

Current status of anthelmintic resistance in meat goats: A comparative efficacy study of albendazole and fenbendazole in Maha Sarakham, Thailand

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Abstract

Anthelmintic resistance in gastrointestinal nematodes threatens sustainable goat production globally. While resistance is well-documented in many regions, data from Thailand remain limited. This study determined the prevalence of gastrointestinal nematodes and assessed the efficacy of albendazole and fenbendazole in meat goats in Maha Sarakham province, northeastern Thailand. A two-stage cross-sectional study was conducted on 10 meat goat farms between August 2021 and March 2022. In Stage 1, fecal samples from 150 goats were examined using simple flotation and sedimentation techniques to identify parasite morphology. In Stage 2, the McMaster technique was employed to quantify fecal egg counts (FEC). Twenty-six goats with FEC ≥ 150 EPG were allocated to receive albendazole (10 mg/kg, n = 11) or fenbendazole (15 mg/kg, n = 15). Fecal egg count reduction (FECR) was calculated on Day 14 following WAAVP guidelines. Resistance was defined as FECR $< 95\%$. Overall prevalence was 84.00% (95% CI: 77.30–89.01%), with Strongyle-type nematodes being most prevalent (77.33%, 95% CI: 70.00–83.30%), followed by *Moniezia* spp. (25.33%). Co-infections were observed in 22.0% of animals. Both drugs showed substantially reduced efficacy: albendazole FECR 71.95% (95% CI: 64.36–79.89%) and fenbendazole FECR 79.56% (95% CI: 68.58–89.78%), with no significant difference ($P = 0.706$). All 10 farms (100%) demonstrated resistance to both benzimidazoles. This study provides the first comprehensive evidence of widespread benzimidazole resistance in Thai goat populations. The universal resistance observed highlights an urgent need for integrated parasite management strategies, including pasture management, selective treatment protocols, and alternative control methods.

Keywords: albendazole, anthelmintic resistance, caprine, fenbendazole, fecal egg count reduction test, gastrointestinal parasites

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Received March 29, 2025

Accepted May 14, 2026

<https://doi.org/10.56808/2985-1130.3847>

Goat production is a key livelihood resource in tropical and subtropical regions, but gastrointestinal nematode (GIN) infections severely limit productivity by reducing growth, feed efficiency, and survival, especially in young animals (Taylor *et al.*, 2016; Charlier *et al.*, 2020). Warm, humid climates, such as those in Southeast Asia, together with ongoing climate change, favour year-round development and survival of free-living parasite stages and are predicted to increase the transmission and geographic range of highly pathogenic species such as *Haemonchus contortus* (Bautista Garfias *et al.*, 2022).

Control of GIN in goats relies mainly on benzimidazoles, macrocyclic lactones and levamisole, with benzimidazoles widely used on smallholder farms because of their broad spectrum and low cost (Prichard, 1994; Lespine *et al.*, 2012). However, decades of frequent and often indiscriminate dosing have driven widespread anthelmintic resistance (AR), which is now recognized as a major threat to sustainable small ruminant production, particularly in tropical regions where rapid parasite development necessitates frequent treatments (Kaplan and Vidyashankar, 2012; Dey *et al.*, 2020; Qamar and Alkheraije, 2023). Goats metabolize benzimidazoles more rapidly than sheep or cattle, so higher dose rates are required; albendazole is typically used at 10 mg/kg and fenbendazole at 10–15 mg/kg, yet recent studies have reported declining efficacy at these doses, indicating emerging resistance (Hennessy *et al.*, 1993; Lespine *et al.*, 2012; Garg *et al.*, 2004; Godara *et al.*, 2011).

In Southeast Asia, high GIN prevalence and reduced albendazole efficacy have been reported in goats and sheep in Malaysia, Vietnam and Indonesia, and resistance to multiple drug classes, including benzimidazoles and levamisole, has been documented in Thai goat herds, with molecular confirmation of benzimidazole-resistant *H. contortus* (Chandrawathani *et al.*, 2009; Nguyen *et al.*, 2012; Ratanapob *et al.*, 2012; Paduang and Thongtha, 2020; Pitaksakulrat *et al.*, 2021; Imanuelle *et al.*, 2023; Rerkyusuke *et al.*, 2023). Nevertheless, epidemiological and efficacy data from northeastern Thailand remain scarce, despite increasing goat numbers and a climate highly conducive to parasite transmission. Maha Sarakham province is a major goat producing area with semi-intensive smallholder systems and frequent anthelmintic use, suggesting strong selection pressure for AR (Ratanapob *et al.*, 2012; Rerkyusuke *et al.*, 2023).

Therefore, this study aimed (1) to determine the prevalence and infection patterns of gastrointestinal nematodes in meat goats on smallholder farms in Maha Sarakham province, northeastern Thailand, and (2) to evaluate the efficacy of albendazole (10 mg/kg) and fenbendazole (15 mg/kg) against strongyle type nematodes using fecal egg count reduction tests (FECRT) in accordance with World Association for the Advancement of Veterinary Parasitology (WAAVP) guidelines (Coles *et al.*, 1992; Geurden *et al.*, 2022).

This investigation employed a two-stage cross-sectional design. In the first stage, a prevalence survey was conducted to characterize the distribution of GIN infections in meat goats in Maha Sarakham province. In the second stage, an anthelmintic efficacy trial using FECRT was carried out on a subset of infected goats to evaluate the therapeutic efficacy of albendazole and fenbendazole following WAAVP guidelines (Coles *et al.*, 1992; Geurden *et al.*, 2022).

Ethical considerations: All procedures involving animals were reviewed and approved by the Institutional Animal Care and Use Committee of Mahasarakham University (IACUC MSU 01/2022). Written informed consent was obtained from all participating farm owners. Anthelmintic treatments were provided free of charge, and animals were monitored for adverse reactions following drug administration. All procedures complied with Thai animal welfare regulations and international guidelines for veterinary research.

Study area and period: The study was conducted on 10 meat goat farms in Maha Sarakham province, northeastern Thailand (approximately 15.5°N–16.5°N, 102.5°E–103.5°E), between August 2022 and March 2023 (Fig. 1). The province has a tropical savanna climate with distinct wet and dry seasons, characterised by high temperatures and moderate to high humidity, conditions that are conducive to year-round GIN transmission (Ratanapob *et al.*, 2012). Farms were selected from four districts using convenience sampling based on farmer willingness to participate and accessibility. All participating farms practiced semi-intensive management with daily grazing and supplementary feeding.

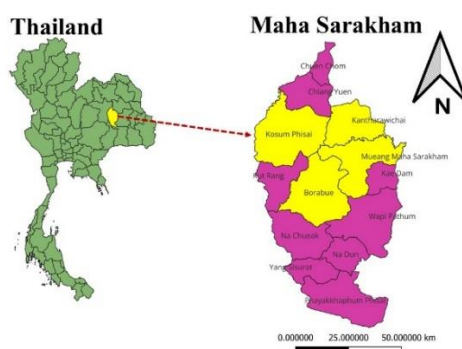


Figure 1 Mapping of Maha Sarakham province, Thailand.

Animals and sample size: Sample size for the prevalence survey was calculated using a single proportion formula, assuming an expected prevalence (P) of 0.5 to maximize variance, a 95% confidence level ($Z = 1.96$), and a desired precision (d) of 0.08, yielding a minimum of 150 goats. Accordingly, 150 meat goats aged 2–4 months, of mixed local breeds and with no anthelmintic treatment in the preceding three months, were selected from the 10 farms using systematic random sampling.

For the anthelmintic efficacy assessment, sample size followed WAAVP recommendations of 10–15 animals per treatment group to reliably detect resistance (Coles *et al.*, 1992; Geurden *et al.*, 2022). From the 150 goats examined, 30 animals with strongyle type infections and baseline fecal egg counts (FEC) ≥ 150 eggs per gram (EPG) were initially selected and randomly allocated into two treatment groups ($n = 15$ per group) to receive either albendazole (10 mg/kg) or fenbendazole (15 mg/kg). Allocation was stratified by farm to ensure balanced representation. During data cleaning, four goats in the albendazole group were found to have baseline FEC < 150 EPG and were excluded from the final FECRT analysis, resulting in 11 goats in the albendazole group and 15 in the fenbendazole group, in accordance with WAAVP criteria (Coles *et al.*, 1992).

Anthelmintic treatments and dosage selection:

Albendazole and fenbendazole were selected because they are commonly used benzimidazole anthelmintics in Thai goat production. Goats were weighed using a portable weighing scale where available or by careful visual estimation when scales were not accessible, and doses were calculated individually on a mg/kg basis. Albendazole was administered orally at 10 mg/kg body weight, which is the recommended dose for goats in the absence of resistance and provides adequate systemic exposure when pharmacokinetic differences from sheep are considered (Lespine *et al.*, 2012). Fenbendazole was administered orally at 15 mg/kg body weight. Goats metabolize and eliminate benzimidazoles more rapidly than sheep and cattle, necessitating higher dose rates; previous work has shown that fenbendazole at 5 mg/kg may result in only partial FEC reduction in goats, whereas 7.5 mg/kg can achieve 100% efficacy in susceptible populations (Hennessy *et al.*, 1993; Garg *et al.*, 2004). More recent studies, however, have reported markedly reduced FECR at standard doses, consistent with emerging resistance (Ram *et al.*, 2007; Godara *et al.*, 2011). The 15 mg/kg fenbendazole dose used here was chosen as a high-end dose within the recommended range to maximize efficacy and reduce the risk of misclassifying underdosing as resistance in a region where benzimidazole resistance was suspected (Lespine *et al.*, 2012; Martin *et al.*, 2018).

Fecal sample collection and parasitological examination:

For the prevalence survey, fresh fecal samples (approximately 10–15 g) were collected directly from the rectum of each goat using disposable gloves and placed in individually labelled plastic containers. Samples were kept in a cool box (4–8 °C)

and transported to the laboratory within 4–6 h of collection.

Parasitological examination involved two qualitative methods to detect and identify gastrointestinal parasites: simple flotation and simple sedimentation. Simple flotation using a saturated salt solution (specific gravity 1.20) was used primarily to detect light eggs, including strongyle-type nematodes and *Moniezia* spp., whereas sedimentation was used to detect heavier eggs such as those of trematodes. Parasite eggs were identified as genus or morphotype based on size, shape, colour, and internal morphology using standard veterinary parasitology keys (Soulsby, 1982; Taylor *et al.*, 2016). Strongyle-type eggs, which include *Haemonchus*, *Trichostrongylus*, *Teladorsagia* and *Oesophagostomum* spp., were grouped together because they cannot be distinguished at the egg stage without larval culture.

Fecal egg count and fecal egg count reduction test (FECRT):

Quantitative FECs for both the prevalence survey and FECRT were performed using the modified McMaster technique with a sensitivity of 50 EPG (Ministry of Agriculture, Fisheries and Food, 1986). For each sample, 4 g of feces were homogenized in 56 mL of saturated salt solution (specific gravity 1.20) and strained through a fine mesh sieve. The resulting suspension was used to fill both chambers of a McMaster slide, which was allowed to stand for 5 minutes to permit egg flotation. Eggs were counted under a light microscope at 100 $\times$ magnification, and FEC (EPG) values were calculated by multiplying the total number of eggs observed in both chambers by 50.

For the FECRT, fecal samples were collected from each goat on Day 0 (immediately before treatment) and Day 14 post-treatment, following WAAVP recommendations for benzimidazole efficacy testing in small ruminants (Coles *et al.*, 1992; Geurden *et al.*, 2022). FECR for each treatment group was calculated using group arithmetic means as:

$$\text{FECR}(\%) = \left[1 - \frac{\text{mean FEC}_{\text{post}}}{\text{mean FEC}_{\text{pre}}} \right] \times 100$$

Ninety-five percent confidence intervals (95% CI) for FECR were estimated by non-parametric bootstrap resampling (10,000 iterations). Anthelmintic response was classified according to WAAVP criteria: resistant if FECR $< 95\%$ and the lower 95% CI $< 90\%$, suspected resistance if FECR $< 95\%$ or lower 95% CI $< 90\%$, and susceptible if FECR $\geq 95\%$ and lower 95% CI $\geq 90\%$ (Coles *et al.*, 1992).

Statistical analysis: Data were analyzed using R software version 4.2.1 (R Core Team, 2022). Descriptive statistics (mean, standard deviation, median and range) were calculated for continuous variables. Prevalence was expressed as a percentage with 95% confidence intervals computed using the Wilson score method. FEC and FECR data were assessed for normality using the Shapiro–Wilk test. Because FEC and FECR were not normally distributed, comparisons between treatment groups were performed using the Mann–Whitney U test. A two-sided alpha level of 0.05 was used to determine statistical significance.

Results

Farm characteristics and management practices: A total of 150 meat goats were sampled from 10 smallholder farms in Maha Sarakham province, northeastern Thailand. Farm characteristics and anthelmintic management practices are summarized in Table 1. Herd size ranged from 35 to 120 goats (mean $\pm$ SD: 68.2 ± 26.5), with most farms (60%) maintaining 50–80 animals. All farms used semi-intensive management combining daily grazing with supplementary feeding. Four farms (40%) practiced rotational grazing with pasture rest periods of 1–3 months, whereas six farms

(60%) maintained continuous grazing on the same pastures year-round.

Anthelmintic treatment frequency ranged from 2 to 6 treatments per year (median: 4). All farms (100%) used albendazole as their primary anthelmintic, while 9 farms (90%) also used ivermectin. Fenbendazole and levamisole were used on 20% and 30% of farms, respectively. Only three farms (30%) reported rotating between anthelmintic classes. Most farms (70%) estimated drug doses by visual assessment of body weight rather than using scales, and none had previously performed FECRT (Table 1).

Table 1 Farm characteristics and anthelmintic management practices on 10 smallholder goat farms in Maha Sarakham province, northeastern Thailand.

Characteristic	Value/Description
Farm demographics	
Number of farms surveyed	10
Total goats sampled	150
Mean herd size $\pm$ SD	68.2 ± 26.5
Herd size range	35–120
Management system	
Semi-intensive management	10 (100%)
Rotational grazing	4 (40%)
Pasture rest period (rotational farms)	1–3 months
Continuous grazing	6 (60%)
Supplementary feeding	10 (100%)
Anthelmintic treatment practices	
Treatment frequency per year (median)	4
Treatment frequency range	2–6
Anthelmintic drugs used	
Albendazole (primary drug)	10 (100%)
Ivermectin (secondary drug)	9 (90%)
Fenbendazole	2 (20%)
Levamisole	3 (30%)
Resistance management practices	
Drug class rotation	3 (30%)
Dose by visual weight estimation	7 (70%)
Dose by actual weighing	3 (30%)

Prevalence and infection patterns of gastrointestinal parasites: Of the 150 goats examined, 126 were positive for at least one gastrointestinal parasite, giving an overall prevalence of 84.00% (95% CI: 77.30–89.01) (Table 2). Strongyle-type nematode eggs were the most prevalent, detected in 116 goats (77.33%, 95% CI: 70.00–83.30), followed by *Moniezia* spp. (25.33%, 95% CI: 19.05–32.85), *Trichostrongylus* spp. (2.67%, 95% CI: 1.04–6.66) and *Strongyloides* spp. (0.67%, 95% CI: 0.12–3.68). Strongyle-type eggs comprise *Haemonchus*, *Trichostrongylus*, *Teladorsagia*, and *Oesophagostomum* genera, which are morphologically indistinguishable at the egg stage.

Among the 126 infected goats, 93 (73.81%, 95% CI: 65.59–80.70) harbored single species infections, most commonly strongyle type nematodes alone. Co-infections with two parasite species were observed in 33 goats (26.19%, 95% CI: 19.30–34.41), with the dominant combination being strongyle type nematodes plus *Moniezia* spp. (30/33, 90.91%). No animals were infected with three or more parasite species (Table 2). All 10 farms had at least one goat positive for strongyle type nematodes (farm level prevalence 100.00%, 95% CI: 72.25–100.00). Within-farm prevalence of strongyles ranged from 60.0% to 86.7%, with a mean $\pm$ SD of $77.3 \pm 8.1\%$.

Fecal egg count reduction test (FECRT): Thirty goats with baseline strongyle type FEC ≥ 150 eggs per gram (EPG) were initially enrolled in the FECRT and randomly assigned to either the albendazole (10 mg/kg; $n = 15$) or fenbendazole (15 mg/kg; $n = 15$) treatment group. Following data cleaning in accordance with WAAVP guidelines, four goats in the albendazole group with baseline FEC < 150 EPG were excluded, resulting in final sample sizes of 11 goats for albendazole and 15 goats for fenbendazole. Baseline FEC did not differ significantly between the two groups ($P = 0.842$, Mann–Whitney U test; Table 3).

Both anthelmintics showed suboptimal efficacy against strongyle-type nematodes. In the albendazole group, mean FEC decreased from the pretreatment value to the post-treatment value corresponding to a mean fecal egg count reduction (FECR) of 71.95% (95% CI: 64.36–79.89). In the fenbendazole group, mean FECR was 79.56% (95% CI: 68.58–89.78) (Table 3). According to WAAVP criteria, both treatments were classified as resistant, as FECR values were $< 95\%$ and the lower 95% confidence limits were $< 90\%$ for both drugs.

Table 2 Prevalence and intensity of gastrointestinal parasite infections in 150 goats from 10 farms in Maha Sarakham province, northeastern Thailand

Parameter	n	%	95% CI
Overall parasite prevalence			
Total positive (any parasite)	126	84.00	77.30-89.01
Total negative	24	16.00	-
Parasite species prevalence			
Strongyle-type nematodes*	116	77.33	70.00-83.30
<i>Moniezia</i> spp.	38	25.33	19.05-32.85
<i>Trichuris</i> spp.	4	2.67	1.04-6.66
<i>Strongyloides</i> spp.	1	0.67	0.12-3.68
Infection patterns			
Single-species infection	93	73.81	65.59-80.70
Co-infection (2 species)	33	26.19	19.30-34.41
Co-infection (≥3 species)	0	0	0.00-2.98
Common co-infection			
Strongyles + <i>Moniezia</i> spp.	30/33	90.91	76.39-96.88
Strongyles + <i>Trichuris</i> spp.	2/33	6.06	1.68-19.57
Strongyles + <i>Strongyloides</i> spp.	1/33	3.03	0.54-15.26
Farm-level prevalence (strongyles)			
Farms with ≥1 positive animal	10/10	100.00	72.25-100.00
Within-farm prevalence range		60.0 - 86.7%	
Mean within-farm prevalence ± SD		77.3 ± 8.1%	

Strongyle-type eggs include *Haemonchus*, *Trichostrongylus*, *Teladorsagia*, and *Oesophagostomum* genera (morphologically indistinguishable)

CI = confidence interval (Wilson score method); SD = standard deviation

Comparison between treatment groups showed no statistically significant difference in FECR ($p = 0.706$, Mann-Whitney U test), despite the numerically higher mean FECR in the fenbendazole group (mean difference: 7.61 percentage points). Similarly, no significant difference was observed in post-treatment FEC between groups ($P = 0.523$; Table 3).

At the farm level, all 10 farms (100%) demonstrated benzimidazole resistance to at least one

of the tested drugs. On every farm, FECR for either albendazole or fenbendazole (or both) was below 95%, and the corresponding lower 95% confidence interval was below 90%, indicating that benzimidazole resistance is widespread among strongyle-type nematode populations infecting meat goats in Maha Sarakham province.

Table 3 Fecal egg count reduction test (FECRT) results for albendazole and fenbendazole against strongyle-type nematodes in goats from Maha Sarakham province, northeastern Thailand.

Parameter	Albendazole (10 mg/kg)	Fenbendazole (15 mg/kg)	P-value*
Pre-treatment FEC (Day 0)*			
Mean ± SD (EPG)	518 ± 229	527 ± 537	0.842
Median (EPG)	500	300	
Range (EPG)	250-900	150-2,200	
95% CI	395-650	307-823	
Post-treatment FEC (Day 14)*			
Mean ± SD (EPG)	159 ± 109	130 ± 168	0.523
Median (EPG)	150	50	
Range (EPG)	0-350	0-500	
95% CI	100-223	50-217	
FECR (%)*			
Mean ± SD	71.95 ± 13.96	79.56 ± 21.79	0.706
95% CI	64.36-79.89	68.58-89.78	

*Mann-Whitney U test.

Discussion

This study provides the first comprehensive field evidence of reduced benzimidazole efficacy in meat goats in Maha Sarakham province, northeastern Thailand, and confirms that GIN infections are endemic across all surveyed farms. The combination of high parasite prevalence, universal farm-level resistance to albendazole and fenbendazole, and management practices that favour resistance selection indicates that current control strategies are unsustainable and require urgent modification

(Kaplan and Vidyashankar, 2012; Ratanapob *et al.*, 2012; Rerkyusuke *et al.*, 2023).

Prevalence and epidemiology of gastrointestinal parasites: The overall parasite prevalence of 84.00% observed in this study is comparable to reports from other tropical and subtropical small-ruminant systems, where year-round parasite transmission is common. Studies from central Thailand, Vietnam and Malaysia have reported GIN prevalence in goats and sheep ranging from approximately 65% to over 90%, reflecting the suitability of humid tropical climates for continuous parasite transmission (Chandrawathani *et*

al., 2009; Nguyen *et al.*, 2012; Ratanapob *et al.*, 2012). In the present study, all 10 farms had at least one infected animal, and within-farm prevalence of strongyle-type nematodes ranged from 60.0% to 86.7%, confirming that GIN infection is endemic rather than sporadic in meat-goat herds in Maha Sarakham.

Strongyle-type nematodes were the predominant parasites (77.33%), in agreement with their recognised status as the most economically important GIN in small ruminants worldwide (Soulsby, 1982; Taylor *et al.*, 2016). The relatively high mean fecal egg count (856 ± 624 EPG) among positive animals, with a substantial proportion carrying heavy burdens, indicates considerable parasite pressure that is likely to impair growth and productivity, particularly in young goats (Hoste *et al.*, 2015). The high prevalence and intensity of infection can be attributed to several interrelated factors: the warm, humid climate of northeastern Thailand; semi-intensive management systems with regular access to pasture; and frequent continuous grazing, all of which favour the development, survival and ingestion of infective third-stage larvae (Bautista-Garfias *et al.*, 2022).

The detection of *Moniezia* spp. in 25.33% of goats is noteworthy because cestode infections are often under-reported in resistance studies despite their potential contribution to poor weight gain and ill-thrift in growing animals (Soulsby, 1982). The relatively high proportion of co-infections (26.19%), predominantly strongyle-type nematodes combined with *Moniezia* spp., is typical of grazing systems and may further compromise clinical outcomes (Chandrawathani *et al.*, 2009). In contrast, the low prevalence of *Trichuris* spp. and *Strongyloides* spp. suggests these parasites are of minor epidemiological importance in the adult meat-goat population studied, which is consistent with previous observations in other regions (Taylor *et al.*, 2016).

Phenotypic evidence of benzimidazole resistance: The most striking finding of this study is the consistently poor performance of both benzimidazole drugs across all farms. Using standardised FECRT procedures, albendazole at 10 mg/kg and fenbendazole at 15 mg/kg achieved mean fecal egg count reductions of only 71.95% and 79.56%, respectively, with lower 95% confidence limits well below the 90% threshold recommended by the WAAVP (Coles *et al.*, 1992; Geurden *et al.*, 2022). According to these criteria, both treatments must be classified as resistant, and all 10 farms met the definition of benzimidazole resistance. These results indicate that reduced efficacy is not restricted to a few problem herds but is widespread in meat-goat nematode populations in Maha Sarakham province.

The lack of a statistically significant difference in FECR between albendazole and fenbendazole was expected, as both drugs share the same benzimidazole core structure and act primarily by binding to β -tubulin and disrupting microtubule formation in nematode intestinal cells (Prichard, 1994). Cross-resistance within the benzimidazole class is well documented and is commonly associated with single nucleotide polymorphisms in the β -tubulin gene at codons 167, 198, or 200 in *Haemonchus contortus* and

other trichostrongylid nematodes (Silvestre and Humbert, 2002; Pitaksakulrat *et al.*, 2021). The slightly higher FECR observed with fenbendazole (approximately 8 percentage points) likely reflects the higher dose used (15 mg/kg) rather than inherently greater susceptibility of the parasite population to this molecule (Garg *et al.*, 2004; Lespine *et al.*, 2012). Importantly, even at this elevated dose, fenbendazole efficacy remained far below 95%, which is highly suggestive of established resistance rather than dose insufficiency alone (Ram *et al.*, 2007; Godara *et al.*, 2011).

When compared with international reports, the FECR values observed here fall within the range described for advanced benzimidazole resistance in tropical small-ruminant systems. Studies from Malaysia and Indonesia, for example, have reported markedly reduced albendazole efficacy against strongyle-type nematodes in goats, with FECR values often between 60% and 90%, indicating heavy resistance in multiple regions (Chandrawathani *et al.*, 1999; Imanuelle *et al.*, 2023). Similarly, case reports and surveys from other parts of Thailand have documented resistance to albendazole and levamisole in goats and molecular confirmation of benzimidazole-resistant *H. contortus* (Paduang and Thongtha, 2020; Pitaksakulrat *et al.*, 2021; Ratanapob *et al.*, 2022). The present findings extend this evidence base to northeastern Thailand and provide quantitative farm-level data that support the conclusion that benzimidazole resistance is now endemic in meat-goat nematode populations in this region.

Pharmacokinetic considerations versus true resistance: Interpreting reduced FECRT results in goats requires careful consideration of species-specific pharmacokinetics. Goats metabolize and eliminate benzimidazoles more rapidly than sheep or cattle, resulting in lower systemic drug exposure at equivalent mg/kg doses and an increased risk of apparent treatment failure when sheep dosing regimens are directly extrapolated (Hennessy *et al.*, 1993; Lespine *et al.*, 2012). Experimental work has shown that standard fenbendazole doses of 5 mg/kg may provide only moderate efficacy in goats; in naturally infected animals, a dose of 5 mg/kg achieved approximately 74% reduction in FEC, whereas increasing the dose to 7.5 mg/kg reduced FEC to zero and eliminated *Haemonchus* worms in a controlled infection trial (Garg *et al.*, 2004). These data illustrate how under-dosing, especially in a species with faster drug clearance, can mimic resistance by producing sub-optimal FECRT values in the absence of genuine genetic resistance.

In the present study, however, relatively high doses were deliberately chosen to minimize the risk of pharmacokinetic under-exposure: 10 mg/kg albendazole, which is considered the standard goat dose in the absence of resistance, and 15 mg/kg fenbendazole, at the upper end of the recommended range for situations where resistance is suspected (Lespine *et al.*, 2012; Martin *et al.*, 2018). Despite this, both drugs yielded FECR values far below 95%, and the lower 95% confidence limits were <90% for both treatments, fulfilling strict WAAVP criteria for

resistance (Coles *et al.*, 1992; Geurden *et al.*, 2022). Given that dosing was performed individually on a mg/kg basis and that a fenbendazole dose exceeding the 7.5 mg/kg shown to be fully effective in susceptible populations still failed to restore acceptable efficacy, pharmacokinetic explanations alone are unlikely to account for the magnitude of treatment failure observed (Garg *et al.*, 2004; Ram *et al.*, 2007; Godara *et al.*, 2011).

Taken together, the use of elevated dose rates, adherence to FECRT guidelines and the consistent pattern of sub-optimal FECR across multiple farms provide strong phenotypic evidence highly suggestive of true benzimidazole resistance in the strongyle-type nematode populations infecting these meat goats. Nevertheless, without species-specific larval culture and molecular assays targeting β -tubulin mutations, the precise contribution of individual nematode genera and specific resistance alleles cannot be determined, and the present conclusions should therefore be regarded as robust phenotypic indicators rather than definitive genetic confirmation (Silvestre and Humbert, 2002; Pitaksakulrat *et al.*, 2021).

Farm management practices and resistance development: The management practices observed across the 10 farms are consistent with known risk factors for the development and spread of anthelmintic resistance in small ruminants. Treatment frequency was relatively high (median 4 treatments per year), exposing parasite populations to repeated and often calendar-based drug administration (Kenyon *et al.*, 2009; Ratanapob *et al.*, 2012). Frequent whole-herd treatments reduce the proportion of parasites in refugia—those not exposed to the drug—thereby diminishing the dilution of resistant alleles by susceptible genotypes and accelerating the increase in resistance frequency (van Wyk, 2001; Kenyon and Jackson, 2012). Only 30% of farms reported rotating between anthelmintic classes, and albendazole was used as the primary drug on all farms, further intensifying selection pressure on benzimidazole-susceptible parasites (Chandrawathani *et al.*, 1999; Imanuelle *et al.*, 2023).

Inaccurate dosing was another pervasive issue: 70% of farms estimated body weight visually rather than weighing animals, a practice that often results in under-dosing, particularly in growing or well-conditioned goats (Lespine *et al.*, 2012). Subtherapeutic dosing is widely recognized as a major driver of resistance because it exposes worms to drug concentrations that are sufficient to eliminate susceptible individuals but allow survival and reproduction of partially resistant genotypes (Garg *et al.*, 2004; Sangster *et al.*, 2018). In goats, where benzimidazole pharmacokinetics already favour rapid drug elimination, the combination of under-dosing and high treatment frequency is especially problematic (Hennessy *et al.*, 1993; Lespine *et al.*, 2012).

Grazing management further contributed to the unfavorable resistance landscape. All farms practiced semi-intensive systems with daily grazing, and 60% relied on continuous grazing of the same paddocks year-round, which promotes steady accumulation of infective L3 on pasture and continuous reinfection

cycles (Ratanapob *et al.*, 2012). Field work on *H. contortus* in warm climates has shown that L3 can survive in soil for at least three weeks and rapidly migrate onto herbage following rainfall events, leading to sharp, weather-driven peaks in pasture infectivity (Amaradasa *et al.*, 2010). Under such conditions, continuous grazing offers no opportunity for pasture “rest” to reduce larval contamination, whereas rotational grazing with adequate rest periods can substantially lower exposure to peak L3 burdens (Bautista-Garfias *et al.*, 2022). In this study, 40% of farms reported rotational grazing, but rest periods were relatively short (1–3 months) and not explicitly designed around parasite biology or climatic conditions, which may explain why resistance still became universal despite these efforts.

The complete absence of prior FECRT monitoring on all farms meant that farmers continued to rely on benzimidazoles long after their efficacy had declined, unintentionally maintaining intense selection pressure on already resistant populations (Kenyon *et al.*, 2009; Preston *et al.*, 2014). Similar patterns—frequent use of albendazole, empirical dosing, minimal drug rotation and no resistance testing—have been reported in Indonesian and Malaysian goat systems and have been strongly associated with the emergence and spread of benzimidazole resistance (Chandrawathani *et al.*, 1999; Imanuelle *et al.*, 2023). This convergence of risk factors suggests that the situation in Maha Sarakham is not unique but part of a broader regional trend in tropical small-ruminant systems.

Implications for parasite control and future directions:

The universal benzimidazole resistance documented in this study has serious implications for parasite control, animal welfare and the economic sustainability of meat-goat production in northeastern Thailand. Continued reliance on albendazole and fenbendazole at current doses is unlikely to provide acceptable clinical or production outcomes and may further entrench resistance (Kaplan and Vidyashankar, 2012; Sangster *et al.*, 2018). There is an urgent need to transition from sole dependence on chemotherapy to integrated parasite management strategies that combine pharmacological, management, nutritional and genetic tools (Hoste *et al.*, 2015; Bautista-Garfias *et al.*, 2022).

In the short term, alternative anthelmintic classes with different modes of action, such as macrocyclic lactones or levamisole, may be considered; however, emerging evidence of macrocyclic lactone resistance in northeastern Thailand indicates that these options are also at risk (Qamar and Alkheraije, 2023; Rerkyusuke *et al.*, 2023). Where effective drugs remain, their use should be optimized through targeted selective treatment (TST) rather than whole-herd dosing. TST approaches that treat only the most heavily infected or clinically affected animals—identified using FAMACHA© scoring, body condition, and/or FEC—can maintain adequate parasite control while preserving refugia and slowing the spread of resistance (Kenyon *et al.*, 2009; Kenyon and Jackson, 2012).

Pasture and grazing management offer another critical pillar of integrated control. Strategic rotational

grazing with adequately long rest periods, informed by knowledge of local climate patterns and L3 survival, can substantially reduce pasture infectivity (Bautista-Garfias *et al.*, 2022). Experimental work has shown that *H. contortus* L3 can survive in soil and subsequently colonize herbage when rainfall and humidity increase, supporting the rationale for avoiding grazing contaminated paddocks immediately after rainfall events, especially following dry spells (Amaradasa *et al.*, 2010). Incorporating these principles into farm grazing plans could decrease larval intake and reduce reliance on anthelmintics.

Nutritional and genetic strategies provide complementary, longer-term solutions. Improved nutrition, particularly protein supplementation, can enhance host immunity and resilience, allowing goats to tolerate higher parasite burdens without overt clinical disease and thereby reducing the perceived need for frequent treatments (Hoste *et al.*, 2015). Over time, selection for parasite-resistant genotypes—based on low FEC, favourable FAMACHA© scores and acceptable growth performance under natural challenge—could contribute to more sustainable control, as has been demonstrated in sheep and some goat populations in other tropical regions (Bishop, 2012; Bautista-Garfias *et al.*, 2022).

From a research and policy perspective, there is a clear need to expand resistance surveillance beyond this initial cohort of farms. Molecular characterization of β -tubulin resistance alleles in *Haemonchus* and other strongyle genera would provide definitive confirmation of benzimidazole resistance mechanisms and enable development of rapid diagnostic tools (Silvestre and Humbert, 2002; Pitaksakulrat *et al.*, 2021). Additionally, systematic assessment of resistance to macrocyclic lactones and levamisole in goats in northeastern Thailand is essential to guide rational drug use and avoid repeating the trajectory seen with benzimidazoles (Qamar and Alkheraije, 2023; Rerkyusuke *et al.*, 2023). Longitudinal studies evaluating integrated control packages—combining TST, improved grazing management and nutrition—under real farm conditions would generate much-needed evidence on the feasibility, effectiveness and cost-benefit of alternative strategies for smallholder systems (Kenyon *et al.*, 2009; Hoste *et al.*, 2015).

Study limitations: Several limitations of this study should be acknowledged when interpreting the findings. First, the number of farms was relatively small ($n = 10$) and selected by convenience, which may limit strict statistical generalization to all goat farms in northeastern Thailand. However, the consistency of resistance across all farms suggests that the problem is likely widespread. Second, FECRT sample sizes per treatment group ($n = 11$ – 15) were modest, reflecting logistical constraints in smallholder settings, but still sufficient to meet WAAVP minimum recommendations, and the magnitude of FECR reduction was large enough that classification of resistance was unambiguous (Coles *et al.*, 1992; Geurden *et al.*, 2022). Third, larval cultures and species-specific FECRT analyses were not performed, so the relative contribution of individual nematode

genera to resistance could not be determined. Finally, molecular assays for β -tubulin mutations were beyond the scope of this study, which precludes definitive genetic characterisation of benzimidazole resistance (Silvestre and Humbert, 2002; Pitaksakulrat *et al.*, 2021).

Despite these limitations, the combination of high parasite prevalence, universally reduced benzimidazole efficacy and management practices favouring resistance selection provides compelling evidence that benzimidazole resistance in GIN of meat goats in Maha Sarakham is both widespread and epidemiologically important. Future work that integrates parasitological, molecular, management and economic perspectives will be essential to design and implement sustainable parasite control strategies for this and similar production systems (Kaplan and Vidyashankar, 2012; Sangster *et al.*, 2018).

Acknowledgement

The authors would like to express their sincere thanks to the goat owners who kindly allowed us to conduct the experiment for the whole period of study. We extend our knowledge to Mahasarakham University for support via small ruminant research unit, Mahasarakham University. Maha Sarakham, Thailand. This research project was financially supported by Thailand Science Research and Innovation (TSRI).

CRedit Authorship Contribution Statement: **Minta Pipatsakulpak:** Conceptualization, Writing - original draft, Project administration. **Usanisa Boonum:** Investigation, Methodology, Data curation. **Kotchakorn Roongruang:** Investigation, Methodology. **Benjawan Sae-Chue:** Supervision, Validation. **Sukanya Leethongdee:** Supervision, Funding acquisition, Writing - review and editing. **Songsak Chumpawadee:** Resources, Writing - review and editing. **Nattaya Watwiengkam:** Investigation, Validation. **Pongphol Pongthaisong:** Validation, Visualization, Software, Formal analysis, Writing - review and editing.

Declaration of Artificial Intelligence Use: During the preparation of this work, the authors used Claude (Anthropic) solely for language editing. The authors take full responsibility for the integrity, accuracy, and originality of the work.

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