Community-based approach for the control of gastrointestinal parasites under smallholder sheep farming systems

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Acknowledgements

Table of Contents

List of tables

List of figures

Executive summary

Gastrointestinal (GI) nematode infection rates are high in Ethiopia with an average prevalence of 75.8%. GI parasitism has been ranked, by both farmers and pastoralists, as the second or third most important disease problem. Retrospective case studies have also ranked GI parasitism as the first to sixth disease problem across pastoral/agro-pastoral systems in Ethiopia. The main challenge to minimize the impacts of diseases has been the inefficient delivery of animal health services to smallholder and pastoralist livestock keepers. GI parasite control interventions cannot be effectively used by individual farmers due to the uncontrolled and communal animal management system (communal herding, grazing, and watering points) which could dilute the efforts of individual progressive farmers as communal grazing lands are contaminated by untreated flocks.

One way forward for smallholders would therefore be to act as a collective entity, with an aim to improving effectiveness of prevention and reducing high transaction costs of accessing the needed veterinary drugs. A CRP research project on community-based approach for GI parasite control was initiated in SNNP, Amhara and Oromia regions in 2018. Farmers that share common communal grazing and watering points and keep their sheep separated from other village flocks in the vicinity formed groups and as a collective action by all members of the community planned to deworm all their sheep strategically. Nematode egg burden and productivity data were collected before and after the intervention and farmers' experiences during the intervention were captured.

Logistic regression analysis showed that the odds of a randomly selected sheep testing to be negative for strongyle eggs after anthelmintic treatment was significantly *(P < 0.01*) higher than it would be before treatment, odds ratio ranging from 9 to 43 depending on age and body condition of animals. Transitional model analysis at the individual animal level showed that animals that tested positive for strongyles eggs before treatment were 7.68 time more likely to test negative after treatment ($P < 0.01$). The results also indicated a positive long-term impact of community-based intervention on worm burden. The communities participating in the GI parasite control intervention expressed high satisfaction with the intervention, but also identified challenges to continue the intervention sustainably, mainly because of limited access to veterinary services and inputs. Furthermore, the deworming practice followed in the current study was mass deworming of all animals in the flocks. This could be justified under the observed high infection rate in the flocks, but mass deworming could lead to drug resistance and needs to be revised to targeted deworming as the worm load declines in the flocks.

1. Introduction

Sheep production in Ethiopia, with 31,302,257 heads (CSA, 2018) and a diverse genetic resource including 15 local and two exotic breeds, is a major livestock enterprise contributing to the country's economic development, food and nutrition security, and poverty reduction. Sheep in particular are a major source of livelihoods for smallholder farmers in the sub-moist highlands and for pastoralists. However, the off-take rate and per capita consumption of livestock products is one of the lowest in the world. Technical, institutional, infrastructural, environmental and policy challenges are key

constraints for livestock development, disease being ranked as the primary constraint to increasing livestock productivity. The main challenge to minimize the impacts of diseases on animal productivity has been the inefficient delivery of animal health services to smallholder and pastoralist livestock keepers.

Parasite infection is one of the diseases with great economic impact on sheep and goat production worldwide causing poor growth and impaired fertility (van der Voort et al., 2013; Charlier et al., 2014). Gastrointestinal (GI) nematode infection rates are high in Ethiopia with an estimated prevalence of 75.8% (Asmare et al., 2016). GI parasitism has been ranked as the third most important disease problem both by farmers and through a retrospective case study in the highlands of Ethiopia (Ferede et al., 2014) and as the first to sixth disease problem across pastoral/agro-pastoral systems in Ethiopia (Gebremedhin et al., 2017). Alemu et al. (2019) ranked GI parasitism as the second most important disease problem both in the highlands and lowlands of Ethiopia. Research on technical/technological solutions to control GI parasites in Ethiopia has been underway for long, but the focus has exclusively been on efficacy of anthelmintics (Asmare et al., 2016). The challenge to overcome the GI parasite problem has been to introduce technological solutions effectively and sustainably in the smallholder sheep production systems in developing countries. GI parasite control interventions cannot be effectively used by individual farmers due to the uncontrolled and communal animal management system (communal herding, grazing, and watering points) which could dilute the efforts of individual progressive farmers as communal grazing lands are contaminated by untreated flocks. Research has shown that farms using common grazing are at significantly higher risk of infestation than farms not using common

grazing, as were farms that had direct contact with neighbors' sheep. The same was true for scabies, where common grazing would appear to be the largest single obstacle to effective national scab control in the UK (Rose and Wall, 2012). A unique challenge for smallholder farmers in developing regions is that access to veterinary inputs and services by individual smallholders is difficult or uneconomical. One way forward for smallholders would therefore be to act as a collective entity, with the aim to improve effectiveness of prevention and to reduce high transaction costs accessing the needed veterinary drugs. Another issue is smallholders' reliance on reactive (therapeutic) treatment rather than targeted treatment and common malpractices regarding the use of dewormers (Aga et al., 2013; Seyoum et al., 2017), which promotes resistance (Getachew et al., 2016). This paper reports on a community-based approach to introduce strategic GI parasite control under smallholder systems in Ethiopia. It was hypothesized that community engagement and collective action in strategic anthelmintic treatment would enable sustainable control of GI parasites under smallholder systems.

2. Methodology

2.1 Project approach and location

A gastro-intestinal tract (GI) parasite control intervention was initiated in 2018 using a community-based approach around collective action by all members of the community to deworm all their sheep against GI parasites at the most appropriate time taking the parasite cycles into account. The intervention was introduced in 2018. The community groups targeted were formerly organized as breeding cooperatives for small ruminant community-based breeding programs as described by Gizaw et al. (2013) for the Menz project site. The program involved organizing cooperative breeding groups to introduce

genetic improvement of village flocks through selective breeding. Each cooperative group shares common communal grazing resources and watering points and is separated from other village flocks in the vicinity as much as it is feasible. The GI parasite control intervention approach involved strategic deworming of all animals in a cooperative breeding group during peak seasons of GI parasite infections based on recommendations (Aragaw, et al., 2011) for controlling sheep GI parasites in the central highlands of Ethiopia. The recommendation was verified through discussion with the farmers and veterinarians in each project site. Broad spectrum anthelmintic like albendazole (Albentong 2500, Congqing Fangtong Animal Pharmaceutical co. Ltd., China) and ivermectin (Ivermictin, Shenyang Sunvictor, China) for nematodes and narrow spectrum anthelmintic triclabendazole (Fascinex, Ciba-Geigy Ltd., Switzerland) for liver fluke were applied together according to the recommended dose of the manufacturers. The intervention also included capacity building of farmers and livestock extension workers on the concept of collective actions in GI parasite control, identification of animals affected by GI parasites, control methods including time of interventions and grazing land management to reduce parasite build-up, and collective action for delivery of animal health inputs and services.

The project was implemented in three administrative regions of Ethiopia, namely Oromia, Amhara and SNNP regions. Four intervention sites were selected for gastro-intestinal (GI) parasite control interventions based on a survey of disease priorities using participatory epidemiological tools (Wieland et al., 2016; Alemu et al., 2019). The sites selected were Adiyo Kola and Doyo Gena districts in SNNP region, Horro district in Oromia region and Menz district in Amhara region.

2.2 Data collection

Data were collected using laboratory analysis, observations on animal performance and condition, and focus group discussions (FGD) with livestock keepers. Laboratory analysis of faecal samples were conducted to identify GI parasites and count the number of eggs per gram of faeces (EPG). Sedimentation and floatation tests (Tiber, 1999; Garcia, 1997) were conducted to examine *Fasciola* spp. and nematode eggs, respectively. *Haemonchus contortus*, which is the primary parasite affecting small ruminants in warm, moist climates, could not be differentiated from other nematode eggs and thus it was included under strongyles worms. It is known (Chaney, 2012) that differentiation of the most pathogenic nematode, *H. contortus*, from the other common species can be difficult using standard diagnostic fecal floatation techniques because the ova are similar in size and morphology. EPG counts were made for strongyle eggs in Adiyo Kola and Doyo Gena sites and for strongyle and trichuris eggs in Horro site. EPG count was not conducted in Menz site. McMaster egg counting chamber was used for counting eggs per gram of faeces.

Data on animal performance and conditions included body condition score, body weight, and packed cell volume (PCV) following Bath et al. (1996). Separate FGDs were held with women and men farmers, each FGD group consisting of 10 farmers. A total of eight FGDs were held. The discussion points included the farmers' indigenous and acquired (from trainings) knowledge regarding GI parasitism, traditional practices of controlling GI parasites, evaluation of the community-based approach and their opinions towards the sustainability of the intervention. The FGDs were facilitated using proportional piling, in which the FGD participants were asked to discuss and allocate 100 beans to different

possible outcomes presented. The FGD groups were also asked to rank their basis for evaluating the effectiveness of the intervention by allocating the 100 beans to seven criteria including reduction in number of animals with diarrhea, erected hair, ascites, bottle jaw, emaciated body and parasite showing in faeces.

Data were collected just before intervention and 15 days postintervention. The intervention was introduced in two rounds in June and Nov. in Adiyo Kola, June and March in Doyo Gena, Feb and Nov in Horro, and June and Oct in Menz sites, respectively. Prevalence of GI parasitism was assessed based on the preintervention data and additional data collected before the GI parasite control project commenced (sample sizes are shown in Table 1). Data collected postintervention were used to evaluate effectiveness of the intervention (sample sizes are shown in Tables 3 and 4).

==Table 1. Prevalence of gastrointestinal parasite infection expressed as the number of animals tested positive for different GI parasites in different agroecology/geographic regions of Ethiopia.==

2.3 Data analysis
2.3.1 Prevalence of GI parasites
Descriptive statistical analysis was conducted to explore the distribution of GI parasite infections across the sampling sites, which differed in their agro-ecological characteristics. To test the significance of differences in the prevalence of parasite species across agroecologies, age (young, 0-6 months and adult, 6 months and above) and body condition groups (poor, medium and good), a statistical inferential analysis was conducted. The infection state of the sampled sheep with strongyles and *Fasciola*

spp. was considered as the dependent nominal variable with two categories (infected or not infected).

The multinomial logistic regression procedure fitting a proportional odds modelling was chosen, as it is applicable to categorical data (McCullagh and Nelder, 1989). The multinomial logistic model can be described following SPSS (2011). For the dependent variable infection state of a sheep with two categories, there exist two continuous variables Z_k (Z_1 ... Zn) each of which can be thought of as the propensity toward a category (infected or not infected), with larger values of Z_k corresponding to greater probabilities of occurrence of infection or no infection. Mathematically, the relationship between the Z's and the probability of a particular outcome is described in the formula: $\pi_{ik} = (e^{z_{ik}}) / (e^{z_{i1}} + e^{z_{i2}} + ... + e^{z_{iK}})$, where π_{ik} is the probability the ith sheep falls in the k_{th} category and z_{ik} is the value of the k_{th} unobserved continuous variable for the ith sheep.

2.3.2 Evaluation of effectiveness of intervention

Effectiveness of the GI parasite control intervention was evaluated using two approaches of inferential statistical analyses. First, multinomial logistic regression analysis, as described above, was used to test odds of the sampled sheep being positive for parasite infection before and after anthelmintic treatments. This analysis was used to evaluate the effectiveness of the intervention at population level, i.e., population level response to anthelmintic treatment. In this analysis, observations on each animal before and after anthelmintic treatment were considered as unpaired or unrelated.

A second approach, transitional model (Agresti, 2007), was used to evaluate the effectiveness of the intervention at the animal level. Here observations on each animal

before and after anthelmintic treatment were considered as paired or related, and the experiment was planned in a before-and-after design. Two hundred and sixty four sheep that had paired data with before and after treatment observations were identified by their ear tag numbers and used for this analysis. A transitional approach models observation in a longitudinal study using explanatory variables that include previous response outcomes. The analysis was run using the SPSS (2011) procedure for general loglinear models (transitional models have connections with the loglinear models (Agresti, 2007). The paired data were also subjected to McNemar test (Agresti, 2007), which compares proportions in several matched samples, where each subject's response is elicited twice, once before and once after a specified event occurs and the test determines whether the initial response rate equals the final response rate. The interventions were also evaluated by the livestock keepers in FGDs.

3.   Results
3.1   Pre-intervention GI parasite prevalence

The predominant gastro-intestinal parasitic diseases affecting sheep in the sampled areas in this study were strongylosis, fasciolosis, trichuriasis, and coccidiosis (Table 1). The relative prevalence of the parasites differed across agroecologies. Sheep in the wet highlands and midlands are 21.8 and 28.9 times, respectively, more likely to be infected with strongyles than in subalpine highlands ($P<0.01$). The infection rate with strongyles in the wet agroecologies ranged from 50.1% in Adiyo Kola to 75.7% in Doyo Gena sites (Table 1). Nematodes were not prevalent in the sub-moist subalpine highlands, where fasciolosis was 7.1 times ($P<0.001$) and 3.9 times ($P<0.001$) more prevalent than in the wet midlands and wet highlands, respectively.

TABLE 1. PREVALENCE OF GASTROINTESTINAL PARASITE INFECTION EXPRESSED AS THE NUMBER OF ANIMALS TESTED POSITIVE FOR DIFFERENT GI PARASITES IN DIFFERENT AGROECOLOGY/GEOGRAPHIC REGIONS OF ETHIOPIA

Sampling site	Adiyo Kola	Doyo Gena	Horro	Menz	Overall
				Sub-moist	
Agroecology	Wet MH [a]	Wet MH	Wet H	H	
No. of animals examined	477	659	150	841	2127
No. of positive animals:					
Fasciola spp.	133	11	15	248	407
Strongyles	361	330	97	50	838
Paramphistomum	0	0	0	40	40
Trichuris	0	0	62	6	68
Moniezia	30	65	38	23	156
Coccidia	18	178	35	0	231
Ascaris	0	0	32	0	32

Although the sampling was not conducted every month of the year to establish a complete seasonal prevalence (sampling months are shown in Fig. 1), the available data showed strongylosis was prevalent in both dry, (January, November), long rain (June) and short rain seasons (February, March) in the wet agroecologies (Fig. 1). Infection with *Fasciola* spp. in the submoist highland is highest during the long (June, July) and short (February, March) rainy seasons. EPG values for strongyles (Fig. 2) showed a high variation, ranging from 50 to 1150 in Adiyo Kola, 100 to 16200 in Doyo Gena, and 100 to 4200 in Horro sampling sites. PCV also varied from 0 to 36 in Adiyo Kola and 19 to 43 in Menz.
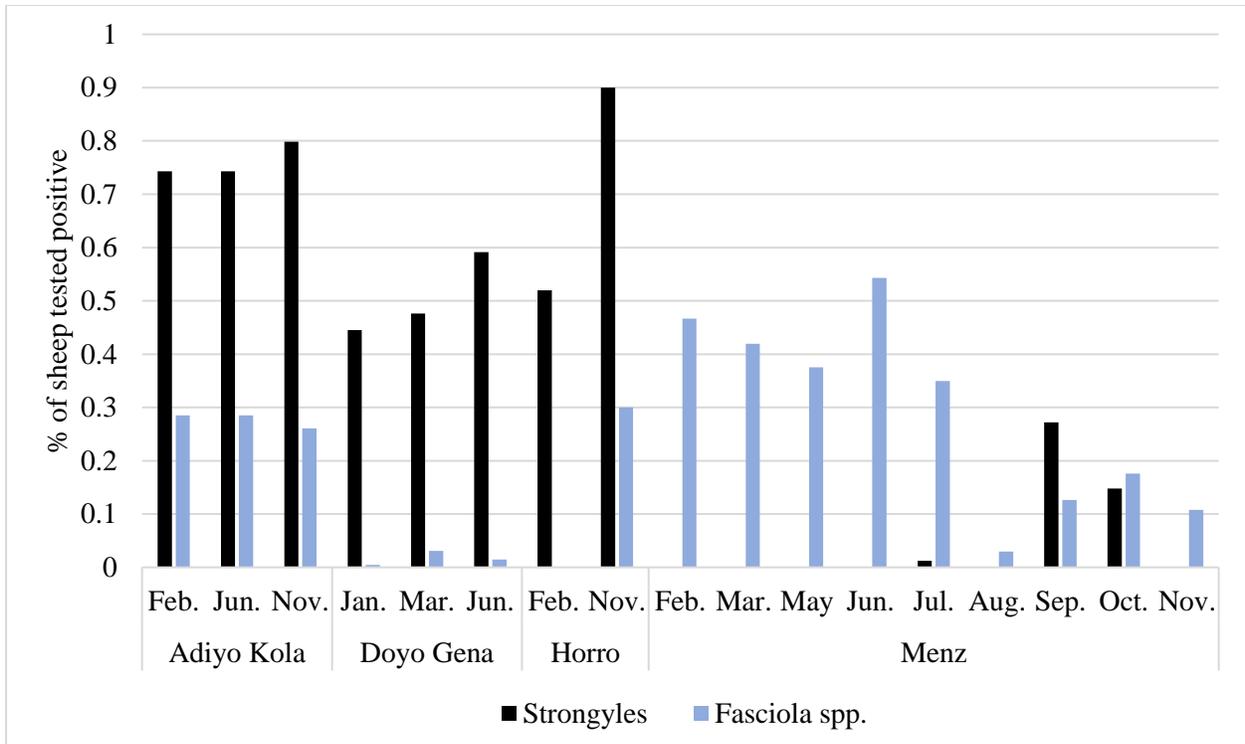
FIGURE 1. SEASONALITY OF GASTROINTESTINAL PARASITE INFECTIONS IDENTIFIED BASED ON PERCENTAGE OF SHEEP TESTED POSITIVE FOR STRONGYLES AND FASCIOLA SPP. EGGS ACROSS GEOGRAPHIC REGIONS/AGROECOLOGIES (ADIYO KOLA AND DOYO GENA – WET MID-HIGHLAND, HORRO – WET HIGHLAND, MENZ – SUBMOIST SUBALPINE HIGHLAND) OF ETHIOPIA
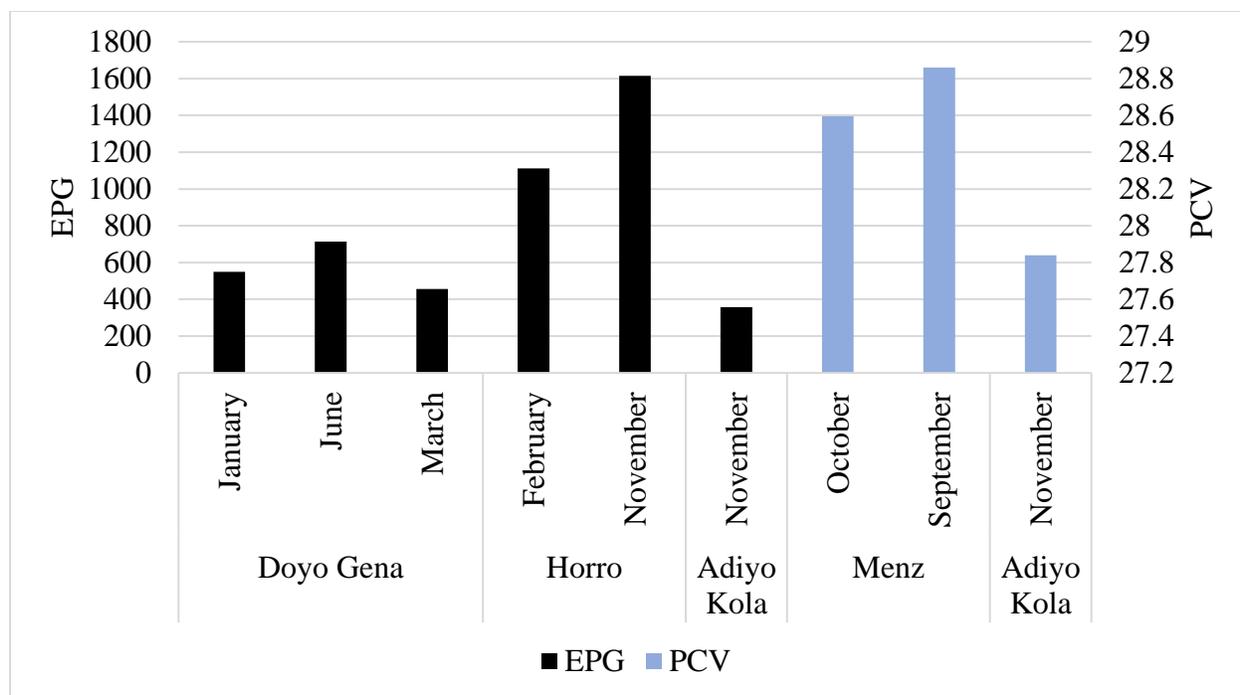
FIGURE 2. NUMBER OF EGGS PER GRAM OF FAECES (EPG) AND PACKED CELL VOLUMES (PCV) ACROSS GEOGRAPHIC REGIONS/AGROECOLOGIES OF ETHIOPIA

Susceptibility to parasite infection during the preintervention period varied between adult and young sheep with various body conditions (Table 2). The odds of young sheep being free from strongyle infection were low under either poor ($P = 0.739$, odds ratio = 1.077), medium ($P = 0.607$, odds ratio = 1.092) or good condition ($P = 0.763$, odds ratio = 0.833). Adult sheep in good condition were more likely to be free from infection ($P = 0.011$, odds ratio = 1.58). Young sheep in poor, medium and good condition were less (young = 48.1% and adult = 62.6%), equally (47.8% and 49.5%), or more (54.5% and 38.7%) affected than adult sheep (Table 3). Within the adult group, sheep in poor condition were less likely (odds ratio = 0.597, $P < 0.01$) but those in good condition were more likely ($P = 0.011$, odds ratio = 1.58) to test negative for strongyle infection (Table 2).

TABLE 2. THE ODDS (EXP(B)) OF SAMPLED SHEEP WITH DIFFERENT AGE AND BODY CONDITIONS TESTING NEGATIVE RATHER THAN POSITIVE FOR THE PRESENCE OF STRONGYLE AND FASCIOLA SPP. EGGS BEFORE AND AFTER GASTROINTESTINAL PARASITE CONTROL INTERVENTION IN ETHIOPIA

Age	Condition	Intervention period	Strongyles [a]				Fasciola spp. [a]			
			β	Std. Error	Sig.(P)	Exp(β)	β	Std. Error	Sig.(P)	Exp(β)
Young	Poor	Postintervention	3.761	1.012	< 0.001	43.000	2.615	0.598	< 0.001	13.667
		Preintervention	0.074	0.222	0.739	1.077	2.721	0.462	< 0.001	15.2
	Medium	Postintervention	2.621	0.518	< 0.001	13.75	2.927	0.593	< 0.001	18.667
		Preintervention	0.088	0.172	0.607	1.092	3.076	0.418	< 0.001	21.667
	Good	Postintervention	2.833	1.029	0.006	17.000	21.203	NA [c]	NA	NA
		Preintervention	-0.182	0.606	0.763	0.833	21.203	NA	NA	NA
Adult	Poor	Postintervention	2.431	0.369	< 0.001	11.375	2.431	0.369	< 0.001	11.375
		Preintervention	-0.515	0.134	< 0.001	0.597	1.661	0.177	< 0.001	5.263
	Medium	Postintervention	2.239	0.23	< 0.001	9.4	3.268	0.36	< 0.001	26.25
		Preintervention	0.02	0.115	0.863	1.02	1.441	0.146	< 0.001	4.224
	Good	Postintervention	3.243	0.456	< 0.001	25.6	2.311	0.303	< 0.001	10.083
		Preintervention	0.457	0.181	0.011	1.58	0.949	0.196	< 0.001	2.583

3.2   Effectiveness of control intervention

3.2.1 Effectiveness at flock level

Anthelminthic treatment significantly reduced the number of sheep infected with gastro-

intestinal parasites. In the postintervention period, young and adult sheep were,

respectively, 13.7 – 43.0 and 9.4 – 25.6 times more likely to test negative rather than positive for strongyle infection (Table 2). Similar results were found for *Fasciola* infection. Reduction in strongyle infection in young sheep in poor and good conditions was 46% and 49%, respectively. The corresponding reductions in adult sheep were 55% and 35%. The reduction in *Fasciola* infections ranged from -1% to 19% (Table 3).

The long-term impact of the intervention was evaluated by comparing the proportion of infected sheep across the intervention period (Table 4). The proportion infected with *Fasciola* spp. declined by 2% in Adiyo Kola to 20% in Menz over two rounds of intervention (Table 4). The decline in strongyle infection ranged from 6% in Horro to 12% in Doyo Gena sites. Both strongyle and *Fasciola* spp. load did not decrease in the other two intervention sites.

TABLE 3. RESPONSE OF SHEEP WITH DIFFERENT AGE AND BODY CONDITIONS TO GASTROINTESTINAL PARASITE CONTROL INTERVENTION MEASURED AS THE NUMBER OF SHEEP TESTED POSITIVE FOR THE PRESENCE OF STRONGYLE AND FASCIOLA SPP. EGGS BEFORE AND AFTER INTERVENTION IN THE HIGHLANDS OF ETHIOPIA.

Age	Body condition	Strongyles Preintervention		Postintervention		*Fasciola* spp. Preintervention		Postintervention	
		Examined	Positive	Examined	Positive	Examined	Positive	Examined	Positive
Young	Poor condition	81	39	44	1	81	5	44	3
	Medium condition	136	65	59	4	136	6	59	3
	Good condition	11	6	18	1	11		18	
Adult	Poor condition	238	149	99	8	238	38	99	8
	Medium condition	303	150	218	21	303	58	218	8
	Good condition	129	50	133	5	129	36	133	12

TABLE 4. NUMBER OF SHEEP WITH DIFFERENT AGE AND BODY CONDITION EXAMINED AND TESTED POSITIVE FOR THE PRESENCE OF STRONGYLE AND FASCIOLA SPP. EGGS BEFORE AND AFTER TWO ROUNDS OF GASTROINTESTINAL PARASITE CONTROL INTERVENTIONS IN THE HIGHLANDS OF ETHIOPIA.

Sampling site	Adiyo Kola		Doyo Gena		Horro		Menz		Overall	
Round 1 intervention	[a] Pre (June)	Post (June)	Pre (June)	Post (June)	Pre (Feb.)	Post (Feb.)	Pre (June)	Post (June)	Pre	Post
No. examined	179	106	203	45	100	100	62	97	544	348
No. positive:										
Fasciola spp.	51	0	3	0	0	0	34	11	88	11
Strongyles	133	31	120	4	52	6	0	0	305	41
EPG count	-	-	714±1566 [b]	-	1245±651	300±126	-	-	-	-
Round 2 intervention	Pre (Nov.)	Post (Nov.)	Pre (March)	Post (March)	Pre (Nov.)	Post (Nov.)	Pre (Oct.)	Post (Oct.)		
No. examined	119	109	229	-	50	50	154	183	552	342
No. positive:										
Fasciola spp.	31	0	7	-	15	7	54	16	107	23
Strongyles	95	32	109	-	45	0	47	2	296	34
EPG count	357±219	144±108	455±425	-	1647±1023	191±99	-	-	724±1056	144±108
PCV	27±4	31±3	-	-	-	-	29±6	33±4		

3.2.2 Effectiveness at animal level

Four types of transitions in the infection states of individual sheep were identified depending on the sheep's state of infection before and after anthelmintic treatment intervention. The transition states could be designated as 'responsive' where the sheep that tested positive before intervention tested negative after intervention, 'non-responsive' including the sheep that tested positive before and after intervention, 'tolerant' in which the sheep tested negative before and after the intervention, and 'new infections' for the sheep that tested negative before the intervention but positive after the intervention.

The MacNemar change test (SPSS, 2011) showed significant ($P < 0.01$) variation in the proportion of sheep in the four transition states. Among the 171 sheep infected with strongyles, 132 responded positively to anthelminthic treatment while the rest remained positive (Table 5). Most of the sheep (78 sheep) that tested negative for strongyles in the preintervention test remained negative during the postintervention test. All the 39 sheep that were infected with *Fasciola* spp. responded positively to the control intervention. Based on the proportion of sheep that responded positively to the intervention, the efficiency of the intervention against strongylosis and fasciolosis was 70.4% and 100%, respectively.

TABLE 5. FOUR POSSIBLE INFECTION STATUS OF SHEEP WITH STRONGYLE AND FASCIOLA SPP. BEFORE AND AFTER DEWORMING EVALUATED AS PAIRED OBSERVATIONS IN THE HIGHLANDS OF ETHIOPIA

	Strongyles (N = 264)		*Fasciola* (N = 264)	
	Pre-intervention infection state			
Post-intervention state	Negative	Positive	Negative	Positive
Negative	78 (a)	132 (c)	225 (a)	39 (c)

| Positive | 15 (b) | 39 (d) | | 0 (b) | 0 (d) |
| Total | 93 | 171 | | 225 | 39 |

Taking the occurrence of infection both before and after anthelmintic treatment as a reference transition state (Table 6), the loglinear analysis strongly indicated that anthelmintic treatment was highly effective in controlling GI parasite infection. It was found that animals that tested positive for the presence of *strongyle* fecal eggs before treatment were 7.68 time more likely to test negative rather than remain positive after treatment ($P < 0.01$). For the sheep that tested negative for strongyle infection before treatment, the likelihood that the sheep remain negative after treatment ($Z = 3.66$; $P < 0.01$) or not transiting to positive state ($Z = -3.37$; $P = 0.001$) was higher than the likelihood of the occurrence of the reference transition state. For fasciolosis, the transition states observed from the current data did not permit a similar analysis as for strongylosis.

TABLE 6. THE LIKELIHOOD OF OCCURRENCE OF FOUR STATES OF GASTROINTESTINAL PARASITE INFECTION BEFORE AND AFTER DEWORMING IN REFERENCE TO THE CHANCE OF INFECTED SHEEP REMAINING INFECTED WITH STRONGYLES AFTER DEWORMING INTERVENTION IN THE HIGHLANDS OF ETHIOPIA

Infection state Pre-intervention	Post-intervention	β	Std. Error	Z	Sig.
	Constant	3.54	.17	20.79	<.001
Negative	Negative	0.76	.21	3.66	<.001
Negative	Positive	-1.19	.35	-3.37	.001
Positive	Negative	1.45	.19	7.68	<.001
Positive	Positive	0[a]	.	.	.

3.2.3 Participatory evaluation

The communities participating in the GI parasite control intervention expressed high satisfaction with the GI parasite control intervention. The women and men FGD (focus group discussion) groups evaluated the intervention positively, allocating on the average 67.25 and 52.75 beans to the highest satisfaction choice ('highly effective'), respectively, of the 100 beans provided. The FGD participants observed reduced cases of diarrhea (average score of 20.25 beans out of 100), emaciated sheep (20.87), sheep with erected hair (11.25), ascites cases (11.25), bottle jaws (17.25) and parasites in faeces (19.12). The farmers' common practice to control GI parasites before the intervention, which included awareness creation and training, was discussed.   Farmers were seeking deworming service from the public health service providers (27.3%), from private health service providers (16.5%), buying dewormers from the open market to treat sick animals by themselves (15.8%), selling sick animals (13.1%), or took no measures (5.3%), or applied traditional treatments (22.3%). The FGD confirmed that after the interventions, most of the farmers understood the concept and the need for a community-based GI parasite control approach. The proportion of farmers understanding the concept, according to the women and men FGDs, being 80 and 80% in Doyo Gena, 21 and 50% in Adiyo Kola, 25 and 75% in Horro, and 60 and 50% in Menz districts. However, they see challenges to continue the intervention sustainably including access to veterinary services and inputs (21.3%), lack of cooperation among villagers to implement the collective action (19.5%), knowledge on the parasite seasonal dynamics (18.4%), shortage of cash (23.6%), inefficacy of anthelmintics (16.3%) and no challenge (1%).

4.   Discussion
4.1   Prevalence and impact

Gastro-intestinal (GI) parasitism is a major health risk in small ruminant production in the highlands of Ethiopia. Based on a review of 50 studies in Ethiopia, Asmare et al. (2016) estimated an average GI nematode prevalence of 75.8%. The GI parasite prevalence in the sheep populations monitored in the current study reached as high as 75.7% although the prevalence was much less in most of the study sites. High GI parasite infection levels have also been reported in previous studies in the Ethiopian highlands. Getachew et al. (2016) reported an overall GI parasite infection rate of 86.6% in the mid-highlands of southern Ethiopia, which is one of the sampling sites for the current study, the infection rates being slightly higher in exotic sheep (90%) and crossbreds (92.9%) compared to the local indigenous sheep breed (84.2%). The current study showed that nematodes, particularly strongyles, including *Haemonchus contortus*, are the predominant GI parasite species in the wet highlands and mid-highlands, which is consistent with Getachew et al.'s (2016) previous findings where strongyles accounted for 71.9% of the nematode infections. Prevalence of nematodes, and in general GI parasites, appears to be dependent on agroecology. Consistent to the current results, nematode infection is relatively lower in the sub-moist subalpine highlands (57.5%; Seyoum et al., 2018) and dry highlands (40.9%, Gebresilassie et al., 2015) compared to the wet highlands. Haile et al. (2018) also reported low levels of nematode infection in goats in three dry lowland regions of Ethiopia and concluded that nematode parasites are not a major problem in these areas and strategic control programs using broad spectrum anthelmintic are not advisable. Higher prevalence of GI parasites in younger than adult animals have been well established (Zvinorova et al., 2016; Abebe et al., 2018), although some reports indicate insignificant association between age and

susceptibility to nematodes in sheep (Waruiru et al., 2005) and cattle (Yonas et al., 2018; Gemechu, 2019). Analysis of the effects of age under different body conditions in the current study showed effect of age on susceptibility to infections and response to anthelminthic treatments varied with body condition of animals.

The impact of GI parasitism on sheep production in Ethiopia is ranked among the top disease problems. Livestock keepers in the highlands (Ferede et al., 2014) ranked fasciolosis (locally well recognized by sheep keepers and known as *kulkult*) as the third most prevalent sheep disease. The preceding ranking was confirmed through a retrospective case study (Ferede et al., 2014) in the same study area where, out of a total of 184 diagnosed sheep in veterinary clinics, fasciolosis accounted for 19.6% of the sheep diagnosed following respiratory disease complex (38.6%) and enteritis (22.6%). The impact of GI parasites on animal productivity depends on the worm load, which is usually measured in parasite egg counts per gram of faeces (EPG), rather than on the state of infection or the mere presence of parasite eggs. Based on the EPG counts, the severity of GI parasite infection could be considered as mild in Adiyo Kola, moderate in Doyogena and heavy in Horro sampling sites according to Chagas et al. (2008) categories. It is known that animals infected with blood sucking GI parasites are anemic, a negative association being reported between EPG and packed cell volume (Haile et al., 2018; $r = -0.28$). The significant correlation between EPG counts and PCV values in the current study strongly indicates the negative impacts of GI parasitism on sheep productivity in the study sites. Fasciolosis and haemonchosis are the two important parasitic diseases known to cause severe anemia, but we could not attribute the observed anemic cases directly to heamonchosis as the method adopted in our study did not allow to identify *H. contortus* at species level.

The direct impacts of GI parasitism on animal performance could not be corroborated with the data from the current study since we found insignificant (though negative) association between body weights of infected sheep and their EPG counts, which was unexpected, although such insignificant association could occur under low parasite load (Haile et al., 2018). Local literature on the direct impacts of GI parasites is scarce, except 11% proportional mortality of lambs attributed to GI parasite infection (Bekele et al., 1992). However, negative impacts of GI infection could be inferred from the direct positive effects of GI control measures. The reported impacts in the central highlands of Ethiopia include significantly higher average daily gain, slaughter weight, and carcass weight in sheep treated with anthelmintics compared to non-treated sheep (Tibbo et al., 2004) and a significant effect of anthelmintic treatment on lambing interval (Aragaw et al., 2011). Studies elsewhere also showed that biannual anthelmintic treatment could generate up to 40% higher weight gain and reduce mortality from 8% in control animals to 3% in treated small ruminants (Nwafor, 2004) and significant extra weight gains could be achieved in treated goats in India (25.2 g/day) and Tanzania (9.88 g/day) compared to untreated goats (Galvamed).

4.2   Community-based intervention

The high GI parasite prevalence in the smallholder system in the highlands of Ethiopia could mainly be due to the unique conditions under the smallholder system that favor the perpetuation of the parasite dynamics. Among such conditions, mixing of village flocks in communal grazing lands and watering points and malpractice by sheep keepers in the use of anthelmintics are the major ones favoring the buildup up of parasite load both on pasture and the host animals. Roberts and Suhardono (1996) argued that treatment recommendations for the control of GI parasites for

subsistence farming families in developing countries may not be feasible since treatment of animals grazing on common lands is inefficient unless a high proportion of livestock owners treat. Rose and Wall (2012) also concluded that in upland and hill regions of the UK where the use of common grazing allows frequent contact between sheep from different farms, coordinated, systematic treatment and gathering, possibly with participation enforced by legislation, with an emphasis on prophylactic treatment, would appear to be necessary to manage parasite problems. In general, for most livestock interventions to succeed under smallholder systems, cooperation among smallholders is a necessity. For instance, it has been shown in the highlands of Ethiopia that lack of cooperation among smallholders would severely slow genetic progress in breeding programs (Gizaw et al., 2014) and that appreciable genetic progress could be achieved through cooperative breeding (Gizaw et al., 2013). Efficiency of community-based GI parasite control intervention could be evaluated at two levels, namely the long- and the short-term impacts on the parasite load. The reduction in the proportions of sheep infected with fasciolosis at the Menz site and strongylosis at the Doyo Gena site between the first and the second rounds of the deworming intervention in the current study could be taken as an indication of the long-term impact of the intervention on the parasite load in the communities. However, the trend in the worm load at the other two intervention sites remains relatively still high. The current results from the four intervention sites indicate that a sustained community-based GI parasite control intervention is required to change/influence the parasite dynamics towards an equilibrium minimum level of parasite load.

The short-term control of GI parasitism through anthelmintic treatment in all the current study sites was found to be highly efficient, with an efficacy of 89.2% against

strongylosis and 100% against fasciolosis. Generally, the efficacy of anthelmintic treatment of GI parasites under research conditions in the highland sheep of Ethiopia can be considered as high. This shows appropriate deworming practice including dose, dosing technique and selecting appropriate anthelmintics could result in high efficacy leading to momentary reduction and eventual eradication of worm load, if complementary interventions to reduce grazing land contamination is introduced. The percentage of non-responsive sheep to anthelmintic treatment in this study was relatively low (10.8%). Adapting the simple post-dosing faecal egg counts ("Drench Tests") method for detecting anthelmintic resistance (Abbot et al., 2012) by using number of sheep that remained positive for *strongyle* and *Fasciola* spp. eggs before and after drenching instead of EPG counts, 10.8% of non-responsive sheep could be taken as rough indication to anthelmintic resistance. It must, however, be emphasized that the test is merely an indicator of anthelmintic inefficacy and not necessarily anthelmintic resistance per se, as many other factors can influence test results (Abbot et al., 2012). However, there are indications of anthelmintic resistance in the highlands of Ethiopia; for instance, Getachew et al. (2016) detected parasite resistance to albendazole and ivermectin with fecal egg count reduction (FECR) of 90.1% and 84.4%, whereas susceptibility to both brands was observed with FECR >95% in other parts of the highlands (Seyoum et al., 2017; Chanyalew et al., 2020).

Inappropriate drug use/abuse could contribute to the high prevalence rate in most parts of the highlands. Deworming of apparently infected animals is a common practice among smallholders and pastoralists in Ethiopia, the proportion of farmers practicing deworming being as high as 81.9% in the current study, 95.3% among Horro sheep keepers (Aga et al., 2013) and 100% among Semien sheep keepers (Seyoum et al., 2017). However, there are malpractices including use of drugs by

farmers without veterinarian prescription accounting for 15.9% in the current study, 21.3% among Horro sheep keepers and 16% among Semen sheep keepers, and purchase of drugs from open market or non-veterinary shops accounting for 23% of the drug purchases by Semen sheep keepers. These and other malpractices including use of anthelmintics for all ailments or signs of sickness including respiratory signs, general disease symptoms (emaciation, rough hair coat, weakness and loss of condition), signs of digestive disturbance (diarrhea and reduced appetite), as well as deworming without any clinical signs (Seyoum et al., 2017) could lead to antimicrobial resistance and low drug efficacy. The deworming practice followed in the current study was mass deworming of all animals in the flocks. This could be justified under the observed high infection rate in the flocks, but mass deworming could lead to drug resistance and needs to be revised to targeted deworming as the worm load declines in the flocks.

This study identified the important GI parasites across agroecologies in the highlands of Ethiopia and provided an early evidence on the positive trends in parasite dynamics resulting from the long-term impact of community-based intervention. The essence of community-based GI parasite control approach involves full participation of livestock keepers within a defined location such as those sharing communal grazing and watering points, appropriate and strategic use of dewormers, and sustained intervention with periodic monitoring. A sponsored treatment program in the Philippines was demonstrably successful; but the livestock owners were unable, or unwilling, to continue the project at their own expense (Dumag et al., 1979). It is therefore vital for a full participation of the communities including in allocation of resources for the interventions, modalities for improved access to inputs and services and capacity building for the sustainable interventions.

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