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Resistance of Boer and Kacang goats and their crosses to *Haemonchus contortus* infection

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ABSTRACT. Understanding host susceptibility and resistance to *Haemonchus contortus* is crucial for developing effective management strategies in goat breeding. This study aimed to evaluate the susceptibility and resistance of male and female goats to *H. contortus* infections and to assess the intra- and inter-breed variability. The research, conducted in North Sumatra Province, Indonesia, involved 45 goats (22 females and 23 males, aged 4 to 6 months) categorised into five groups: A – Kacang goats (100% Kacang), B – crossbred (genetic composition of 50% Kacang and 50% Boer), C – Boer goats (100% Boer), D – crossbred (genetic composition of 25% Kacang and 75% Boer), E – crossbred (genetic composition of 75% Kacang and 25% Boer). The study employed a two-step process of analysing infection and monitoring hatching and infection of *H. contortus* larvae. Worm egg count, packed cell volume, total plasma protein, and body weight were measured over a 10-week period. Boer goats (group C) and their crossbreds (groups B, D, and E) demonstrated higher resistance to *H. contortus* compared to Kacang goats (group A). Male goats exhibited greater resistance, with slower worm egg development and less severe anaemia compared to females. Variability in resistance was observed within breeds, highlighting the importance of individual genetic factors. In conclusion, Boer goats and their crossbreds showed immunity to *H. contortus* infection, with male goats demonstrating enhanced resistance compared to females. These findings underscore the importance of genetic factors in modulating resistance and sustainable solutions for parasite management and emphasise the importance of decreasing treatment expenditures to improve goat health and productivity.

Introduction

Haemonchus contortus poses a significant threat to small ruminant populations worldwide, including goats. The disease caused by this parasite, known as haemonchosis, leads to severe anaemia, reduced overall health, decreased productivity, and, in some cases, mortality (Arsenopoulos et al., 2021). The severity of the disease is influenced by various factors, including age, breed, and nutritional status (Flay et al., 2022). The prevalence and pathogenicity of *H. contortus* in small ruminants result in substantial economic losses (Aimen et al., 2022).

Climate change affects the spread and population dynamics of parasites, including *H. contortus*. Environmental changes alter disease transmission by influencing the development, mortality, and reproduction rates of parasites, vectors, and hosts.

They also induce behavioural changes and modify host susceptibility through impacts on immune responses, stress levels, and physiology (Bautista-Garfias et al., 2022). Rodríguez-Diego et al. (2013) showed how climatic changes impact the temporal and spatial distribution of nematodes.

The use of anthelmintics remains a common strategy for controlling internal parasites. However, anthelmintic resistance poses a significant challenge as indiscriminate use of drugs accelerates resistance through genetic mutations and rapid adaptation of parasites (Troell et al., 2006; Chaudhry et al., 2015; Liu et al., 2023b). Therefore, there is an urgent need to explore alternative management strategies for *H. contortus* infections in goats.

Various alternative methods have been reported as potential measures for controlling *H. contortus*, including feeding strategies, vaccination, selection based on genetic markers or exploiting the advantages of breed resistance. Reported feeding strategies involve supplementation with rumen-protected proteins (Cériac et al., 2019; Tsukahara et al., 2021), diets enriched with *Acacia cochliacantha* leaves and birdsfoot trefoil (Mata-Padrino et al., 2019; Castillo-Mitre et al., 2021), as well as the use of the paraprobiotic Cry5B IBaCC (Sanders et al., 2020). Vaccination offers a potential strategy for immunoprotection against *H. contortus*, with promising results reported for Con A-purified proteins and recombinant Hc8 antigen (Tian et al., 2022; Ye et al., 2022). Additionally, genetic markers, such as single nucleotide polymorphisms (SNPs), provide valuable insight into resistance mechanisms and facilitate selective breeding programs (Alam et al., 2019). Selection of resistant alleles at multiple loci and culling of susceptible individuals offer practical strategies to increase resistance in goat populations (Estrada-Reyes et al., 2019; Gowane et al., 2020).

However, this approach can encounter obstacles in implementation. The use of the aforementioned feeding strategy requires regular provision of feed, which can pose difficulties in terms of supply and cost. Challenges in vaccine development include the need for a more comprehensive understanding of host-parasite interactions and optimisation of vaccine formulations (Liu et al., 2023a). Additionally, the application of genetic markers in developing nations and field settings may be difficult due to cost constraints and the multifactorial nature of the trait (Shrivastava et al., 2022).

Selection for genetic parasite resistance has been proposed as one of the most promising natural, sustainable, and affordable alternatives to synthetic drugs. It introduces permanent genetic changes that can be passed on to future generations, improving animal performance, reducing the infectivity of grazing pastures, and enhancing the socio-economic viability of ruminant producers (Bautista-Garfias et al., 2022). This effort can be carried out by optimally utilising variations in breed resistance to *H. contortus*, as reported by Makun et al. (2020) and Tsukahara et al. (2021). Becker et al. (2020) found that immunity against *H. contortus* is heritable, with breed-specific differences. Crossbreeding offers a potential solution for introducing resistance traits into goat populations, but it requires careful consideration of production traits to avoid compromising the existing flock characteristics.

Although research on resistance to *H. contortus* has been conducted in goats, there is still a gap in understanding the level of resistance in crossbred goats, particularly between the Boer and Kacang breeds. This research aims to evaluate the resistance of Boer, Kacang, and their crossbreds against *H. contortus* infection. We hypothesised that Boer and Boer-Kacang crossbred goats would exhibit higher resistance to *H. contortus* infection compared to purebred Kacang goats.

Material and methods

The study has been approved by the Animal Ethics Committee of the Indonesian Agency for Agricultural Research and Development (Balitbang/Lolitkambing/Rm/01/2017).

Location

This research was conducted for 10 weeks at the Indonesian Goat Research Station, Deli Serdang Regency, North Sumatra Province. The study location was at an altitude of approx. 50.5 m a. s. l., with a relative air humidity range of 74.3–84%, an environmental temperature between 24.1 and 30.5 °C, and a monthly rainfall ranging from 217 to 292.3 mm. The region experiences significant precipitation, particularly from November to March.

Animals

The livestock used in this study comprised 45 goats, including 22 females and 23 males, aged between 4 and 6 months, and weighing between 7 and 14.5 kg. These goats were divided into the following five groups based on their genetic composition:

A – Kacang goats (purebred Kacang goat, 100% Kacang), 4 males and 4 females;

B – crossbred (50% Kacang, 50% Boer), 5 males and 5 females;
C – Boer goats (purebreed Boer goat, 100% Boer), 5 males and 5 females;
D – crossbred (25% Kacang, 75% Boer), 5 males and 5 females;
E – crossbred (75% Kacang, 25% Boer) 4 males and 3 females.

Animals were randomly assigned to the five experimental groups using a computer-generated randomisation design, balancing factors such as age, sex, and body weight to ensure comparability across groups. Each group was housed in a separate pen, and all groups received the same care and management to minimise variability.

Experimental design

Stage 1: Hatching of *Haemonchus contortus* larvae

H. contortus worms were extracted from the abomasum of infected livestock, and approx. 5 g of eggs were isolated and mixed with sterile faecal medium and vermiculite. This mixture was transferred to sealed bottles and stored in the dark at room temperature for one week. After incubation, L3 larvae were harvested by spraying the bottle walls, collected into plastic bottles, and counted using a CX 23 Olympus Microscope at 40× magnification (Olympus Corporation, Tokyo, Japan). Calculations were carried out to obtain a count of 1 000 L3 larvae per individuals/cc.

Verification of *H. contortus* L3 larvae was conducted through microscopic examination, focusing on specific morphological characteristics unique to *H. contortus* larvae. This method followed established protocols in the parasitology literature, as detailed in the standard reference text: Veterinary Parasitology (Taylor et al., 2015), which outlines techniques for larval identification.

Stage 2: Infection with L3 larvae

Prior to larval infection, all goats underwent a comprehensive health assessment, including a physical examination and faecal egg count, to ensure they were free of existing parasitic infections. One week after anthelmintic treatment with albendazole, faecal samples were collected to examine the worm population in the livestock. Only animals without worm population after anthelmintic treatment were included in the study to eliminate confounding factors. The infection with *H. contortus* L3 larvae was then performed using a concentration of 1 000 larvae/cc.

Calculation of worm egg growth

The number of worm eggs per g of faeces (EPG) was calculated according to the method of Santiago et al. (2014). Approximately 10 g of faecal samples were collected directly from the rectum before morning feeding and stored in labelled plastic bags in a cooling container with ice. In the laboratory, 3 g of faeces were mixed with 17 ml of distilled water and incubated overnight at 4 °C. The mixture was then shaken, combined with 40 ml of saturated saline solution, and transferred to a counting chamber. Worm eggs were counted under a microscope at 40× magnification, and the count was multiplied by 40 to determine the EPG. The study lasted 10 weeks, and the development of worm eggs was observed every 2 weeks by collecting rectal faecal samples from all research livestock.

Blood sampling

Blood sampling was routinely conducted every two weeks, with a volume of 3 ml per head using a 5-ml syringe through the jugular vein. This procedure was carried out prior to faecal sample collection and morning feeding. Subsequently, blood samples were transported to the Indonesian Goat Research Station Laboratory for the analysis of packed cell volume (PCV) and total plasma protein (TPP).

The determination of PCV involved collecting blood samples using microhematocrit tubes, which were then centrifuged at 12 000 rpm for 5 min. The sediment volume was measured with a Damon IEC Division Micro-Capillary Reader 2201 (IEC International Equipment Company, MA, USA) and expressed as a percentage (%). TPP was measured using a Goldberg TS Meter Clinical Refractometer (Reichert, Inc., Depew, NY, USA) specifically designed to calculate total solids in plasma. The TS meter was equipped with a direct protein measurement scale in plasma (ranging from 2.5 to 15 g/dl, with an accuracy of 0.1 g/dl). TPP represents the total protein content in the blood and was measured by placing a drop of plasma onto the TS meter. Livestock body weight was recorded every two weeks in the morning, before the collection of faecal and blood samples, and prior to feeding.

Experimental variables included worm population development, measured by counting the number of worm eggs (EFC) in faeces every two weeks. Additionally, the health condition of the livestock was evaluated through blood profile analysis, including measurements of PCV, TPP, and body weight (BW). Research activities were discontinued for livestock exhibiting severe diarrhoea symptoms and anaemia,

characterised by pale whitish eyes and sluggish movement, and resulting in a significant weight loss during two consecutive sampling periods.

Monitoring for diarrhoea and other potential disease symptoms involved daily visual inspections by trained personnel. These observations included assessing the consistency and appearance of faeces, with any signs of loose or watery faeces recorded as diarrhoea. The body condition of each animal was evaluated through visual inspection and palpation to detect weight loss or poor health condition. The activity was monitored for signs of lethargy or abnormal behaviour, while feed intake was monitored to assess appetite. Physical appearance, particularly eye colour, was examined for signs of anaemia or other health issues. Animals showing significant weight loss or severe clinical signs were evaluated by a veterinarian, and appropriate actions were taken to ensure their welfare.

Livestock maintenance management

The goats were housed in spacious, well-ventilated pens to allow for adequate movement. The pens were cleaned daily and periodically disinfected to maintain hygiene and reduce the risk of disease transmission. Fresh drinking water was provided ad libitum, and feed troughs were cleaned before each feeding.

Feed management involved a combination of concentrate and pasture-based forage, primarily consisting of native grass. The concentrate was a blend of fine bran, coconut meal, ground maize, fish meal, and essential minerals. After thorough pen sanitation, the concentrate was administered in the morning between 8:00 and 9:00 to all livestock at a rate of 1.25% BW per day, calculated based on the total weight of goats in the group pen. This level of concentrate supplementation was maintained to avoid excess protein consumption. According to Atiba et al. (2020) and López-Leyva et al. (2022), increased protein supplementation has the potential to improve host response to endoparasitic infection and resistant in grazing goats. Feed sample collection from each pen was performed every three months for periodic nutritional analysis of the forage. The nutritional composition of both the concentrate feed and forage consumed by livestock is outlined in Table 1.

Forage was provided in the pen each evening after the goats returned from grazing. Daily grazing took place from 10:00 to 16:00 daily in the pasture of the Indonesian Goat Research Station.

Table 1. Nutrient composition of concentrate and forage consumed by livestock

Nutrient composition, %	Concentrate	Forage
Dry matter	92.34	–
Ash	11.18	11.06
Crude protein	11.20	8.75
Crude fat	12.00	4.16
Crude fibre	17.10	21.91
Energy	4.20	2.39

Source: Laboratory of Indonesian Goat Research Station, Sungei Putih, North Sumatra

Data analysis

Statistical differences between groups were assessed using a completely randomised design (CRD), with analysis of variance (ANOVA) employed to determine significant differences among groups. Duncan's new multiple range test was applied for post-hoc comparisons when significant differences were detected ($P < 0.05$). All statistical analyses were conducted using SAS software. The mathematical analysis model applied was as follows:

$$PR_{jk} = \mu + T_j + €_{jk},$$

where: PR_{jk} – resistance parameter (EPG, PCV, TPP, BW), μ – population mean, T_j – effect of the ith goat breed (i = 1, ….., 5), $€_{jk}$ – random effect.

Results

Number of worm eggs per g of faeces (EPG = egg/g of faeces)

Male goats started to shed worm eggs in faeces at week 2 (day 14) of the study, although the quantities were initially small and did not differ significantly between breeds (Table 2). Peak worm egg counts were observed at week 6, with males in group A having the highest average EPG at 220 eggs/g of faeces, followed by group E (197), B (180), D (18), and no eggs in group C. At week 4, the average EPG for each breed had fallen below 1000 eggs, with male group A still showing the highest average (956), followed by group E (467), B (370), D (204), and still no eggs in group C.

In female goats, worm eggs were first detected in small numbers at week 2 (day 14). The highest number of worm eggs was observed at week 6 for all breeds, with group C having the highest average EPG (8775 eggs/g of faeces), followed by group E (6830), A (6457), B (5707), and D (4263). The results varied among the crossbred Boer (B, D, and E) and Kacang (A) goats.

Table 2. Average number of worm eggs/g faeces (EPG) in goats grouped based on breed

Week	Breed									
	Male									
	A		B		C		D		E	
	n	EPG	n	EPG	n	EPG	n	EPG	n	EPG
0	4	0	5	0	5	0	5	0	4	0
2	4	220 ± 20.2	5	180 ± 26.1	5	0	5	18 ± 4.0	4	197 ± 19.6
4	3	956 ± 116.8^{a}	3	370 ± 25.5^{ba}	5	0^{b}	5	204 ± 33.8^{ba}	4	467 ± 64.9^{ba}
6	3	9620 ± 687.1^{a}	3	6540 ± 41.4^{ba}	5	1458 ± 45.2^{b}	5	6442 ± 417.1^{ba}	4	7332 ± 434.3^{ba}
8	2	3900 ± 1612.2	–	NA	5	3030 ± 146.1	4	5680 ± 3604.1	3	3153 ± 1808.3
10	2	5610 ± 1739.5^{a}	–	NA	5	2604 ± 293.2^{b}	4	4875 ± 213.7^{ba}	3	4543 ± 1528.9^{ba}
	Female									
0	4	0	5	0	5	0	5	0	3	0
2	4	30 ± 3.5	5	594 ± 81.9	5	72 ± 4.6	5	28 ± 3.9	3	383 ± 34.8
4	4	382 ± 31.1	5	1278 ± 137.7	5	1514 ± 298.4	5	770 ± 85.9	3	860 ± 70.4
6	4	6457 ± 726.2	4	5707 ± 555.3	4	8775 ± 636.4	5	4263 ± 222.5	3	6830 ± 169.7
8	1	3240	4	5452 ± 329.5	4	4455 ± 301.9	3	2630 ± 178.2	3	6780 ± 132.1
10	1	2340	4	3452 ± 217.1	4	3132 ± 205.9	3	1526 ± 90.7	3	2480 ± 175.8

A – Kacang goat (purebred Kacang goat, 100% Kacang), B – crossbred (50% Kacang and 50% Boer), C – Boer goat (purebreed Boer goat, 100% Boer), D – crossbred (25% Kacang and 75% Boer), E – crossbred (75% Kacang and 25% Boer); ^{ab} – different superscripts in the same rows indicate significant differences ($P < 0.05$); NA – animal research was discontinued because goat condition was very poor

Worm populations differed significantly between goat breeds. Female Boer goats (group C) and their crossbreds (groups B, D, and E) showed greater resistance to high worm populations compared to Kacang goats (group A). The presence of worm eggs in Kacang goats (group A) led to weakness in some females, while only one Boer goat (group C) was unable to continue the study due to this condition. Male Kacang goats (group A) and group E crossbreds showed enhanced resistance to high worm populations compared to Boer goats (group C) and their crossbreds (groups B and D).

Individual EPG calculations revealed variations in resistance levels within each breed. For example, males in group A showed EPG differences ranging from 1640 to 3590, while group B exhibited variations in the range of 1850–3200, group C – 0–1890, group D – 67–3760, and group E – 360–2160. Similar variability was observed among female goats, with EPG values ranging from 420 to 5750 (group A), 480–6210 (group B), 1705563 (group C), 4172540 (group D), and 21673087 (group E) after 2–6 weeks of *H. contortus* worm infection.

Packed cell volume

The study investigated the impact of *H. contortus* worm infection on average packed cell volume (PCV) across different goat breeds (Table 3). During week 2, variations in PCV were observed in male and female goats, but there were no statistically significant differences between breeds. However, a significant decrease in average PCV became evident ($P < 0.05$) from at week 4–10 after infection.

At week 4 post-infection, all goats exhibited a significant decrease in PCV values. Crossbred goats (group B) showed the largest decline by 10.3%, followed by Kacang goats (group A) at 6.9%, group D at 6.7%, group E at 4.7%, and Boer goats (group C) at 2.6%, compared to their initial PCV levels. While some breeds showed minor declines in PCV at week 6, others, such as groups D and E, experienced slight increases.

Males from group B were particularly affected, and all individuals were excluded from the study at week 6 due to severe anaemia, as indicated by pale conjunctiva. The most significant overall decrease in PCV occurred in Kacang goats (group A) at week 8, dropping from 24.9 to 12.8%, reflecting more severe anaemia compared to Boer goats (group C) and their crossbreds (groups D and E).

Before the fourth week after infection, variations in PCV development were observed between female goats, although they were not statistically significant. From week 4 onwards, however, significant differences ($P < 0.05$) in PCV levels were recorded among breeds. At week 4 post-infection, the greatest PCV decrease (by 10.9%) among females was observed in Kacang goats (group A), followed by Boer goats (group C) (6.1%), group D (5.8%), group B (5.7%), and group E (3.5%) compared to their initial PCV values. It is noteworthy that the PCV values in Kacang goats (group A) were significantly lower than those in Boer goats (group C), while crossbred goats (groups B, D, and E) displayed intermediate values.

Table 3. Average packed cell volume (PCV) in goats grouped based on breed

Week	Breed									
	Male									
	A		B		C		D		E	
	n	PCV, %	n	PCV, %	n	PCV, %	n	PCV, %	n	PCV, %
0	4	24.9 ± 3.84	5	23.8 ± 2.14	5	21.8 ± 2.86	5	22.1 ± 3.26	5	21.2 ± 3.14
2	4	23.7 ± 3.68	5	20.6 ± 1.91	5	20.9 ± 2.55	5	19.5 ± 1.39	4	19.3 ± 3.28
4	3	18.0 ± 2.40^{ba}	3	13.5 ± 2.02^{b}	5	19.2 ± 1.49^{a}	5	15.4 ± 4.17^{ba}	4	16.5 ± 4.49^{ba}
6	3	17.8 ± 1.78^{a}	3	13.4 ± 3.41^{b}	5	17.9 ± 1.76^{a}	5	15.7 ± 1.89^{ba}	4	17.9 ± 3.69^{a}
8	2	12.8 ± 1.77^{b}	–	NA	5	20.9 ± 1.77^{a}	4	13.5 ± 4.96^{b}	3	18.1 ± 2.01^{ba}
10	2	13.2 ± 2.83^{b}	–	NA	5	20.0 ± 1.88^{a}	4	12.8 ± 4.62^{b}	3	17.5 ± 1.76^{ba}
						Female				
1.5	4	25.7 ± 2.65	5	24.3 ± 3.58	5	25.2 ± 3.11	5	25.5 ± 4.93	3	24.7 ± 1.47
2	4	23.0 ± 2.90	5	21.0 ± 3.76	5	23.4 ± 3.31	5	24.9 ± 5.38^{a}	3	23.5 ± 0.61
4	4	14.8 ± 1.35^{b}	5	18.6 ± 4.91^{ba}	5	19.1 ± 2.22^{ba}	5	19.7 ± 2.39^{a}	3	21.2 ± 1.87^{a}
6	4	16.8 ± 0.54^{b}	4	21.7 ± 4.40^{a}	4	17.8 ± 3.64^{ba}	5	17.7 ± 1.81^{ba}	3	19.4 ± 1.06^{ba}
8	1	14.8	4	16.9 ± 3.90	4	19.4 ± 2.46	3	15.8 ± 1.34	3	14.4 ± 1.06
10	1	14.0	4	17.9 ± 4.71	4	19.3 ± 2.35	3	17.6 ± 0.55	3	16.9 ± 1.81

A – Kacang goat (purebred Kacang goat, 100% Kacang), B – crossbred (50% Kacang and 50% Boer), C – Boer goat (purebred Boer goat, 100% Boer), D – crossbred (25% Kacang and 75% Boer), E – crossbred (75% Kacang and 25% Boer); ^{ab} – different superscripts in the same rows indicate significant differences ($P < 0.05$); NA – animal research was discontinued because goat condition was very poor

Total plasma protein

The study examined total plasma protein (TPP) levels in male and female goats of different breeds over a 10-week period following infection with *H. contortus* worms. TPP levels in male goats showed no significant variation in week 0 – 10 of the study. Across all breeds, TPP levels increased steadily from week 0, reaching their peak at week 4. Subsequently, a decline was observed until week 8, followed by a slight increase until week 10.

Female goats exhibited similar TPP trends, with peak levels occurring uniformly at week 4 in all breeds. Unlike male goats, TPP levels in females remained relatively stable after week 6.

Table 4 illustrates significant differences in TPP levels between goat breeds throughout the study, although these differences did not reach statistical significance. In male goats, TPP levels ranged from 4.4 to 6.47 g/dl in Kacang goats (group A), 4.6 to 6.60 g/dl in group B, 5.52 to 5.84 g/dl in Boer

Table 4. Average total of plasma protein (TPP) in goats grouped based on breed

Week	Breed									
	Male									
	A		B		C		D		**E**	
	n	TPP, g/dl	n	TPP, g/dl	n	TPP, g/dl	n	TPP, g/dl	n	TPP, g/dl
0	4	5.14 ± 0.285	5	5.49 ± 0.365	5	5.45 ± 0.564	5	5.09 ± 0.283	4	5.24 ± 1.114
2	4	5.40 ± 0.490	5	5.64 ± 0.573	5	5.64 ± 0.740	5	5.36 ± 0.699	4	5.58 ± 1.059
4	3	6.47 ± 2.003	3	6.60 ± 0.721	5	5.84 ± 0.611	5	5.42 ± 0.642	4	6.30 ± 0.841
6	3	4.97 ± 0.586	3	4.60 ± 0.529	5	5.60 ± 0.678	5	4.66 ± 0.720	4	5.80 ± 1.178
8	2	4.40 ± 1.131^{b}	–	NA	5	5.52 ± 0.642^{ba}	4	4.50 ± 1.183^{b}	3	6.20 ± 0.265^{a}
10	2	4.50 ± 0.141^{b}	–	NA	5	5.64 ± 0.590^{ba}	4	4.58 ± 1.179^{b}	3	6.20 ± 0.200^{a}
						Female				
0	4	5.60 ± 0.476	5	5.12 ± 0.849	5	5.20 ± 0.445	5	5.18 ± 0.921	5	5.20 ± 0.469
2	4	6.20 ± 0.849	5	5.32 ± 0.626	5	5.96 ± 1.152	5	5.32 ± 0.179	3	5.50 ± 0.436
4	4	7.65 ± 0.971^{a}	5	5.88 ± 0.653^{b}	5	5.74 ± 0.871^{b}	5	5.52 ± 1.188^{b}	3	5.83 ± 1.012^{b}
6	4	5.50 ± 0.383	4	5.90 ± 0.503	4	5.35 ± 0.790	5	5.44 ± 0.498	3	5.43 ± 0.404
8	1	5.80	4	5.60 ± 0.712	4	5.35 ± 0.929	3	5.47 ± 0.115	3	5.33 ± 0.231
10	1	5.80	4	6.15 ± 0.443	4	5.55 ± 1.204	3	5.87 ± 0.231	3	5.33 ± 0.306

A – Kacang goat (purebred Kacang goat, 100% Kacang), B – crossbred (50% Kacang and 50% Boer), C – Boer goat (purebred Boer goat, 100% Boer), D – crossbred (25% Kacang and 75% Boer), E – crossbred (75% Kacang and 25% Boer); ^{ab} – different superscripts in the same rows indicate significant differences ($P < 0.05$); NA – animal research was discontinued because goat condition was very poor

goats (group C), 4.5 to 5.42 g/dl in group D, and 5.24 to 6.30 g/dl in group E. Similarly, TPP levels in female goats varied from 5.50 to 7.65 g/dl in Kacang goats (group A), 5.12 to 6.15 g/dl in group B, 5.20 to 5.96 g/dl in Boer goats (group C), 5.18 to 5.87 g/dl in group D, and from 5.20 to 5.83 g/dl in group E. The highest TPP levels coincided with a significant increase in the worm population after week 4.

Body weight

Overall, male goats showed an increase in BW until week 4 post-infection (Table 5). An exception was observed in Boer males (group C), whose BW continued to rise until week 8 before showing a decline. Peak BW were recorded at week 4 for most groups: 8.6 kg (group A), 8.7 kg (group B), and 10.2 kg (group E). In contrast, Boer (group C) and group D goats reached the highest weight at week 8: 17.2 kg and 13.2 kg, respectively (Table 5). Initial weight gains were recorded as follows: 1.5 kg (group A), 1 kg (group B), 1.2 kg (group E), 2.7 kg (group C), and 3.9 kg (group D).

Similarly, female goats showed weight gains after infection, with their peaks occurring at different intervals. Kacang (group A) and group D females reached highest weights at week 4, while group B females continued gaining weight until week 8. Boer females (group C) experienced a decline after week 6, while group E females reached their maximum weight at week 10. The heaviest weights for female goats were: 8.7 kg (group A), 11.8 kg (group D), 10.7 kg (group B), 13.7 kg (group C), and 10.1 kg (group E) (Table 5). Initial weight gains were as follows: 0.7 kg (group A), 2.5 kg (group B), 1.9 kg (group C), 2.2 kg (group D), and 1.5 kg (group E).

Male goats of Kacang breed (groups A, B, and D) reached the highest weight gains in the first 2 weeks post-infection, followed by a subsequent decrease. Boer (group C) and D males showed fluctuating weight gains, with their peaks occurring at week 8. Similarly, females of Kacang (group A), B, and D goats showed the greatest weight gains in the first 2 weeks, followed by a decrease. Boer females (group C) reached the highest weight gain at week 6, while group E females peaked at week 10. Boer females (group C) showed an initial decline in weight gain up to week 4. Group E females exhibited a similar trend, with the most significant rise in weight gain occurring after week 8.

Table 5. Average body weight in goats is grouped based on breed

Week	Breed									
	Male									
	A		B		C		D		E	
	n	Body weight, kg	n	Body weight, kg	n	Body weight, kg	n	Body weight, kg	n	Body weight, kg
0	4	7.1 ± 1.66^{b}	5	7.7 ± 1.88^{b}	5	14.5 ± 5.68^{a}	5	9.0 ± 1.96^{ba}	4	9.0 ± 0.99^{b}
2	4	7.9 ± 1.96^{b}	5	8.3 ± 1.54^{b}	5	15.4 ± 5.61^{a}	5	10.8 ± 3.53^{ba}	4	9.7 ± 0.36^{b}
4	3	8.6 ± 0.67^{b}	3	8.7 ± 2.45^{b}	5	15.7 ± 5.51^{a}	5	11.3 ± 3.69^{ba}	4	10.2 ± 1.40^{ba}
6	3	7.8 ± 1.14^{b}	3	7.9 ± 1.84^{b}	5	17.1 ± 6.03^{a}	5	11.1 ± 4.15^{b}	4	10.1 ± 2.08^{b}
8	2	8.3 ± 0.14^{b}	–	NA	5	17.2 ± 6.22^{a}	4	13.2 ± 2.06^{b}	3	10.1 ± 2.45^{b}
10	2	7.8 ± 0.35^{b}	–	NA	5	16.9 ± 6.63^{a}	4	12.9 ± 2.11^{ba}	3	9.5 ± 2.11^{ba}
						Female				
0	4	8.0 ± 0.35^{c}	5	8.2 ± 0.94^{bc}	5	11.8 ± 1.88^{a}	5	9.6 ± 1.30^{ba}	3	8.6 ± 2.37^{bc}
2	4	8.6 ± 0.30^{c}	5	9.1 ± 0.91^{bc}	5	12.6 ± 1.88^{a}	5	11.3 ± 1.03^{ba}	3	9.5 ± 2.13^{bc}
4	4	8.7 ± 0.32^{b}	5	9.9 ± 2.11^{ba}	5	12.4 ± 2.02^{a}	5	11.8 ± 0.75^{a}	3	9.4 ± 2.55^{ba}
6	4	8.2 ± 0.33^{c}	4	10.5 ± 1.50^{bc}	4	13.7 ± 0.57^{a}	5	11.5 ± 1.05^{ba}	3	9.3 ± 2.74^{bc}
8	1	7.7^{c}	4	10.7 ± 1.94^{ba}	4	13.5 ± 0.99^{a}	3	11.2 ± 1.11^{ba}	3	8.7 ± 2.89^{bc}
10	1	7.5^{b}	4	10.3 ± 1.95^{ba}	4	13.1 ± 1.06^{a}	3	10.8 ± 0.96^{ba}	3	10.1 ± 2.46^{ba}

A – Kacang goat (purebred Kacang goat, 100% Kacang), B – crossbred (50% Kacang and 50% Boer), C – Boer goat (purebred Boer goat, 100% Boer), D – crossbred (25% Kacang and 75% Boer), E – crossbred (75% Kacang and 25% Boer); ^{ab} – different superscripts in the same rows indicate significant differences ($P < 0.05$); NA – animal research was discontinued because goat condition was very poor

Discussion

The determination of helminth egg counts in faeces, expressed as the number of eggs per g (EPG), serves as an important indicator of the level of gastrointestinal worm infection. An increase in EPG reflects a higher level of worm burdens. In this study, the initial discovery of worm eggs in male goats' faeces was earlier, with the peak worm population reaching the same level as previous research on crossbred sheep. Romjali et al. (1997) reported that they found the first eggs in the faeces of crossbred sheep at week 3 (21 days), reached the peak of worm eggs at week 5 (day 35) for Barbados cross, St. Coix cross and Sumatran sheep at week 6, and Fat-tail sheep at week 7.

The research underscores the importance of genotype in susceptibility to gastrointestinal worm infections. According to Abosse et al. (2022), goats are more susceptible to gastrointestinal worm infections than sheep, as evidenced by higher helminth egg production and parasitaemia rates in goats compared to sheep. Specifically, the latter authors found that goats, when infected with *H. contortus*, tend to exhibit a higher mean worm burden (5590) compared to sheep (2887). Additionally, the severity of anaemia is more pronounced in goats, with mean packed cell volume (PCV) levels of 13% versus 18.6% in sheep. Moreover, goats show a significant weight loss compared to pre-infection levels, control animals, as well as infected sheep. Zanzani et al. (2020) emphasised the role of genetic factors in modulating the rate of egg production in nematodes, demonstrating that Nera di Verzasca (NV) goats consistently showed lower mean EPG in comparison to Alpine goats, indicating increased resistance to nematode infections. The observed lower EPG values in this study, relative to other studies, such as those involving lambs infected with 20 000 L3 *H. contortus*, may be attributed to factors like age, diet, and genotype. Mature male sheep generally demonstrate lower EPG values, likely due to the enhanced development of the host immune system that inhibits the growth and development of larvae and adult worms (Yuswandi and Rika, 2015). Goat resistance to *H. contortus* infection is also affected by age, sex, breed, and environmental conditions, with older goats and females being more susceptible to haemonchosis, and climatic variations further exacerbating infection rates (Jabar et al., 2023).

One of the host defence mechanisms against gastrointestinal worm disorders, known as the "self-cure" reaction, occurs when worms release antigens during their third ecdysis. These antigens acts as allergens, stimulating a local acute type 1 hypersensitivity reaction in the intestine, where the parasites reside. This reaction involves mast cell degranulation, higher vascular permeability, and strong contraction of intestinal muscles, which increases capillary permeability and allows fluid to enter the intestinal lumen. The resulting effects promote the release and expulsion of most worms from the gastrointestinal tract (Yuswandi and Rika, 2015). The results of the study show a decrease in EPG values in all goat breeds after week 6 (Table 2).

The present study also highlights the relationship between blood composition and the level of resistance to *H. contortus* worm infections in goats. A higher genetic composition of Boer (group C) goats corresponds to a slower development of worm eggs in faeces, indicating higher resistance. Conversely, Kacang (group A) goats are more vulnerable to *H. contortus* worm infections. Data in Table 2 demonstrated that Boer female goats (group C) and their crossbreds (groups B, D, and E) were more resistant to higher worm populations in the body compared to Kacang goats (group A). This was exemplified by Kacang goats (group A), where a population of 6457 eggs/g faeces was found in three female goats, whose condition was so poor that they had to be withdrawn from the trial. Conversely, Boer female goats (group C), despite having an EPG of 8775 eggs/g, and crossbreds with EPGs of 6830 (group E), 5707 (group B), and 4263 (group D) eggs/g faeces, only one was found female goat in each group, whose condition did not allow further research.

Variations in mean EPG in female goats indicated that blood composition, both in Boer goats (group C) and their crossbreds (groups B, D, and E), affected the development and mean number of worm eggs in faeces. These variations indicated differences in the level of resistance to *H. contortus* infection between goat breeds. The observed increase in worm egg counts at week 4 in all goat breeds underscores the importance of selective breeding and targeted treatment strategies to reduce the risk of anthelmintic resistance at this growth stage and prevent rapid increases in worm populations. In summary, this study provides a comprehensive understanding of the factors influencing the level of infection and resistance to *H. contortus* worms in goats. The findings have practical implications for guiding genotype selection, nutritional management, and the development of more effective treatment programs to improve the health and productivity of goat livestock.

Blood PCV levels are closely linked to the severity of anaemia, with a decrease in PCV values signifying a worsening anaemia condition. Anaemia in livestock can also act as an indicator of their nutritional status. In goats infected with gastrointestinal worms, anaemia generally occurs due to nutritional deficiencies, as worms absorb vital nutrients from the digestive tract (Mpofu et al., 2022). Infection with *H. contortus* worms had a significant impact ($P < 0.05$) on the mean blood PCV of male goats of different breeds, with changes detected from week 4–10 of the experiment.

The study also revealed that the decline in PCV among male goats of all breeds was most pronounced at week 4 after *H. contortus* worm infection. The highest decline in PCV was observed in group B, reaching 10.3%, while the lowest decrease occurred in Boer goats (group C) at 2.6% com-

pared to the initial PCV in the study. Although a decrease in PCV was observed at week 6 in group B, Kacang (group A), and Boer (group C) goats, it was relatively small. In contrast, groups D and E showed a slight increase in PCV during the same period. In this context, Boer (group C) goats and the crossbreds of Boer (groups B, D, and E) and Kacang (group A) goats demonstrated a stronger natural ability to overcome worm infections.

Unfortunately, research on all male group B had to be discontinued after week 6 due to the weakened condition of the goats caused by severe anaemia, as evidenced by pale conjunctiva. The highest reduction in PCV was observed in Kacang goats (group A) during week 8 after infection, with levels decreasing from an initial PCV of 24.9% to 12.8%. In contrast, Boer (group C) goats and their crossbreds (groups B, D, and E) showed a less severe decline in this parameter. The fluctuations in PCV levels reflect the degree of anaemia in goats caused by worm infection. Based on the rate of PCV reduction, *H. contortus* infection resulted in the highest level of anaemia in male Kacang goats (group A) compared to Boer goats (group C) and their crossbreds (groups B, D, and E).

The concentration of total plasma protein (TPP) in the goat's blood serves as an indicator of the level of parasitic worm infection in the digestive tract and the goat's ability to produce antibodies to fight infections, including those caused by worms. The resistance of the body to infections relies on the production of antibodies against infectious organisms or foreign substances entering the body. A deficiency in dietary protein can significantly increase mortality risk, as the body fails to produce sufficient antibodies to counteract infections (Soul et al., 2019). TPP levels in male goats of all breeds steadily rose from week 0, reaching a peak at week 4. Subsequently, TPP levels decreased until week 8, with a modest increase recorded at week 10. The average TPP concentrations for both male and female goats, grouped by breed, are documented in Table 4.

The progression of TPP levels in the blood reflects the goats' response to the increasing worm population in their digestive tract. The increase in TPP levels from week 0 to week 4 indicated that male goats could initially inhibit worm population growth by enhancing antibody synthesis. This was evident in the relatively slow increase in the number of worm eggs in faeces until week 4. However, from week 6 onwards, the goats' resistance to parasitic worm attacks decreased, leading to a rapid escalation in worm populations. This condition was likely due to a constant intake of nutrients from the early stages of infection, while the body required more nutrients, especially protein, to synthesise antibodies against the growing worm population. Under conditions of nutrient deficiency, the body prioritises essential processes, with antibody synthesis taking precedence during infection. Amino acids, derived from available potential nutritional sources, are necessary for antibody synthesis (Rose, 2019). Adult animals with protein or amino acid deficiencies have lower antibody levels, making them more susceptible to infections. The progression of TPP levels in female goats is highly similar to that recorded in male goats. The highest TPP levels in female goats were determined in week 4 for all goat breeds, followed by a decline by week 6. However, unlike in males, TPP levels in female goats remained relatively stable after week 6.

Table 4 demonstrates significant variations in TPP levels between goat breeds during the study period, although these differences were not statistically significant. Host genetic variability plays a pivotal role in conferring resistance to *H. contortus*. Selective breeding of animals with enhanced resistance can increase the prevalence of specific beneficial alleles, thereby creating a distinctive genetic profile of the species genome. Consequently, this results in increased efficacy against parasites of these animals. Recent studies have identified specific loci associated with resistance to *H. contortus* in sheep and goats (Estrada-Reyes et al., 2019). Sheep with genetic resistance demonstrate innate defence mechanisms that hinder the colonisation of *H. contortus* larvae during the initial stages of infection. They also elicit a Th2 immune response within the abomasal mucosa, which provides protection against subsequent infections. The expression of genetic resistance is crucial in mediating the immune response necessary for protection against *H. contortus*. An alternative and complementary strategy for managing haemonchosis in goats involves the use of resistant and adaptive genetic variants, coupled with nutritional manipulation to accelerate the development of the immune system (Alba-Hurtado and Muñoz-Guzmán, 2013; Estrada-Reyes et al., 2019). Research indicates that nutritional support for immune system development should be administered between week 3 and 4 after infection. This timing is recommended because blood PCV typically declines most sharply in the 4th week, TPP levels peak during this period, and the worm population increases most rapidly after week 4.

Overall, the body weight of both male and female goats of all breeds increased up to week 4

following infection with *H. contortus*. However, it should be noted that body weight in male Boer goats (group C) continued to rise until week 8 and then decreased, as indicated in Table 5.

Analysis of Figure 1 shows that the immune system in male Kacang (group A), group E, and group B goats was only able to delay the impact of *H. contortus* infection, but could not fully counteract it, as evidenced by the continuous decrease in body weight gain. Weight gains in Boer goats (group C) exhibited a decline until week 4, followed by an increase at week 6, surpassing the previous period. Similar results were observed in group D goats, with the highest increase in body weight recorded after week 6. These results indicate that Boer (group C) and group D goats have a more effective immune response against *H. contortus* infection.

Genotypic effects on resistance to gastrointestinal nematodes in goats

Genetic factors play a crucial role in determining the susceptibility or resistance of goats to gastrointestinal nematode infections. Studies have highlighted significant differences in resistance levels among individual goat genotypes, particularly between breeds like Boer and Kacang. Alba-Hurtado and Muñoz-Guzmán (2013) noted that genetic resistance to *H. contortus*, a common gastrointestinal nematode, varied widely between breeds. Boer goats (group C) have been observed to show higher resistance due to specific genetic traits that enhance their immune response and reduce worm burden compared to Kacang goats (group A).

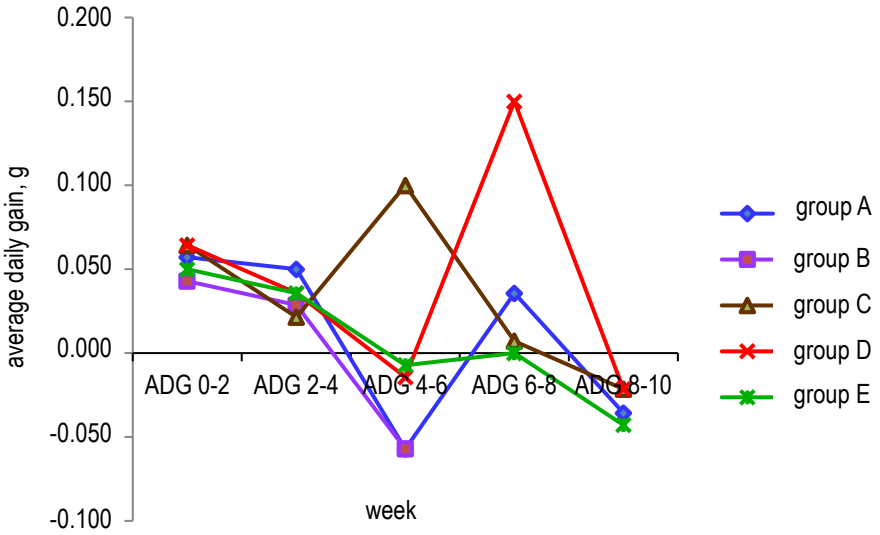

Figure 1. Changes in body weight gain or loss of male goats per week grouped by breed

ADG 0–2 – changes in body weight from 0 to 2 weeks of age, ADG 2–4 – from 2 to 4 weeks of age, ADG 4–6 –from 4 to 6 weeks of age, ADG 6–8 – from 6 to 8 weeks of age, ADG 8–10 – from 8 to 10 weeks of age, Group A – Kacang goats (100% Kacang), Group B – crossbred (50% Kacang and 50% Boer), Group C – Boer goats (100% Boer), Group D – crossbred (25% Kacang and 75% Boer), Group E – crossbred (75% Kacang and 25% Boer)

Figure 2 illustrates that the immune system in Kacang (group A), group B, and D goats also only managed to slow down the impact of *H. contortus* infection rather than fully overcoming it. Despite differences in the rate of body weight decline, the trend continued in all three breeds. Boer goats (group C) showed a decline in body weight until week 4, followed by an increase at week 6, surpassing the previous period. Meanwhile, group E goats showed the highest increase in body weight after week 8. Therefore, it can be concluded that the immune system in female Boer (group C) and group E goats were more effective in resisting *H. contortus* infections.

Estrada-Reyes et al. (2019) further explored the genetic basis of immunity in sheep and goats, identifying specific loci associated with enhanced resistance to *H. contortus*. These genetic markers not only facilitate breeding programs aimed at selecting for resistance, but also provide insights into the underlying biological mechanisms that govern immune responses against nematode infections in small ruminants. Understanding these genetic factors is essential to explain why Boer goats (group C) tend to be more resistant to infections compared to Kacang goats (group A).

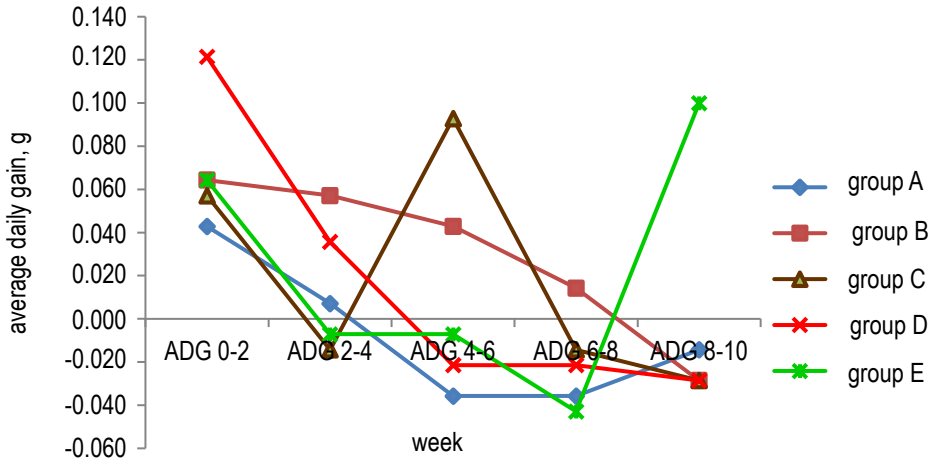

Figure 2. Changes in body weight gain or loss of female goats per week grouped by breed

ADG 0–2 – changes in body weight from 0 to 2 weeks of age, ADG 2–4 – from 2 to 4 weeks of age, ADG 4–6 – from 4 to 6 weeks of age, ADG 6–8 – from 6 to 8 weeks of age, ADG 8–10 – from 8 to 10 weeks of age, Group A – Kacang goats (100% Kacang), Group B – crossbred (50% Kacang and 50% Boer), Group C – Boer goats (100% Boer), Group D – crossbred (25% Kacang and 75% Boer), Group E – crossbred (75% Kacang and 25% Boer)

Biological mechanisms underlying resistance

The biological mechanisms underlying resistance to gastrointestinal nematodes involve complex interactions between host immune responses and parasite biology. Rose et al. (2019) argued that resistance is often dependent on the effective immune response of the host, including the production of antibodies against nematode antigens. This immune response varies between genotypes, with some breeds, such as Boer goats (group C), demonstrating a more robust immune reaction that limits parasite colonisation and reproduction.

Alba-Hurtado and Muñoz-Guzmán (2013) discussed the role of genetic factors in shaping host-parasite interactions, influencing factors such as parasite development and immune evasion strategies employed by nematodes. These interactions may involve various biological mechanisms, including resistance to larval movement and development within the host. Elucidating such mechanisms may help further explain the differences in resistance observed between Boer (group C) and Kacang (group A) goats.

Blood parameters as indicators of infection and resistance

Blood parameters such as PCV and TPP serve as valuable indicators of health status and immune response in goats infected with gastrointestinal nematodes. Soul et al. (2019) emphasised the importance of TPP levels in assessing the host's ability to produce antibodies and control infections. These authors observed that variations in TPP levels reflect differences in immune system activation and infection severity in individual goat breeds. The significant decrease in PCV observed in susceptible breeds like Kacang goats (group A), as compared to more resistant breeds such as Boer goats (group C), confirms the utility of PCV as an early indicator of anaemia caused by nematode infections.

Mpofu et al. (2022) further investigated the relationship between blood parameters and nutritional status in goats infected with *H. contortus*. Their findings demonstrated that blood test results not only reflected the extent of anaemia and antibody response to infection, but also revealed the body's overall capacity to respond to nematode infections. The more pronounced decrease in PCV in Kacang goats (group A) suggested more sever anaemia, potentially due to genetic susceptibility or differences in biological response mechanisms to infection.

Comparison with other internal parasites

Comparative studies on resistance patterns to other internal parasites in goats offer further understanding of the genetic and immunological basis of resistance. Piedrafita et al. (2010) discussed the development of a protective vaccine against haemonchosis, emphasising both shared and distinct immune responses elicited by different parasite species. Hoste and Chartier (1993) compared the effects of concurrent infections with *H. contortus* and Trichostrongylus colubriformis, and found breed-specific responses to mixed-species infections. Evaluating whether Boer goats (group C) exhibit consistent resistance patterns against various internal parasites

or whether these responses vary depending on the parasite type can provide a broader perspective on genetic resistance and biological mechanisms involved in different parasitic infections in goats.

To address haemonchosis and anthelmintic resistance, strategies such as developing breeds resistant to *H. contortus* infection and implementing vaccination programmes should be considered. Genetic development in sheep or goat breeds with genetic resistance has promising potential as this immunity traits can be inherited in subsequent generations, including through crossbreeding as with Boer and Kacang goats. Consequently, the dissemination of these genes through livestock trading mechanisms may prove to be an effective strategy (Piedrafita et al., 2010).

Conclusions

The Boer goats and their crossbreds show higher levels of resistance to *Haemonchus contortus* infection compared to Kacang goats. However, there is a variability observed between individual goats within the breed concerning their resistance to the nematode studied. Specifically, male goats demonstrate greater resistance to higher worm populations in the digestive tract compared to their female counterparts.

Our study reveals substantial benefits for husbandry practices, particularly through the use of crossbreeding strategies that incorporate Boer goat genetics. These approaches significantly enhance parasite resistance in goats, offering both sustainable management solutions and potential economic advantages. By reducing treatment costs and improving productivity, these findings contribute to more efficient and environmentally responsible livestock management. Our research offers farmers practical, evidence-based strategies to optimise flock health and support sustainable farming practices.

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Conflict of interest

The Authors declare that there is no conflict of interest.

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