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Assessment of a pragmatic strategy to improve health of kacang goats in subsistence agricultural communities in Indonesian Borneo

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Abstract

Poverty limits options available to smallholder, subsistence farmers to prevent or reverse livestock malnutrition and endoparasitism, two of the global drivers of goat morbidity and mortality in resource-constrained, tropical, agricultural communities. Our first study objectives describe changes observed in body condition and anaemia after implementation of three feasible and simple husbandry changes to improve health of smallholder herds of kacang goats in rural, Indonesian Borneo. These changes included routine hoof trimming and increased access to food and fresh water. We observed an impressive six-fold decrease in emaciated animals from 26 % to 4 % and an almost doubling of goats in ideal body condition from 29 % to 54 % after fourteen months of improved hoof care and nutrition. The second study objective described herd health changes observed fourteen months after adding a targeted, selective, refugia deworming regimen to the enhanced husbandry program. We observed a significant decrease in proportion of anaemic goats from 88 % to 74 % fourteen months after initiating the targeted selective herd anthelmintic treatment. Impoverished, smallholder subsistence agricultural communities with limited resources should first initiate feasible husbandry enhancements to begin improving overall herd health especially when anthelmintic expense or availability delays establishing an ideal program which includes a deworming component.

Keywords: Subsistence, goat health, refugia deworming, FAMACHA©, body condition score, anaemia

1 Introduction

Smallholder, mixed crop-livestock farming creates food security and a pathway out of poverty for 90 % of the world's population living on less than $1.25 USD per day (Benda *et al*., 2015; Graham *et al*., 2013; Soedjana *et al*.,1988). However, constrained resources limit availability of interventions to prevent or reverse the herd morbidity and mortality associated with malnutrition and endoparasitism common to livestock in tropical regions (Benda *et al*., 2015; Kapa *et al*., 2001; Knipscheer *et al*., 1984; McGregor, 1985; Singh & Swarnkar, 2008). We describe significant improvements in kacang goat herd health in subsistence, agricultural communities in rural Indonesian Borneo observed fourteen months after implementation of three practicable husbandry program enhancements including routine hoof trimming and increased access to food and water. These new practices were easily implemented well before it was feasible to incorporate a deworming regimen into the herd health program.

2 Materials and methods

Approvals: All goat herd health management strategies were endorsed by the regional National Animal Health Service veterinarian.

Animals: The animals were enrolled in Goats for Widows (GFW), a capacity building program designed by nongovernmental organisation Health in Harmony (www.healthinharmony.org) to promote sustainable, economic self-reliance for impoverished and marginalised widows in Sukadana, West Kalimantan, Indonesian Borneo (1.2469° S, 110.0926° E). The 137 locally sourced kacang goats beginning the study expanded to over 300 animals

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through breeding success over this 28-month, herd health assessment. The sale of goats privately or to the market primarily accounted for herd attrition. Participants in the GFW program met three requirements: the owners must be a widow, the first litter of kids must be returned to the GFW program and full participation in herd health training and oversight programs were mandatory.

Animal Care Leadership: Two community-based animal health workers were trained by veterinarians in Body Condition Scoring (BCS), FAMACHA anaemia scoring, hoof trimming and anthelmintic drenching of goats.

Surveys: The authors completed three, herd health surveys at fourteen-month intervals during the rainy season (December 2013, February 2015 and April 2016). The baseline survey sampled a representative 58 goats across 82 owners of 127 goats while the second (n=218) and third (n=218) surveys included more animals from the expanding herd of over 300 goats. A control group was not identified due to ethical concerns and welfare risks of not correcting overgrown hooves of goats enrolled in our community's capacity building program.

FAMACHA© Anaemia Scoring: A handheld card with five colours (bright red to almost white) was used to correlate lower palpebral conjunctival colour with hematocrit to estimate gradations of anaemia in goats from less than 12 % to greater than 28 % packed cell volume (Van Wyk & Bath, 2002).

Fig. 1: *FAMACHA© Anaemia Guide for correlating conjunctival colour with packed cell volume in goats and sheep (sourced from Southern Consortium for Small Ruminant Parasite Control, University of Georgia College of Veterinary Medicine, Athens, Georgia, USA).*

Body Condition Score (BCS): A practical, standardized technique where thickness of the subcutaneous and muscle tissue covering boney prominences (vertebrae, ribs and pelvis) was used to determine body condition of ruminants ranging from emaciated to obese (Villaquiran *et al*., 2005).

Table 1: *FAMACHA© score (after Van Wyk & Bath, 2002).*

Score	*Lower conjunctival colour*	*Estimated hematocrit %*	*Anthelmintic treatment?*
1	Red	≥28	No
2	Red–Pink	23–27	No
3	Pink	18–22	No
4	Pink-White	13–17	Yes
5	White	≤12	Yes

Faecal examinations: An initial faecal flotation for each herd was accomplished by adding 5 grams of fresh faeces to a Fecalyzer™ (Vetoquinol USA, 4250 N. Sylvania Ave, Ft Worth TX 76139) using Sheather's hyperosmotic solution to promote ova flotation. Sheather's solution was made by adding 454 grams of granulated sugar to 355 ml of boiled tap water (Foreyt, 2013). After 20 minutes of contact time between a 22 mm cover slip and the faecal solution meniscus, the cover slip was examined microscopically for endoparasite ova or larvae at 10× and 40× magnification.

Study Design: Qualitative, observational, descriptive, longitudinal, 28–month assessment.

Study Phase 1 (Husbandry Enhancement): Over the first fourteen-month phase of the study, goats were evaluated monthly for hoof trimming, received increased daily access to fresh water and hand cut and carried forage and fodder when confined in pens. Goats were also afforded browsing opportunity by free-ranging or tethering outside of pens in the afternoons. Two community animal health care workers trained by veterinarians performed hoof trims as needed at monthly evaluations based on overgrown hoof walls, toes and heels. Baseline assessments identified that no goats experienced hoof trims and that almost all goats were housed in elevated wooden pens with slatted floors. Caregivers provided water in a pail once daily to penned goats or never provided water if goats were ever tethered outside of the pens. Baseline assessments identified that caregivers cut and carried browse to pens once daily. To improve nutrition for Study Phase 1, caregivers provided penned goats with buckets or bowls of fresh water and browse at least twice daily.

Study Phase 2 (Targeted Selective Deworming): During the second fourteen-month phase of the study, we implemented a monthly refugia deworming strategy using 0.08 % ivermectin (Ivomec Sheep Drench, Merial Ltd-Boehringer Ingelheim,3239 Satellite Blvd., Duluth, GA, 30096). We treated only the most emaciated (BCS= 1) and anaemic

Table 2: *Body condition score (BCS) (after Villaquiran et al., 2005).*

BCS	*Lumbar vertebrae*	*Ribs*	*Summary*	*Anthelmintic treatment?*
1	Prominent dorsal and lateral processes easily grasped between fingers and thumb. Half or more of transverse processes visible. Saw tooth appearance.	Intercostal spaces visible behind front leg easily probed with fingers due to absence of soft tissue.	Emaciated	Yes
2	Processes visible and grasped between thumb and fingers but muscle present between skin and bone. One third to one half of transverse processes visible.	Ribs and intercostal spaces visible, partially filled with thin layer of soft tissue but penetrable with fingers.	Thin	No
3	Processes not easily grasped between fingers and thumb due to layer of soft tissue. Less than one fourth of transverse processes visible.	Ribs barely visible. Intercostal spaces only palpable with digital pressure and not visible due to layer of soft tissue.	Desired	No
4	Backbone not visible. Processes not graspable because covered with soft tissue.	Ribs not visible. Smooth body appearance with layer of soft tissue over intercostal spaces.	Over conditioned	No
5	Backbone covered in fat with a bulging appearance.	Ribs covered in an excessive layer of fat.	Obese	No

(FAMACHA© score = 4 or 5) goats in addition to all weanlings (~3 months old) regardless of scores. An estimated dose of 0.4 mg of ivermectin per kilogram of body weight was administered orally via 20 ml syringe at two standard volumes of 12.5 ml (10 mg) per 25 kg adult and 6 ml (4.8 mg) once per 12 kg weanling goat.

Statistical Analyses: Data were analysed using Instat 3™ for Windows (GraphPad Software, La Jolla, California). Anaemia score, body condition score and goat herd age data were compared between consecutive herd health assessments by using the two-tailed, nonparametric, Mann–Whitney test. Statistical significance was established at p values less than 0.05. All analyses were performed with a confidence level of 95 %.

3 Results

Faecal flotations: Initial, composite herd faecal flotation examinations across all herds tested positive for strongyle ova resembling *Haemonchus contortus* and *Trichostrongylus colubriformis*. *Trichuris* sp ova and coccidia were infrequently seen.

Body condition: After fourteen months of experiencing enhanced husbandry practices, the mean herd body condition score significantly improved (p=0.002) from thin (BCS=2.16) towards ideal (BCS=2.63) (Table 3). We observed no additional, significant change (p=0.35) in body condition score after an additional 14 months of enhanced husbandry practices and implementation of a monthly targeted selective (refugia) deworming strategy (Table 3).

Table 3: *Baseline, Phase 1 and Phase 2 body condition scores (BCS) of the goats.*

BCS (1–5)	*Baseline*	*Phase 1*	*Phase 2*
Mean	2.16	2.63	2.69
N	31	218	217
SD	0.89	0.66	0.54
Min	1	1	1
Max	4	4	4
Median	2	3	3
Lower 95 % CI	1.83	2.55	2.62
Upper 95 % CI	2.49	2.72	2.76
p* from prior column		0.002	0.35

†Mann-Whitney Test

Anaemia: We observed no significant improvement (p=0.63) in FAMACHA© anaemia score after the first fourteen months of enhanced husbandry practices. We found significant improvement (p<0.001) in mean herd FAMACHA© anaemia score decreasing from a mean of 3.29 to 3.02 (from about 18 % toward 23 % hematocrit) after fourteen months of targeted selective anthelmintic treatment (Table 4).

Table 4: *Baseline, Phase 1 and Phase 2 FAMACHA© assessment of the goats.*

FAMACHA©	*Baseline*	*Phase 1*	*Phase 2*
Mean	3.38	3.29	3.02
N	29	218	215
SD	0.90	0.75	0.85
Min	2	1	1
Max	5	5	5
Median	3	3	3
Lower 95 % CI	3.04	3.19	2.91
Upper 95 % CI	3.72	3.39	3.14
p* from prior column		0.63	0.001

†Mann-Whitney Test

Age: No significant change in mean herd age was observed from baseline through Phase 1 (p=0.32) or between Phase 1 and 2 (p=0.12) of husbandry changes and targeted selective deworming treatment. Mean herd age remained stable despite herd size changes from breeding and sales (Table 5).

Table 5: *Baseline, Phase 1 and Phase 2 ages & sex of the goats.*

	Baseline	*Phase 1*	*Phase 2*
		Age (months)	
Mean	19.9	16.9	16.0
N	25	213	215
SD	13.1	12.7	15.3
Min	1.5	0.1	0.07
Max	48	60	72
Median	18	18	10
Lower 95 % CI	14.5	15.2	14.0
Upper 95 % CI	25.3	18.6	18.1
p* from prior column		0.32	0.12
% Female	84	67	66

†Mann-Whitney Test

4 Discussion

The United Nations Food and Agricultural Organization's (FAO) strategic objectives align with Indonesia's development priorities reducing rural poverty and food insecurity with implementation of feasible, sustainable and efficient agricultural initiatives (FAO, 2019). Small-scale, subsistence farmers in Indonesia and around the world value goats as a cashable source of income to pay for food, housing, school, health care and hospital expenses (Graham *et al.*, 2013; Gatenby, 1988). Surveys in our study area where 60,000 villagers reside in communities surrounding 90,000 hectare, Gunung Palung National Park in West Kalimantan, Indonesian Borneo identified that these family expenses were met with revenue from unsustainable, illegal logging (Redford *et al.*, 2013). Armed with this information, the nongovernmental organisations, U.S. based, Health in Harmony (HIH) and Indonesian partner, Alam Sehat Lestari (ASRI), implemented a community-defined and directed, initiative to replace illegal logging with smallholder goat rearing, compost production and organic farming of barren, slash and burn sites adjacent to the national park (Redford *et al.*, 2013). Baseline surveys of the kacang goats initially enrolled in the initiative identified poor body condition (72 % prevalence), anaemia (44 % prevalence), endoparasitism (100 % herd prevalence) and lack of hoof health care as leading causes of suboptimal herd health (Tables 3 and 4). In our longitudinal study, we measured herd health changes after new management practices were implemented over two consecutive, fourteen-month phases.

The two morbidity markers, body condition score (BCS) and FAMACHA© anaemia score, provide the simplest ways to objectively track herd health trends. Body condition scoring of meat producing livestock affords a practical method for assessing fat and muscle characteristics of a carcass to ultimately determine marketability and cash value. The best areas to score meat producing goats entail palpation of soft tissue coverage between the second and fifth lumbar vertebrae and over the ribs with body condition scores ranging from emaciated (BCS=1) to obese (BCS=5) (Smith & Sherman, 2009; Villaquiran *et al.*, 2005). Aumont *et al.*, (1994) found the 5-point scale for BCS to be a reliable *in vivo* predictor of abdominal adipose tissue as well as total adipose tissue in tropical creole goats of a similar 26 kg size to our kacang goats. Emaciated or thin, underconditioned animals scoring 1 or 2 with prominent vertebral processes and deep intercostal spaces, applicable to most of our goats at baseline, require corrective action such as improved nutrition, anthelmintic treatment and assessment for debilitating disease. We found no evidence of endemic viral or bacterial diseases in any of these unvaccinated goats throughout the study. A BCS of at least 3, the goal for our animals, is ideal for a marketable goat (McGregor, 1985).

FAMACHA© scores assess harm (i.e. anaemia) done by hematophagous nematodes such as *Haemonchus contortus* while BCS measures health impact of malnutrition and non-hematophagous endoparasites such as *Teladorsagia* sp and *Trichostrongylus* sp (Besier, 2012; Jackson *et al.*, 2009; Kenyon *et al.*, 2009). Burke *et al.* (2007) demonstrated an 89 % correlation across 676 goats in the southern United States and Puerto Rico between mucous membrane colour (FAMACHA© score) and hematocrit. While FAMACHA© scores correlated well with strongyle parasite-induced anaemia in a study of 1,585 adult goats in tropical Mexico, there was no association with faecal egg count (Torres-Acosta *et al.*, 2014). In a similar field study of 537 grazing goats in the Southern United States, Kaplan *et al.*, (2004) identified a correlation between FAMACHA© score and hematocrit. Mahieu *et al.*, (2007) also described the correlation between hematocrit and FAMACHA© score of 230 goats grazing in a tropical island environment. For all three of these field studies, the strongest statistical agreement between FAMACHA© score and hematocrit existed for goats scoring 4 or 5 with the packed cell volumes less than 19 %, below the preferred range of 22-38 % found in healthy goats (Fielder, 2019). These published studies validate the use of the FAMACHA© Anaemia guide card (Fig. 1) using our criteria (Table 2) for selectively deworming goats presenting with severely anaemic FAMACHA© Scores of 4 and 5 throughout the second phase of our study.

The initial housing of goats for prolonged periods in raised pens with slatted floors contributed to overgrown hooves, lack of physical activity and prevented the opportunity to forage for browse and water. The first husbandry enhancement of Phase 1 performing once monthly assessments of hooves for trimming immediately resolved and prevented the lameness and health challenges associated with overgrown heel bulbs, soles, walls and claws.

Baseline surveys identified that goat owners did not provide water inside pens if goats were offered daily opportunities to seek browse or water when tethered or free ranging outside the pen. Permanently penned goats typically received a bucket or bowl of water once daily, often supplemented by owners with variable amounts of salt to reportedly meet electrolyte and mineral needs and improve appetite. Even though goats are known to situationally prefer consuming water supplemented with salt, chronic access to water supplemented with salt at concentrations greater than 9,500 mg per litre decreases food and water intake leading to dehydration and malnutrition (McGregor, 2004). The amount of salt added to water varied widely resulting in uncertain and possibly unpalatable or unhealthy concentrations. The variable volumes of water provided once daily in a bowl or pail to the penned goats likely did not meet their physiological intake needs of up to 6 litres per kg of consumed dry matter (Smith & Sherman, 2009) nor the ideal frequency offering water three to five times daily to goats in tropical, hot climates (Kawas *et al.*, 2012). The second husbandry change implemented for our study's Phase 1 provided access to fresh water at least twice daily to all penned goats. As an alternative to adding salt to the water, goat owners created a coconut 'saltshaker' suspended above the cut and carried foliage so goats may head butt the shaker and deliver salt to their taste (Figure 2).

Fig. 2: *Coconut saltshaker (Photograph by Jeff Wyatt)*

The amount of hand cut and carried foliage and fodder delivered once daily to the penned goats did not appear to meet nutritional needs of all animals since it was often completely consumed at our baseline assessment's farm visits. The third husbandry change implemented for Phase 1 offered goats opportunities to browse outside of pens and also provided penned goats with multiple, daily deliveries of hand cut herbaceous vegetation and fodder such as sun-dried cassava leaves (*Manihot esculenta*), and tree legumes (*Sesbania* sp, *Leucaene* sp, *Gliricidia* sp) all high in crude protein, metabolisable energy and calcium (Devendra, 1991). Such high protein foliage may increase average daily weight gain as experimentally observed in kacang goats fed supplemental protein in the form of fishmeal, soybean meal and leguminous forage (Kustantinah *et al.*, 2017).

Fourteen months after implementation of a hoof trimming program and increase in availability of food and water, we observed a significant increase in mean BCS from a thin score of 2.16 to 2.63 approaching the ideal score of 3.0. We also observed a dramatic 6-fold decrease in proportion of emaciated animals from 26 % to 4 % and almost a doubling of goats in ideal body condition from 29 % to 54 %. While our study did not track financial gains of the goat owners, any improvement in body condition is desirable especially since market price of meat goats in Indonesia is based on animal size. Goat meat, selling for 10-30 % more than beef in Indonesia (McGregor, 1985), is most in demand with a 25 % to 300 % increase in market price for celebrations such as Aqiqah in honor of a family birth and Islamic holidays such as Eid ul Adha, Ramadan and Eid al Fitr (Soedjana *et al.*, 1988; Valdivia, 1999). Intact male goats, preferred for Islamic holiday celebrations over females, increase carcass weight faster than females as evidenced by heavier shoulder, neck, breast and shank muscle (McGregor, 2012). The heaviest, healthiest male goats bringing the highest cash value are preferred for these ceremonies since the meat is shared across families (Kapa *et al.*, 2001; Knipscheer *et al.*, 1987). While the most marketable, mature, male goats that typically comprise about 50 % of the herd births are surplus to the breeding program, the healthy female goats, in contrast, are most valued for reproduction. All healthy goats are additionally treasured for long-term manure production for compost. However, emaciated goats, comprising 26 % of our animals at the baseline assessment, are not marketable and destined for slaughter and consumption by the owner's family to cut losses especially if the animals continue to deteriorate.

Counter to significantly increased mean BCS, there was no significant change in mean FAMACHA© anaemia score over the first fourteen months of enhanced nutrition and hoof trimming. The observed, yet statistically insignificant, decrease in proportion of severely anaemic goats from 43 % baseline to 38 % after Phase 1 as well as the improved mean, herd body condition score may in part be due to a phenomenon termed immunonutrition or immunomodulation (Singh & Swarnkar, 2008; Houdijk *et al.*, 2012). With this phenomenon, health indices (hematocrit and BCS) of the most clinically affected animals improve due to enhanced nutrition alone, especially protein, resulting in herd resilience and heightened immunity promoting coexistence with gastrointestinal nematodes (GIN) without the use of commercial anthelmintics (Knox *et al.*, 1996; Coop & Kyriazakis,1999; Coop & Kyriazakis, 2001). The high protein in sun-dried cassava leaves, tree legumes and tubers increase gastrointestinal tract protein while the tannins possess beneficial anthelmintic properties (Gatenby, 1988; Houdijk *et al.*, 2012; Coop & Kyriazakis, 1999; Coop & Kyriazakis, 2001; Hoste *et al.*, 2012; Knox *et al.*, 2012; Ravindran, 1992).

Jan *et al.* (2015) experimentally demonstrated that *Haemonchus contortus*-parasitised goats fed tannin-rich browse had increased hemoglobin, hematocrit, serum total protein, globulin, glucose and calcium over a brief 90-day feeding trial compared with untreated controls. Stabilisation of the overall herd anaemia scoring or the observed decrease, albeit statistically insignificant, in proportion of severely anaemic goats in our herd over the first fourteen months may partially be explained by an anthelmintic benefit from feeding increased amounts of high protein, tannin-rich plants.

Globally, endoparasitism is responsible for up to 10 % mortality and 20 % morbidity in ruminants (Sharma *et al.*, 2015). One member of the family of strongyles, *Haemonchus contortus*, may consume 10 % of a goat's circulating blood volume per day (Coop & Kyriazakis, 1999). A 45 % and 89 % prevalence of *Haemonchus contortus* and *Trichostrongylus* sp, respectively, in goat herds in neighbouring West Java resulted in an estimated 3.2 to 4.4 million kg annual loss in meat production in 1998 (Satrija & Beriajaya, 1998). Recent PCR and DNA sequencing of faeces from nearby Malaysian goat herds demonstrated 45 % prevalence of co-infections in individuals with *Haemonchus contortus* and *Trichostrongylus colubriformes* with an overall 63 % prevalence of strongyles (Tan *et al.*, 2014). It is not surprising that our herd baseline faecal flotations confirmed 100 % prevalence of strongyle ova in all samples since exams were performed during the rainy season when the highest egg shedding occurs (Beriajaya & Copeman, 1996) and since our study goats were never treated with commercial anthelmintics except for an occasional low dose of injectable ivermectin for sarcoptic mange. We were unable to microscopically differentiate between *Haemonchus contortus*, *Trichostrongylus colubriformis* and *Teladorsagia* (*Ostertagia*) sp eggs given their similar appearance. Speciation of these strongyles requires larval culture, a laboratory technique unavailable to us (Fox, 2019). The McMaster faecal flotation and concentration technique, used by some parasitologists to estimate worm burden (eggs per gram of faeces), was not performed given limited utility considering wide variation in egg shedding complicating consistent correlation with worm burden (Fox 2019) or FAMACHA© score (Torres-Acosta *et al.*, 2014). Identification of the species of the strongyles nor the worm burden were of primary importance to our herd health strategies. Our goal throughout both phases of the study was not to eliminate GIN from the herds but rather to promote co-existence with minimal to no impact on herd health and marketability.

In effort to manage GIN-related anaemia and production loss as well as minimize emergence of drug resistance, we implemented a refugia anthelmintic regimen over the second fourteen- month phase of the study. Refugia-based deworming selectively treats only the most vulnerable or clinically affected goats so to retain a population of anthelmintic-sensitive, genetically susceptible worms and eggs in the most resilient goats (Besier, 2012; Jackson *et al.*; 2009, VanWyk

& Bath, 2002). This targeted selective treatment (TST) successfully minimizes anthelmintic resistance (AR), a significant challenge to small ruminant herd health globally (Kaplan & Vidyashankar, 2012; Singh & Swarnkar, 2008; Knox *et al.*, 2012; Besier, 2012; Gray *et al.*, 2012; Kenyon *et al.*, 2009; Kenyon & Jackson, 2012). AR emerges as a herd management problem due to mass flock treatments in contrast to herds receiving only TST (Singh & Swarnkar, 2008; Gaba *et al.*, 2010). When less than 30 % of a flock receives anthelmintic treatment, which was our study goal, 90 % of the worms remain sensitive to the dewormer reducing both development of AR and total drug cost (Torres-Acosta *et al.*, 2014; Gaba *et al.*, 2010; Terrill *et al.*, 2012). The goats hosting most of the GIN are also the most clinically affected and benefit as recipients of selective deworming. By contrast, the higher the refugia population of untreated GIN in the healthier appearing, subclinically parasitized goats, the lower the risk of development of herd AR. Since AR persists in a herd for more than a decade, a strategy such as TST yields long term benefits (Singh & Swarnkar, 2008). Even though herds of small ruminants managed with TST overall have a higher worm burden than those receiving mass treatment, their production metrics such as weight gain are identical (Gaba *et al.*, 2010). Coexistence of host and parasite with no impact on production without costly deworming of all animals is an economic windfall for subsistence farmers.

We selected oral ivermectin as the dewormer because it has not been used to treat GIN in goats in the region and has also been shown to be more effective than fenbendazole in tropical regions, such as West Kalimantan, where benzimadazoles likely have been used in the past (Sharma *et al.*, 2015). Ivermectin must be administered at 0.4 mg/kg orally in goats, twice the dose used in sheep, based on therapeutic levels determined in pharmacokinetic studies (Smith & Sherman, 2009). Torres-Acosta *et al.*, (2014) identified low BCS and high FAMACHA© scores as the two most reliable and practical morbidity markers to use for selectively treating parasitized goats. We selected the BCS of 1 and FAMACHA© scores of 4 and 5 as triggers for TST to reverse parasite related morbidity and poor welfare of the remaining 4 % of emaciated goats and 38 % of critically anaemic goats present in our herds after Phase 1. Additional rationale for selecting FAMACHA© scores of 4 or 5 as criteria for TST was based on findings of a study of 1,585 subsistence farmed goats in tropical Mexico. In that study, no significant, additional herd health benefit was realised when the threshold for monthly refugia deworming included goats with FAMACHA© scores of 3 in addition to 4 and 5 (70.5 % of the herd) compared with only treating goats scoring 4 or 5 (20.4 % of the herd) (Torres-Acosta *et al.*, 2014). We routinely treated three-month old weanlings once regardless of BCS or FAMACHA© scores given their frail immune status and lack of resilience against GIN compared with adults (Benda *et al.*, 2015).

After fourteen months of selective deworming, we observed significant improvement in mean anaemia score by 11 % and more than doubling of the proportion of goats scoring with healthy (good to excellent) hematocrits from 12 % to 26 % likely due to reduction of the anaemia-inducing GIN, *Haemonchus contortus* (Table 4). Even though Beriajaya & Copeman (1996) identified that anthelmintic treatment improved weight gain in goats, we saw no significant increase in mean body condition score after fourteen months of TST. We achieved our goal of deworming no more than 30 % of the herd at the end of Phase 2 when the herd morbidity markers decreased to 1 % for emaciated goats and 30 % with anaemia. The significant decrease in herd anaemia observed after Phase 2 TST underscores the value of incorporating a herd deworming regimen as soon as feasible.

Our 2.3-year longitudinal study demonstrates that when designing goat herd health programs in resource-constrained areas of the world where poor hoof health, malnutrition and endoparasitism drive herd morbidity and mortality, implementing a first phase strategy of feasible husbandry changes is prudent and immediately impactful especially when deworming medication is not immediately available. We observed significant improvement in overall herd health and welfare fourteen months after implementation of achievable, low to no-cost husbandry changes such as routinely trimming hooves and increasing availability of cut and carry browse, fodder and fresh water. Once anthelmintic medication became available, we observed a significant reduction in anaemia fourteen months after implementation of a targeted selective anthelmintic treatment reversing the adverse health effect of hematophagous nematodes.

Given lack of a control group, we may only surmise a causal relationship between implementation of our four goat health management tools and the significant improvement in herd health. Regardless of a proven causal effect, our community of goat rearing widows' families tell us they did not anticipate that their goats would become the healthiest they have ever seen. Based on this experience, they have incorporated the routine hoof trimming practices, provision of additional access to food and water and the cost-effective, refugia deworming regimen into their small-scale goat production programs. Development and assessment of pragmatic and effective strategies to promote smallholder livestock health and welfare aid the world's 1.2 billion subsistence farmers seeking a pathway out of poverty.

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Conflict of interest

Authors state they have no conflict of interests.

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