	7342	2788 (37.9 %)	658 (8.9 %)	58 (8.8 %)	7 (1.0 %)	136 (20.7 %)	NS	457 (69.5 %)	NS

NS: Not sample and not treated. a, b: Different letters in the same column indicate significant difference ($P < 0.05$).

Table 2
Sensitivity (%), specificity (%), false positives (%), false negatives (%) and odds ratio (OR), with their respective 95% confidence intervals resulting from the use of either body condition score 1, 2 or FAMACHA© scores 4, 5 or FAMACHA© scores 3, 4, 5 used as criteria to identify adult hair-sheep ewes with faecal excretions > 750 EPG of gastrointestinal nematodes in the surveyed farms.

Criteria used to identify ewes with > 750 EPG of gastrointestinal nematodes	Sensitivity % (95% CI)	Specificity % (95%CI)	False positives % (95%CI)	False negatives % (95% CI)	Odds Ratio (95% CI)
Body Condition Scores 1 and 2	98.9% (97.8–99.5%)	15.2% (13.9–16.6%)	84.8% (83.4–86.1%)	1.1% (0.5–2.2%)	16.7 (7.8–35.3%)
FAMACHA© scores 4 and 5	44.4% (36.7–52.3%)	79.1% (77.6–80.6%)	20.9% (19.4–22.4%)	55.6% (47.7–63.3%)	3.0 (2.1–4.2%)
FAMACHA© scores 3, 4 and 5	49.4% (45.6–53.2%)	67.8% (65.8–69.6%)	32.2% (30.4–34.2%)	50.6% (46.8–54.4%)	2.1 (1.7–2.4%)

(Torres-Acosta et al., 2014) and hair-sheep sheep (Medina-Pérez et al., 2015) overlooked the importance of BCS as the crucial criteria to apply an AH, because those studies highlighted the evaluation of the FAMACHA© scores ≥ 4 to identify animals with high GIN burdens.

The information on sensitivities, specificities, percentage of false positives and percentage of false negatives helped to identify the value of using each of the criteria to identify animals with ≥ 750 EPG (Table 2). Considering that a TST scheme should aim to reduce the risk of leaving without AH treatment those ewes with high worm burdens, the best criteria to identify animals needing treatment would be the one with the lowest proportion of false negative events. Hence, the BCS ≤ 2 was the best screening criterion to find animals with FEC ≥ 750 as it recorded only 1.1% false negative events. Meanwhile, the FAMACHA©, scores ≥ 4 or ≥ 3, resulted in 50%–55% false-negative events respectively.

This is the first study that compares the false negative events reported for BCS ≤ 2 and for FAMACHA© ≥ 4 or ≥ 3. The first evaluation of the TST scheme in goats (Torres-Acosta et al., 2014) reported a poor concordance (0.43) between FEC (≥ 750 EPG) and FAMACHA ≥ 4, while the first evaluation of the TST scheme in hair-sheep reported also a poor concordance between those parameters (Medina-Pérez et al., 2015). The quantification of false negatives in the present study provided a better indication of the problem of using FAMACHA© ≥ 4 or ≤ 3, which is the large number of animals crossing the EPG threshold at any FAMACHA© score. A relation between FAMACHA© and EPG would only be possible if *H. contortus* is present. Thus, it is important to consider that previous studies monitoring the GIN infectivity in the study area, using post-mortem worm counts from tracer animals (Torres-Acosta et al., 2004, 2006), animals from experimental groups (Retama-Flores et al., 2012), or faecal culture results from anthelmintic resistance surveys (Sepúlveda-Vázquez et al., 2017) confirmed that *Haemonchus contortus* and *Trichostrongylus colubriformis* are the main GIN species followed by small proportions of *Oesophagostomum columbianum* and *Trichuris* spp. Those studies showed that small ruminants can pick up *H. contortus* L3 larvae mainly from June to December, but adult ewes may shed *H. contortus* eggs year-round as the majority of L3 in faecal cultures are *Haemonchus* spp. followed by *Trichostrongylus* spp.

Table 4
Number and proportion of adult ewes maintained without an anthelmintic treatment or receiving one, two and 3 or more treatments per year in three farms using a targeted selective treatment scheme under hot humid tropical conditions of Yucatán.

Farms[a]	Total adult sheep[b]	Non Treated ewes	Ewes Treated once	Ewes Treated twice	Ewes Treated three times or more
Farm 1	452	232 (51.3 %)	134 (29.6 %)	61 (13.5 %)	25 (5.5 %)
Farm 2	133	81 (60.9 %)	33 (24.8 %)	19 (14.3 %)	0
Farm 3	361	288 (79.8 %)	52 (14.4 %)	19 (5.3 %)	2 (0.6 %)
All Farms	946	601 (63.5 %)	219 (23.2 %)	99 (10.5 %)	27 (2.9 %)

[a] Farms 1 and 3 were surveyed during 11 months and Farm 2 was surveyed for 6 months.
[b] Only those ewes that were present in the respective farms at least on three months were included in this Table.

The present study showed that ewes with BCS > 2 can be left without any exploration or faecal sample. By excluding those ewes *a priori* from the screening methodology, the workload involved on the TST scheme can be reduced without a negative impact on welfare or health due to GIN infections. On the other hand, although it can be considered acceptable to treat with an AH those false positive animals (i.e., ewes with BCS ≤ 2 and < 750 EPG), the use of FEC helps to reduce the number of ewes receiving unnecessary AH treatments, limiting the costs concerned with treatment of false positives and reducing the selection pressure of resistant GIN isolates.

4.5. Distribution of EPG data from all the sampled ewes

The distribution of EPG counts from all sampled events (Table 3), showed that the threshold (≥ 750 EPG) used in the present TST scheme resulted in 19.5% to 28.1% of animals treated with AH, and all the other animals were kept without an AH treatment. Raising the threshold to ≥ 1000 EPG might further reduce the proportion of treated animals, with only 13.8%–16.8% of events. Considering the

Table 3
Distribution of events with a faecal sample in each farm based on to the respective faecal egg counts (eggs per gram of faeces, EPG), including the median (50% of population), the third quartile (75% or population), the minimum and maximum EPG values. The number and proportion of events with ≥ 750 EPG and ≥ 1000 EPG is also included for each farm.

Farms	Number of sampled events	Eggs per gram (EPG) data distribution				Number (proportion) of sampled events	
		Minimum	Median	Third quartile	Maximum	≥ 750 EPG	≥1000 EPG
Farm 1	1729	0	50	700	36650	420 (24.3%)	291 (16.8%)
Farm 2	370	0	150	750	6750	104 (28.1%)	57 (15.4%)
Farm 3	689	0	100	400	25350	134 (19.5%)	95 (13.8%)
Total	2788	0	100	650	36650	658 (23.6%)	443 (15.9%)

importance of limiting exposure of GIN populations to AH drugs, a threshold ≥ 1000 EPG can further help reducing the development of AH resistant populations and might be used in other farms in the same region. A FEC threshold ≥ 1000 EPG was also proposed by Medina-Pérez et al. (2015), as it would result in a very small number of ewes treated with AH in hair-sheep farms.

4.6. Number of AH treatments administered to each ewe in surveyed farms

As expected for any TST scheme designed to control GIN in small ruminants (Van Wyk et al., 2006), a large proportion of ewes was maintained without any AH treatment for the duration of the survey at the different farms (from 51.3% to 79.8%) (Table 4). The latter was similar to the proportion of animals maintained without AH treatment in a previous 5 year TST survey with goats in the same region, where the best three years maintained 60.0% to 77.6% of the goats without any AH treatment (Torres-Acosta et al., 2014). The present results were also similar to the proportion of hair-sheep maintained without a single AH treatment in six-month survey performed under hot humid tropical conditions in México (overall 65.5% without treatment) (Medina-Pérez et al., 2015). Thus, the proportion of ewes treated with an AH (one or more times) ranged from 20.3% (Farm 3) to 48.6% (Farm 1), most of which were treated only once during the study. Such low percentages of dewormed animals may help maintaining a low selection pressure for AH resistance in the GIN population at each farm (Gaba et al., 2010). Those ewes without any AH treatment harbor small to medium adult GIN populations not exposed to AH, which can seed the pasture with their eggs. Those eggs will transform into infective larvae that will be consumed by grazing ewes, helping to dilute the AH resistant genotypes of worms in the farm. The dilution would result from the constant consumption of GIN not exposed to AH that could mate with resistant GIN (Kaplan et al., 2004; Van Wyk et al., 2006; Chan-Pérez et al., 2015).

Only few animals received three AH treatments and, according to the records, these animals had high FEC on consecutive months. The latter could have resulted from at least from three situations: Firstly, animals might have not been dewormed and carried the same GIN infection from the previous month, secondly, the drug might have been incorrectly applied, or thirdly, those animals might have hosted drug resistant GIN and presented a FEC ≥ 750 EPG even after the correct use of AH.

The present survey provided information that could improve the TST scheme that combines BCS, FAMACHA© scores and FEC proposed by Torres-Acosta et al. (2014) when applied to hair-sheep under tropical conditions:

(i) Make the necessary adjustments on the nutrition of ewes to reach BCS > 2. An improved nutrition will help ewes to improve their resilience and resistance against GIN (Coop and Kyriazakis, 1999; Hoste et al., 2016). From a practical point of view, improving the flocks' BCS should represent fewer ewes sampled and treated with AH, slowing the development of AH resistance of worm populations at the farm. Nutritional adjustments can differ depending on the farm. It may represent more supplementary feed, a better quality of supplementary feeding, reduce the number animals in the paddock to ensure more pasture per ewe, or planting more grass to increase dry matter production per surface of land.

(ii) The TST should target ewes with BCS ≤ 2. Although monthly screening of all ewes may allow tighter control on animals' health and the additional advantage of generating a monthly inventory of all ewes in the flock, most farmers prefer not to examine all their ewes because it takes roughly one minute and a half to screen FAMACHA©, BCS and take the faecal sample with the help of a person to hold the animal. That is without consideration of the time to perform the McMaster tests in the laboratory. For farms like those included in the survey, it was necessary to work approximately 100 min for every 100 ewes evaluated, even when a large proportion of animals did not need a faecal sample. Thus, the logical option is to target the screening only to ewes with BCS ≤ 2, leaving all ewes with BCS > 2 without screening. By skipping all the ewes with BCS > 2 the workload for screening FAMACHA© and faecal samples in all those animals can be saved. The latter may also represent fewer faecal samples processed in the laboratory and fewer treated animals. Such strategy is consistent with the "happy factor"® and other TST strategies that suggest not to treat lambs with good bodyweight gain (Greer et al., 2009; Busin et al., 2014).

(iii) Use ≥ 1000 EPG as threshold for AH treatment. Such treatment threshold would represent nearly 80% of animals without AH treatment, ensuring to treat only the ewes with high EPG counts in all farms. Although such threshold seems feasible for Criollo goats and hair-sheep in tropical México (Medina-Pérez et al., 2015), it might need to be increased for other regions and other breeds of sheep and goats (Martínez-Ortíz-de-Montellano et al., 2017).

(iv) The FAMACHA© scores can be included. FAMACHA© scores did not represent a major improvement in the search for animals with FEC ≥ 750 EPG under the conditions of the present survey. However, FAMACHA© scores ≥ 4 can help identifying animals with anemia, which may benefit from support therapies or the selective use of dietary supplementation, as well as solving for other stress factors.

In the present TST scheme, the decision of treating animals was not "sheep-side" because faecal samples needed processing in the laboratory, which took an extra day of work. Thus, AH treatments were applied within a couple of days after the sampling date, when workers needed to find again those animals that required treatment. From a practical point of view, this is a time consuming process that discourages the use of the proposed TST scheme. By keeping the sampled animals in a separate pen while processing the faecal samples, farmers can reduce the time required to find those ewes that need AH treatment. The inclusion of FEC is a procedure that increases the complexity of TST schemes. Thus, the implementation of any fast-read faecal egg count methodology, preferably to perform "sheep-side" treatment decisions, could be important to increase the acceptability of this TST amongst farmers and veterinarians.

5. Conclusion

The TST survey showed that BCS ≤ 2 is the best criteria to find ewes with FEC ≥ 750 EPG as it results in 1.1% false negative events. Meanwhile, FAMACHA© scores ≥ 4 or ≥ 3, resulted in 50%–55% false negative events. Thus, the TST scheme should focus on ewes with BCS ≤ 2, and the FEC can be used to avoid unnecessary AH treatments. The treatment threshold of EPG ≥ 750 safely maintained > 63% of the ewes without AH treatment on average in all the farms.

Animal welfare declaration

The authors assert that all procedures contributing to this work complied with the ethical standards of the relevant national and institutional guides on the care and use animals.

Conflict of interest

The authors of this manuscript have no financial, personal or other relationships with other people or organizations that could inappropriately influence or bias the content of the study.

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