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Research Article

Haemobiochemical Alterations Associated with Haemoparasitic Infections in Dogs in Jos North, Nigeria

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ABSTRACT

Introduction: Dogs in Nigeria are commonly affected by haemoparasitic infections. These infections are mainly transmitted by ticks and cause significant illness. The present study aimed to investigate the impact of blood parasites on the haemobiochemical parameters in dogs in Jos North, Plateau State, Nigeria.

Materials and methods: Forty dogs from three different veterinary clinics in Jos North, Plateau State, Nigeria, were examined. Dogs were grouped by sex (male and female), age (puppies under 6 months, young dogs 6-24 months, adults over 24 months), and breed, such as Nigerian indigenous breeds (NIBD) and exotic breeds. The study lasted for 10 months. Blood samples from all dogs were collected for haematological and serum biochemical analyses. Giemsa-stained smears were examined under a light microscope to identify haemoparasites. Haematological parameters and serum biochemical markers, including urea, creatinine, liver enzymes (alkaline phosphatase, alanine aminotransferase, and aspartate aminotransferase), bilirubin, and electrolytes, were assessed. Haemobiochemical evaluations were conducted on the same day as sample collection.

Results: The present study found a high prevalence of haemoparasites (77.5%) among the 40 dogs examined in Jos North, with *Babesia* spp. being the most prevalent (52.5%), followed by *Anaplasma platys* (20%), *Mycoplasma haemocanis* (20%), and *Hepatozoon canis* (5%). Infected dogs with these parasites demonstrated significant haematological alterations, including anaemia, thrombocytopenia, and lymphopenia, with puppies (12.5%) and NIBD (20%) most severely affected. Inflammatory changes such as neutrophilia and leukocytosis were common and varied among breeds. Biochemical changes included elevated urea, creatinine, liver enzymes, and bilirubin in puppies and NIBD. The mineral alterations, specifically Na, Cl, Ca, HCO3, and phosphorus, exhibited significant variation based on age (puppies) and breed (NIBD), but demonstrated no significant difference concerning sex.

Conclusion: The current results provided essential baseline data to improve the diagnosis, management, and control of haemoparasitic infections, ultimately supporting stronger canine health and welfare in Jos North, Plateau State, Nigeria. Biochemical abnormalities, such as elevated urea, creatinine, liver enzymes, and bilirubin levels, indicated hepatic and renal involvement, as well as significant electrolyte disturbances associated with haemoparasite infection.

1. Introduction

Dogs (*Canis lupus familiaris*) are widely kept as pets, companions, and working animals worldwide, including in Nigeria[1]. Despite their importance, dogs are highly susceptible to a range of infectious diseases, notably haemoparasitic infections, blood-borne diseases caused by parasites that invade red blood cells (RBC), white blood cells (WBC), or platelets[2]. These haemoparasites constitute a major health challenge, contributing significantly to

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morbidity and mortality in canine populations globally and locally[3]. Most haemoparasitic infections are transmitted through ticks, though blood transfusion and transplacental transmission have also been documented[4]. Infected dogs often present with non-specific but clinically important signs such as fever, lethargy, pale mucous membranes, red or orange urine, jaundice, lymphadenopathy, splenomegaly, tachycardia, tachypnea, vomiting, bleeding tendencies, and weight loss[3,4] These common clinical signs make the diagnosis difficult without laboratory confirmation.

In Nigeria, several haemoparasites have been documented in dogs, including *Babesia canis*, *Ehrlichia canis*, *Mycoplasma haemocanis* (*M. haemocanis*), and *Hepatozoon canis* (*H. canis*)[2]. These pathogens cause profound haematological disturbances such as anaemia, thrombocytopenia, and leukopenia[5], which may progress to severe clinical disease, debilitation, or death if not promptly diagnosed and treated[6]. Unfortunately, effective management remains challenging in many parts of Nigeria due to limited awareness, inadequate diagnostic facilities, high vector burdens, and poor treatment outcomes[1,2]. Haemoparasitic infections pose an even greater threat in tick-endemic areas. The warm climate, vegetation, and common practices such as free roaming and inadequate ectoparasite control promote high tick infestation rates, increasing disease transmission risks[2]. These infections not only compromise animal health but also lead to major haematological and biochemical alterations that reduce productivity and elevate treatment costs[2].

Despite the clinical and economic implications of haemoparasitic diseases, data on the prevalence of haemoparasites and their associated haemobiochemical changes in dogs in Jos North, Plateau State, Nigeria, remain scarce. Reporting such haemobiochemical data is essential for accurate diagnosis, effective treatment, and targeted control strategies in highly susceptible animals such as puppies and Nigerian indigenous breeds (NIBD). Establishing such baseline information is essential for improving diagnostic accuracy, guiding effective treatment, and developing targeted control strategies. The present study aimed to assess the effects of blood parasites on haemobiochemical parameters in dogs from Jos North, Plateau State, Nigeria, and to provide evidence-based information to support veterinarians, dog owners, and public health staff in enhancing canine health and welfare.

2. Materials and Methods

2.1. Ethical approval

This study was approved by the Ethical Committee of the Animal Experimental Unit of the Faculty of Pharmaceutical Sciences, University of Jos, Plateau State, Nigeria, with approval number F17-00379 on 10 October 2024, having met the conditions of the Institutional Animal Care and Use (IACU) in collaboration with the Office of Laboratory Animal Welfare (OLAW). Additionally, written informed consent was obtained from the owners before carrying out the experimental tests.

2.2. Study location

This study was conducted in three locations within Jos Metropolis -Veterinary Teaching Hospital, University of Jos, Farin Gada, and Rukuba Road. Jos is situated in the northern part of Plateau State, Nigeria, between latitudes 8°24′N and 10°38′E. The region lies at elevations ranging from approximately 1,200 m to 1,829 m above sea level. Plateau State experiences a near-temperate climate, with mean annual rainfall of 131.75–146 cm and average annual temperatures of 16.3°C-28.1°C. Relative humidity ranges between 46.9% and 51.3%.

2.3. Animals and selection criteria

A total of 40 dogs of both sexes (17 males and 23 females) and different breeds including local NIBD (8) and exotic breed such as German Shepherds (12), Russian shepherd (9), Lhasa (4), Siberian husky (1), Bull mastiff (2), Boerboel (1), Neapolitan mastiff (3), aged less than 6 months (puppies), young (6 months to 2 years), adult (2 years and above) were included in the present study. Puppies were 5 (12.5%); young dogs were 8 (20%), while adult dogs were 27 (67.5%) of the total population.

Dogs were selected using convenience sampling based on accessibility to veterinary clinics, households, and kennels in Jos North, Plateau State, over a 10-month period (October 2024-July 2025). Dogs presented with one or more clinical signs suggestive of haemoparasitic infection, including pale mucous membranes, fever, rough hair coat, epilation, jaundice, and lethargy, were selected. Breed identification was based on morphological features, while age estimation was carried out using dentition and owners' records.

Comprehensive clinical history and physical examinations (tick presence, decreased PCV, identification of parasites in blood smears under light microscopy, eosinophilia) were performed to support the diagnosis of haemoparasitic infection and to exclude other non-haemoparasitic conditions, in accordance with internationally accepted ethical guidelines[7]. All dogs were humanely restrained by their owners using muzzles and placed in sternal recumbency before sample collection[7].

2.4. Sample collection

Sampling was performed in all 40 dogs in the morning to minimise diurnal variation in haematological parameters. Blood samples were collected from calm, properly restrained dogs. Samples placed in heparinised tubes were promptly packaged and transported on ice packs to the laboratory and analysed within four hours to minimise pre-analytical errors. All sampling procedures adhered to standard laboratory protocols[8,9]. Blood was collected via cephalic venipuncture using a 5 mL syringe with a 21-gauge needle for adults and a 23-gauge needle for young dogs. A total of 5 mL of whole blood was obtained from each dog; 3 mL was placed into EDTA-tubes for haematological analysis, while 2 mL was placed in plain tubes to obtain serum for biochemical assays.

2.5. Haematological analysis

Haematological parameters, including RBC count ($\times 10^{12}$/L), total WBC count ($\times 10^{9}$/L), packed cell volume (PCV, %), haemoglobin (Hb, g/L), mean corpuscular volume (MCV, flL), mean corpuscular haemoglobin (MCH, pg), and mean corpuscular haemoglobin concentration (MCHC, g/dL), were analysed using a three-part AutoHaemoAnalyzer (ADVAI-20, Siemens Healthineers, Germany). Differential leucocyte counts (neutrophils, basophils, eosinophils, lymphocytes, and monocytes) were manually determined using a 100x oil-immersion objective (Zenith Lab, Jiangsu, China).

2.6. Blood smear preparation

Thin blood smears were prepared using approximately 2 µL of blood via the slide–slide technique. Smears were air-dried, labelled on the frosted end of the slide, and fixed in methanol. Staining was performed with Wright-Giemsa stain (Turner Wright Biosciences, Lagos, Nigeria) for 15 minutes, followed by rinsing and air-drying. Slides were examined using a light microscope (Olympus XSZ107BN, Olympus Corporation, Japan) under oil immersion at 1000x magnification. One hundred WBCs were counted and classified morphologically[9]. Absolute cell counts were calculated using the formula[9].

$$\text{Absolute count } (\times 10^{9}/\text{L}) = (\%\text{WBC}/100) \times \text{TWBC}$$

2.7. Serum biochemistry procedure

Blood samples were collected in serum separator tubes, allowed to clot at room temperature, and centrifuged at 6,000 × g for 10 minutes to obtain clear, non-haemolyzed, non-lipaemic serum. Serum was transferred into appropriately labelled sample cups compatible with the Cobas c111 analyzer (Roche Diagnostics International Ltd, Switzerland). Forty samples were analysed and 16 different serum biochemical analytes were evaluated which are sodium (Na, mmol/L), potassium (K, mmol/L), chloride (Cl, mmol/L), bicarbonate (HCO3, mmol/L), calcium ion (Ca2+, mmol/L), phosphate, mmol/L), alkaline phosphatase (ALP, U/L), alanine aminotranferase (ALT, U/L), aspartate aminotransferase (AST, U/L), urea (mmol/L), creatinine (µmol/L), albumin (g/dL), uric acid (mmol/L), total protein (g/dL), total bilirubin (mmol/L) and conjugated bilirubin (mmol/L).

2.8. Statistical analysis

Descriptive statistics were generated for all measured variables. Data were analysed using Two-Way Analysis of Variance (ANOVA) in JMP Version 18. The chi-square test was used to analyse data for a significant association between sex, age, and breed (data groups). Standard deviation (SD) was employed to measure the data distribution in the study. Post hoc comparisons were performed using the least significant difference (LSD) test, and statistical significance was set at a p-value less than 5% ($p < 0.05$). The F-ratio in ANOVA was calculated to determine whether the differences between group means were significant.

3. Results

3.1. Demography of dogs

Descriptive statistics for the 40 dogs sampled in Jos North were summarised by sex, age, and breed. The overall prevalence of haemoparasites was high, with 31 dogs (77.5%) testing positive and nine dogs (22.5%) testing negative. Of the sampled population, 17 (42.5%) were male dogs, and 23 (57.5%) were female dogs, indicating a slightly higher representation of female dogs.

The age distribution comprised all categories, including puppies (<6 months), young dogs (6-24 months), and adults (>24 months). Puppies were five (12.5%); a relatively small but important subgroup, given their susceptibility to infections. Young dogs accounted for eight (20%), while adults formed the largest group with 27 dogs (67.5%), reflecting the typical age structure of owned dogs in the study area.

Breed distribution revealed that German Shepherd (12/40, 30%) made up the majority of the sampled dogs, followed by NIBD (8/40, 20%) and other exotic breeds such as Russian Shepherd (9/40, 22.5%), Lhasa (4/40, 10%), Siberian Husky (1/40, 2.5%), Bull Mastiff (2/40, 5.0%), Boerboel (1/40, 2.5%) and Neapolitan Mastiff (3/40, 7.5%). This pattern was likely due to NIBD's common use as guard and companion animals, while exotic breeds were less widespread and more commonly found in specific households.

Overall, the distributions of sex, age, and breed were sufficiently balanced to justify the use of parametric statistical tests in subsequent analyses. These descriptive findings provided an essential context for interpreting patterns of haemoparasite prevalence and the associated haematological and biochemical alterations observed in the present study.

3.2. Occurrence and distribution of haemoparasites

A total of 40 dogs were examined, and *Babesia* spp. (Figure 1), *M. haemocanis* (Figure 2) and *H. canis* (Figure 3) were identified through microscopic evaluation of Giemsa-stained blood smears. The prevalence and percentage of each parasite species, along with the statistical significance of their distribution, indicated that *Babesia* spp. was the most prevalent haemoparasite, found in 21 (52.5%) of the sampled dogs, followed by *M. haemocanis* and *Anaplasma platys*, each in eight dogs (20%), while *H. canis* had the lowest prevalence, observed in two dogs (5%). The present results indicated that the distribution of haemoparasites was statistically significant for *Babesia* spp. compared to *H. canis* ($\chi^2 = 19.5578$, $p = 0.0002$), indicating a non-random pattern of occurrence within the study population.

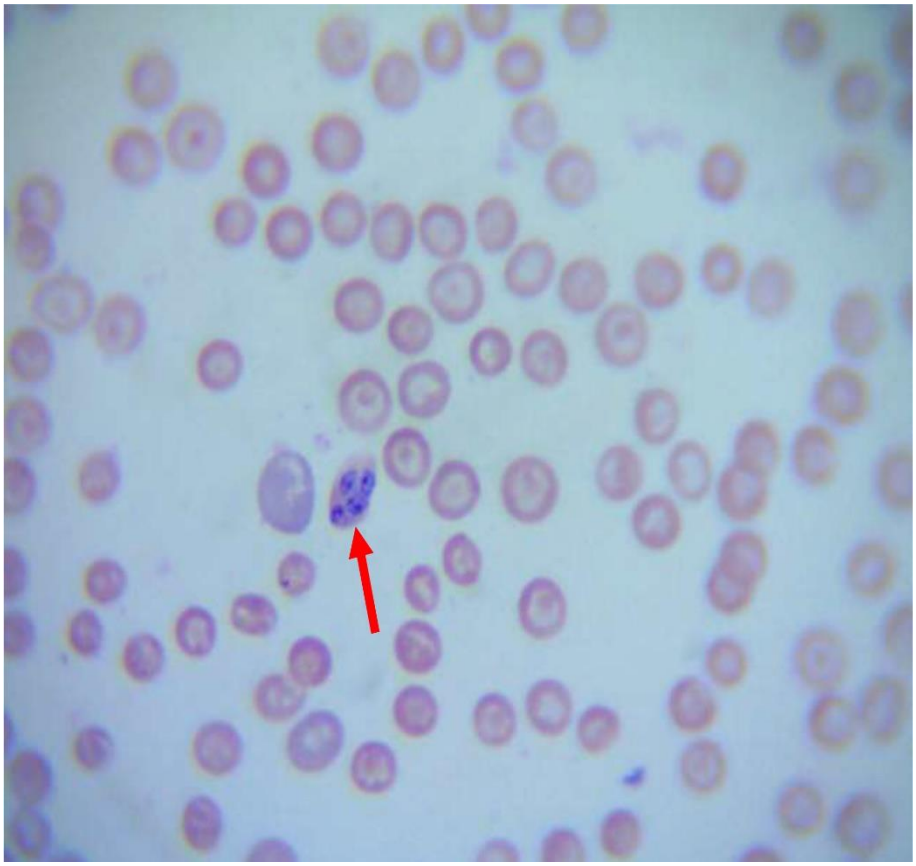

Figure 1. *Babesia* spp. in blood smear (red arrow) of a 3-year-old German Shepherd dog at the Veterinary Teaching Hospital in Nigeria. Giemsa staining, 100x. Source: The image was taken by the authors of the present study.

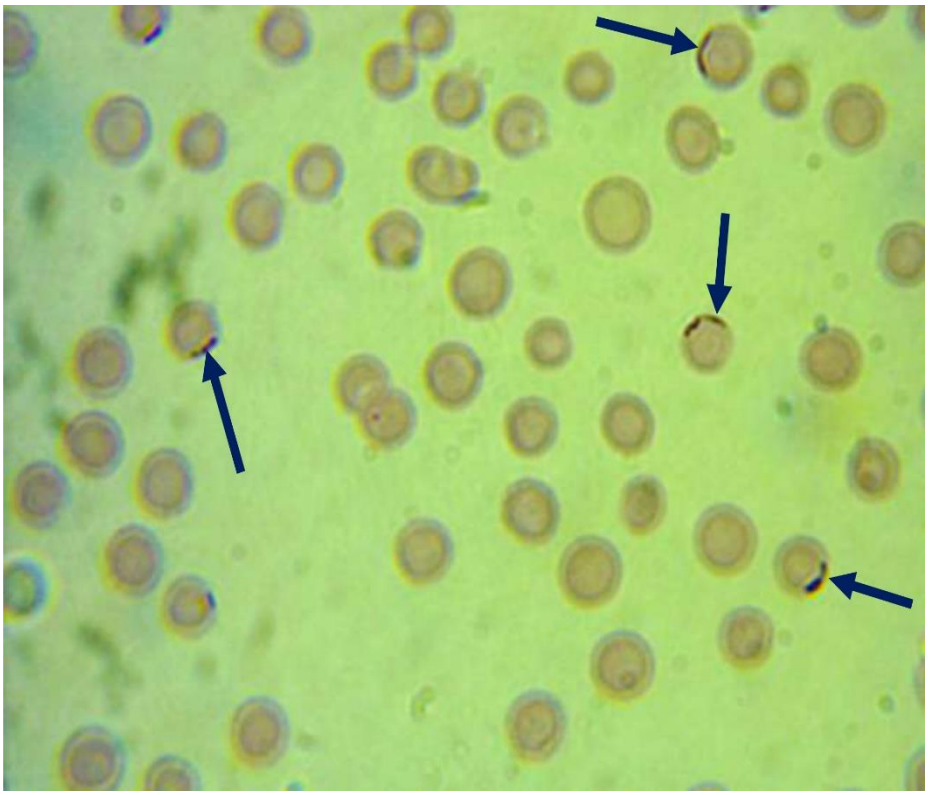

Figure 2. *Mycoplasma haemocanis* in blood smear (black arrow) of a 2-year-old female Nigerian Indigenous breed of dog, at the Veterinary Teaching Hospital, University of Jos, Nigeria. Giemsa staining, 100x. Source of Image: The image was taken by the authors of the present study.

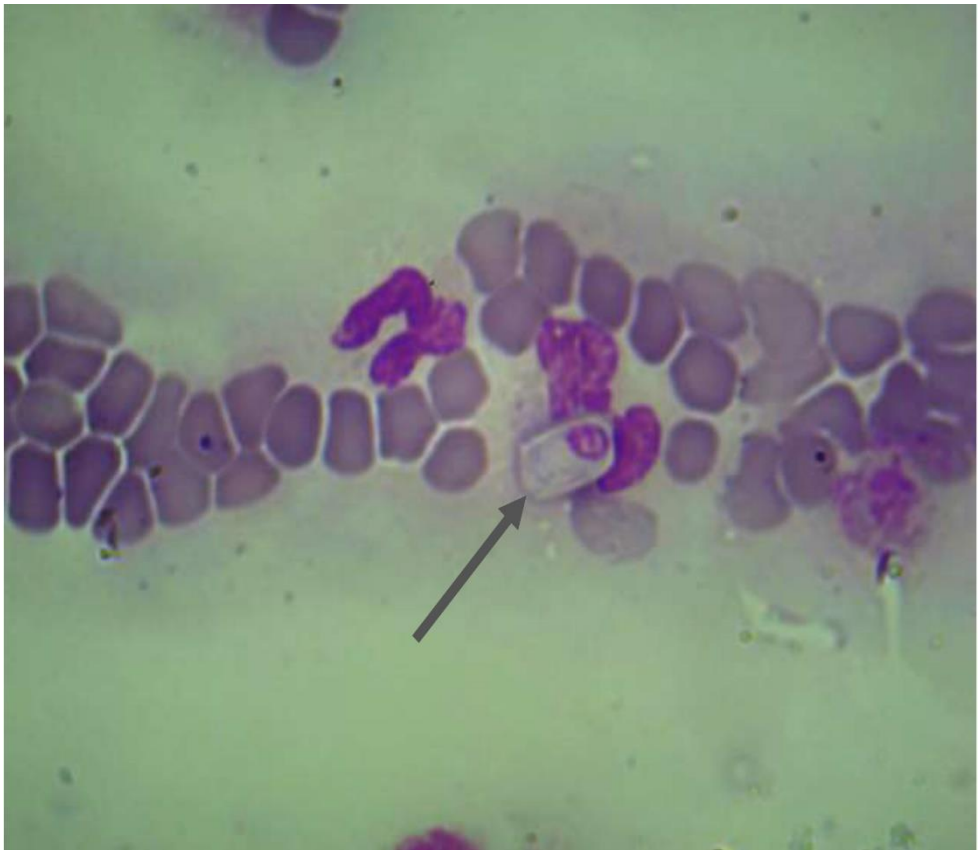

Figure 3. Intracytoplasmic inclusion in neutrophils consistent with *Hepatozoan canis* (black arrow) in a 2-year-old German Shepherd dog, at the Veterinary Teaching Hospital, University of Jos, Nigeria. Giemsa staining, 100x. Source of Image: The image was taken by the authors of the present study.

3.3. Erythrogram changes

3.3.1. Sex

Parasitaemia caused significant reductions in PCV and RBC counts in both male and female dogs (Table 1). Male dogs with multiple infections recorded the lowest values for PCV (26.50 ± 4.95%), and RBC (4.17 ± 0.81 × 10^{12}/L), followed by female dogs with multiple infections (PCV: 32.50 ± 10.25%; RBC: 4.97 ± 1.39 ×10^{12}/L). Male dogs with single infections had a lower PCV (34.60 ± 8.00%) than female dogs with single infections (37.50 ± 6.45%); however, this difference was not statistically significant ($p > 0.05$). In contrast, male and female non-parasitised dogs (NPD) maintained significantly higher PCV values (48.00 ± 2.35% and 46.00 ± 2.12%, respectively) than male and female dogs with multiple or single infections. Despite these reductions, differences were not statistically significant across MCV, MCH, MCHC, Red cell distribution width-coefficient of variation (RDW-CV), and Red cell distribution width-standard of variation (RDW-SD; $p > 0.05$), indicating that sex did not significantly affect the impact of parasitemia on erythrogram indices.

Table 1. Haematology parameters in dogs with parasitaemia and their changes in relation to sex

Gender	Parasitemia	PCV (%)	RBC (×10^{12}/L)	MCV (fL)	MCH (pg)	MCHC (g/dL)	RDW-CV (%)	RDW-SD (fL)
Female	SI	37.50 ± 6.45^{c}	5.52 ± 0.94^{c}	71.07± 3.45	23.23 ± 1.43	32.17 ± 0.94	14.46 ± 0.63	42.64 ± 2.16
	MI	32.50 ± 10.25^{cd}	4.97± 1.39^{d}	72.28 ± 3.91	23.17 ± 2.48	31.83 ± 1.33	14.45 ± 0.80	42.88 ± 2.28
	NPD	46.00 ± 2.12^{b}	6.62 ± 0.22^{ab}	69.20 ± 0.84	22.00 ± 0.00	34.00 ± 0.00	13.50 ± 0.00	40.00 ± 0.00
Male	SI	34.60 ± 8.00^{cd}	5.21 ± 1.14^{cd}	71.03 ± 3.59	23.40 ± 1.96	31.70 ± 1.06	14.74 ± 0.79	43.70 ± 2.50
	MI	26.50 ± 4.95^{e}	4.17 ± 0.81^{e}	72.00 ± 4.24	23.00 ± 4.24	29.50 ± 0.71	15.40 ± 0.42	45.10 ± 1.98
	NPD	48.00 ± 2.35^{a}	6.90 ± 0.26^{a}	69.20 ± 0.84	22.00 ± 0.00	34.00 ± 0.00	13.40 ± 0.22	39.80 ± 0.45
F-ratio		0.3417	0.2182	0.1252	0.0319	0.1708	0.2595	0.3079
p-value		0.00712	0.00805	0.8827	0.9686	0.8436	0.7729	0.7369

PCV: Packed cell volume, RBC: Red blood cell, MCV: Mean corpuscular volume, MCH: Mean corpuscular haemoglobin, MCHC: Mean corpuscular haemoglobin concentration, RDW-CV: Red cell distribution width-coefficient of variation, RDW-SD: Red cell distribution width-standard of variation, SI: Single infection, MI: Multiple infections, NPD: Non-parasitised dogs. Data are presented as mean ± SD. ^{a,b,c,d,e} Mean different superscript letters in a column are significant at $p < 0.05$.

3.3.2. Age

No young dogs with multiple infections were recorded in the present study, however, puppies with multiple infections demonstrated the most pronounced erythrogram alterations, showing severe significant reductions in PCV (23.50 ± 0.71%) and RBC (3.70 ± 0.14 ×10^{12}/L) compared to puppies with single infections (PCV: 41.29 ± 5.06%; RBC:

6.11 ± 0.72^{12} × 10^{12}/L; p < 0.05), consistent with marked haemolytic anaemia. Young dogs with single infections had significantly higher PCV (41.29 ± 5.06%) and RBC (6.11 ± 0.72 ×10^{12}/L) values than adult dogs with single infections (p > 0.05). Young NPD indicated the highest overall erythrogram values for PCV (50.00%) and RBC (7 × 10^{12}/L). The MCV and MCH were not significantly different in puppies, young dogs, or adult dogs, regardless of multiple or single infections or NPD status (p > 0.05). However, MCHC showed significant differences across all groups, including puppies, young, adults with single or multiple infections, and the NPD (p = 0.0234). The MCHC level in the young single infected dogs (32.71 ± 0.76 g/dL) was not significantly different from that in the adult dogs with single infection (31.54 ± 0.88 g/dL; p > 0.05). In addition, the MCHC level in NPD did not differ significantly across the three age groups (34.00 ± 0.00 g/dL). Statistically significant differences for PCV, RBC, and MCHC confirmed that parasitaemia significantly affected erythrogram parameters in an age-dependent manner (p < 0.05), with puppies being the most vulnerable group (Table 2).

Table 2. Haematology parameters in dogs with parasitaemia and their changes in relation to age

Age group	Parasitemia	PCV (%)	RBC (×10^{12}/L)	MCV (fL)	MCH (pg)	MCHC (g/dL)	RDW-CV (%)	RDW-SD (fL)
Adult	SI	33.23 ± 6.10^{c}	4.96 ± 0.89^{b}	72.16 ± 3.38	23.75 ± 1.75	31.54 ± 0.88^{a}	14.76 ± 0.70	43.82 ± 2.22
	MI	33.50 ± 9.52^{c}	5.12 ± 1.29^{b}	71.45 ± 4.01	22.33 ± 2.58	31.50 ± 1.76^{b}	14.42 ± 0.76	42.67 ± 2.09
	NPD	45.60 ± 1.82^{ab}	6.62 ± 0.22^{a}	68.80 ± 0.84	22.00	34.00^{a}	13.50	40.00
Puppy	SI	37.50 ± 13.44^{c}	5.50 ± 1.84^{ab}	71.50 ± 3.54	23.50 ± 2.12	32.00 ± 1.41^{ab}	14.75 ± 1.06	43.50 ± 3.54
	MI	23.50 ± 0.71^{d}	3.70 ± 0.14^{c}	74.50 ± 0.71	25.50 ± 0.71	30.50 ± 0.71^{b}	15.50 ± 0.28	45.75 ± 1.06
	NPD	48.00^{a}	6.80^{a}	70.00	22.00	34.00^{a}	13.50	40.00
Young	SI	41.29 ± 5.06^{b}	6.11 ± 0.72^{a}	68.86 ± 2.79	22.43 ± 1.13	32.71 ± 0.76^{ab}	14.21 ± 0.57	41.71 ± 1.89
	NPD	50.00^{a}	7.00^{a}	70.00	22.00	34.00^{a}	13.00	39.00
F-ratio		2.5672	2.4334	1.1949	0.9577	2.4805	2.0012	1.9257
p-value		0.0196	0.0257	0.3424	0.5294	0.0234	0.0634	0.0744

PCV: Packed cell volume, RBC: Red blood cell, MCV: Mean corpuscular volume, MCH: Mean corpuscular haemoglobin, MCHC: Mean corpuscular haemoglobin concentration, RDW-CV: Red cell distribution width-coefficient of variation, RDW-SD: Red cell distribution width-standard of variation, SI: Single infection, MI: Multiple infections, NPD: Non-parasitised dogs. Data are presented as mean ± SD. ^{a,b,c,d} Mean different superscript letters in a column are significant at p < 0.05.

3.3.3. Breed

The NIBD with multiple infections demonstrated significantly lower PCV (23.50 ± 0.71%) and RBC (3.70 ± 0.14 ×10^{12}/L) values than German Shepherds with multiple infections (p < 0.05), indicating more severe anaemia. German Shepherds maintained significantly higher PCV (37.00 ± 8.04%) and RBC (5.69 ± 0.91 ×10^{12}/L) values even under multiple infections than both NIBD and other dog breeds (p < 0.05). Significant differences in PCV and RBC confirmed that breed significantly influenced erythrogram alterations, with NIBD being the most affected species (p < 0.05; Table 3).

Table 3. Haematology parameters in dogs with parasitaemia and their changes in relation to breed

Breed	Parasitemia	PCV (%)	RBC (×10^{12}/L)	MCV (fL)	MCH (pg)	MCHC (g/dL)	RDW-CV (%)	RDW-SD (fL)
German Shepherd	SI	37.25 ± 8.38^{b}	5.55 ± 1.14^{b}	69.33 ± 3.24	22.50 ± 1.73^{b}	32.25 ± 0.96^{ab}	14.38 ± 0.75^{b}	42.50 ± 2.38^{ab}
	MI	37.00 ± 8.04^{b}	5.69 ± 0.91^{b}	69.43 ± 3.19	21.50 ± 2.38^{b}	31.50 ± 1.91^{b}	14.13 ± 0.67^{b}	41.63 ± 1.39^{b}
	NPD	45.75 ± 2.06^{a}	6.65 ± 0.24^{a}	68.75 ± 0.96	22.00^{b}	34.00^{a}	13.50^{c}	40.00^{c}
NIBD	SI	31.67 ± 6.15^{bc}	4.82 ± 0.93^{bc}	72.17 ± 3.66	24.00 ± 2.00^{ab}	31.33 ± 1.03^{b}	15.00 ± 0.72^{ab}	44.50 ± 2.24^{a}
	MI	23.50 ± 0.71^{d}	3.70 ± 0.14^{d}	74.50 ± 0.71	25.50 ± 0.71^{a}	30.50 ± 0.71^{c}	15.50 ± 0.28^{a}	45.75 ± 1.06^{a}
	NPD	47.83 ± 2.32^{a}	6.83 ± 0.29^{a}	69.50 ± 0.55	22.00^{b}	34.00^{a}	13.42 ± 0.20^{c}	39.83 ± 0.41^{c}
Other breeds of dogs	SI	38.08 ± 6.80^{b}	5.60 ± 1.01^{b}	71.00 ± 3.42	23.00 ± 1.43^{b}	32.00 ± 0.94^{ab}	14.00 ± 0.65^{bc}	42.00 ± 2.25^{b}
	MI	26.50 ± 10.61^{cd}	4.00 ± 1.41^{cd}	75.50 ± 0.71	24.00 ± 2.83^{ab}	31.50 ± 2.12^{b}	15.00 ± 0.71^{ab}	44.75 ± 1.77^{ab}
	NPD	47.83 ± 2.32^{a}	6.83 ± 0.29^{a}	69.50 ± 0.55	22.00^{b}	34.00^{a}	13.42 ± 0.20^{c}	39.83 ± 0.41^{c}
F-ratio		6.5446	5.8669	1.7110	2.5732	5.5013	5.1482	4.9096
p-value		<0.0001	<0.0001	0.1200	0.0202	0.0001	0.0002	0.0003

PCV: Packed cell volume, RBC: Red blood cell, MCV: Mean corpuscular volume, MCH: Mean corpuscular haemoglobin, MCHC: Mean corpuscular haemoglobin concentration, RDW-CV: Red cell distribution width-coefficient of variation, RDW-SD: Red cell distribution width-standard of variation, SI: Single infection, MI: Multiple infections, NPD: Non-parasitised dogs, NIBD: Nigerian indigenous breed, Other breeds of dogs: Russian shepherd, Lhasa, Siberian husky, Bull mastiff, Boerboel, and Neapolitan mastiff. Data are presented as mean ± SD. ^{a,b,c,d} Mean different superscript letters in a column are significant at p < 0.05.

The NIBD and other breeds of dogs with multiple infections had slightly higher MCV values (74.50 ± 0.71 fL and 75.50 ± 0.71 fL, respectively), although these differences were not statistically significant across all groups (p = 0.1200). The MCH was highest in NIBD with multiple infections (25.50 ± 0.71 pg), whereas MCHC was lowest (30.50 ± 0.71 g/dL). German Shepherds with single infections had the highest MCHC among infected groups

(32.25 ± 0.96 g/dL). German Shepherds maintained lower MCV (69.43 ± 3.19 fL) and significantly higher MCHC (31.50 ± 1.91 g/dL) compared to other breeds of dogs, suggesting better maintenance of erythrocyte indices. Significant differences for MCH ($p = 0.0202$) and MCHC ($p = 0.0001$) in NIBD confirmed breed-dependent variation in erythrocyte indices. Furthermore, NIBD with single infections also showed elevated RDW values (RDW-CV: 15.00 ± 0.72%; RDW-SD: 44.50 ± 2.24 fL). German Shepherds had lower RDW values (RDW-CV: 14.13 ± 0.67%; RDW-SD: 41.63 ± 1.39 fL). Significant p-values (0.0002 for RDW-CV; 0.0003 for RDW-SD) suggest that breed significantly influences red cell size variability. Non-parasitised dogs across all breeds had the lowest RDW-CV and RDW-CV values.

3.4. Leucogram changes

3.4.1. Sex

Parasitised dogs exhibited elevated WBC counts, with male dogs recording the highest values in multiple infections (17.89 ± 0.16 $\times 10^9$/L), compared to female dogs (12.31 ± 6.37 $\times 10^9$/L; $p > 0.05$; Table 4). Neutrophil counts followed a similar pattern, with male dogs exhibiting higher values during multiple infections (13.33 ± 2.37 $\times 10^9$/L) than female dogs (10.24 ± 5.62 $\times 10^9$/L; $p > 0.05$), suggesting an increased leucocyte response. In contrast, NPD had lower WBC and neutrophil counts, with female NPD showing 10.00 ± 0.71 $\times 10^9$/L compared to male NPD. The current results indicated that sex did not significantly influence the leucocyte response to parasitaemia ($p > 0.05$).

Lymphocyte counts demonstrated a non-significant reduction in parasitized dogs, specifically in male dogs with multiple infections (0.75 ± 0.21 × 10^9/L), compared to male NPD (2.76 ± 0.25 × 10^9/L; $p > 0.05$). Female dogs with multiple infections had lower lymphocyte counts (0.78 ± 0.15 $\times 10^9$/L) than female NPD (2.46 ± 0.29 $\times 10^9$/L), but the difference was not significant ($p > 0.05$). The present results indicated that sex had minimal influence on lymphocyte suppression ($p > 0.05$).

Monocyte counts were slightly higher in male dogs with single infections (1.33 ± 0.33 $\times 10^9$/L) compared to female dogs with single infections (1.11 ± 0.51 $\times 10^9$/L; $p > 0.05$), while eosinophil values demonstrated minor variations, with male NPD recording the highest counts (0.34 ± 0.15 $\times 10^9$/L) compared to female NPD (0.22 ± 0.04 $\times 10^9$/L; $p > 0.05$). The current results confirmed that sex did not significantly influence monocyte and eosinophil counts in dogs with parasitaemia ($p > 0.05$).

Table 4. Leucogram parameters in dogs with parasitaemia and their changes in relation to sex

Gender	Parasitaemia	WBC ($\times 10^9$/L)	NEU ($\times 10^9$/L)	LYM ($\times 10^9$/L)	MON ($\times 10^9$/L)	EOS ($\times 10^9$/L)
Female	SI	13.46 ± 5.44	10.87 ± 4.67	0.81 ± 0.09	1.11 ± 0.51	0.22 ± 0.12
	MI	12.31 ± 6.37	10.24 ± 5.62	0.78 ± 0.15	0.97 ± 0.43	0.23 ± 0.15
	NPD	10.00 ± 0.71	6.50 ± 0.35	2.46 ± 0.29	0.82 ± 0.04	0.22 ± 0.04
Male	SI	15.55 ± 4.30	12.78 ± 3.58	0.78 ± 0.10	1.33 ± 0.33	0.29 ± 0.09
	MI	17.89 ± 0.16	13.33 ± 2.37	0.75 ± 0.21	1.20 ± 0.28	0.25 ± 0.07
	NPD	11.00 ± 1.00	7.00 ± 0.50	2.76 ± 0.25	0.90 ± 0.10	0.34 ± 0.15
F-ratio		0.2015	0.1952	0.0338	0.3012	0.7162
p-value		0.8184	0.8235	0.9668	0.7417	0.4952

WBC: White blood cell, NEU: Neutrophil, LYM: Lymphocyte, MON: Monocyte, EOS: Eosinophil, SI: Single infection, MI: Multiple infections, NPD: Non-parasitised dogs. Data are presented as mean ± SD.

3.4.2. Age

Puppies with multiple infections exhibited the highest WBC (17.75 ± 0.35 $\times 10^9$/L) and neutrophil counts (14.75 ± 0.35 $\times 10^9$/L; Table 5). Adults (WBC 14.93 ± 4.89 $\times 10^9$/L) and young dogs (WBC 14.43 ± 4.44 $\times 10^9$/L) demonstrated moderate elevations during single infections ($p > 0.05$). The NPD consistently exhibited lower WBC values, with puppies demonstrating a WBC count of 10.00 ± 0.00 × 10^9/L ($p > 0.05$) compared with puppies with multiple infections, which had a WBC count of 17.75 ± 0.35 × 10^9/L.

Lymphocyte counts were significantly reduced in parasitised dogs, with puppies having multiple infections exhibiting the lowest values (0.65 ± 0.07 $\times 10^9$/L) compared to NPD young dogs, adult and puppies, respectively (3.00 $\times 10^9$/L; 2.46 ± 0.29 $\times 10^9$/L; 2.50 $\times 10^9$/L; $p < 0.05$). The current results indicated that lymphocyte suppression was strongly age-dependent ($p < 0.0001$), with puppies most affected, possibly due to age-related immune factors.

Table 5. Leucogram parameters in dogs with parasitaemia and their changes in relation to age

Age Group	Parasitaemia	WBC ($\times 10^9$/L)	NEU ($\times 10^9$/L)	LYM ($\times 10^9$/L)	MON ($\times 10^9$/L)	EOS ($\times 10^9$/L)
Adult	SI	14.93 ± 4.89	12.22 ± 4.13	0.77 ± 0.09^b	1.22 ± 0.45	0.25 ± 0.12
	MI	12.36 ± 6.42	9.77 ± 5.30	0.82 ± 0.15^b	0.88 ± 0.35	0.22 ± 0.15
	NPD	10.00 ± 0.71	6.50 ± 0.35	2.46 ± 0.29^a	0.82 ± 0.04	0.22 ± 0.04
Puppy	SI	11.00 ± 9.19	8.85 ± 7.99	0.75 ± 0.07^b	0.95 ± 0.78	0.18 ± 0.18
	MI	17.75 ± 0.35	14.75 ± 0.35	0.65 ± 0.07^b	1.45 ± 0.07	0.30
	NPD	10.00	6.50	2.50^a	0.80	0.20
Young	SI	14.43 ± 4.44	11.67 ± 3.81	0.86 ± 0.08^b	1.27 ± 0.39	0.26 ± 0.09
	NPD	12.00	7.50	3.00^a	1.00	0.50
F-ratio		0.9739	1.2929	80.6023	0.8191	0.6829
p-value		0.5149	0.2819	<0.0001	0.6589	0.7870

Note: No young dogs with multiple infections were recorded in this study. WBC: White blood cell, NEU: Neutrophil, LYM: Lymphocyte, MON: Monocyte, EOS: Eosinophil, SI: Single infection, MI: Multiple infections, NPD: Non-parasitised dogs. Data are presented as mean ± SD. ^{a,b} Mean different superscript letters in a column are significant at $p < 0.05$.

Puppies with multiple infections indicated the highest monocyte counts (1.45 ± 0.07 $\times 10^9$/L) compared to adult dogs with multiple infections (0.88 ± 0.35 $\times 10^9$/L). However, differences in monocyte counts were not statistically significant across age groups ($p = 0.6589$). No young dogs with multiple infections were observed in the present study.

Eosinophils were slightly elevated in young dogs with single infections (0.26 ± 0.09 $\times 10^9$/L) compared to puppies with single infections (0.18 ± 0.18 $\times 10^9$/L), while young NPD demonstrated the highest baseline values for eosinophils (0.50 ± 0.00 $\times 10^9$/L). The current findings indicated that age did not significantly influence monocyte or eosinophil changes, and the observed eosinophilia was not significantly elevated ($p > 0.05$).

3.4.3. Breed

The NIBD with multiple infections exhibited the highest WBC (17.75 ± 0.35 $\times 10^9$/L) and neutrophil counts (14.75 ± 0.35 $\times 10^9$/L) compared to German Shepherds with multiple infections (WBC: 13.03 ± 5.84 $\times 10^9$/L; NEU: 10.15 ± 4.72 $\times 10^9$/L) and other breeds with multiple infections (WBC: 11.00 ± 9.90 $\times 10^9$/L; NEU: 9.00 ± 8.49 $\times 10^9$/L). The NIBD with single infections displayed significantly elevated WBC (17.08 ± 0.74 $\times 10^9$/L) and NEU (14.08 ± 0.74 $\times 10^9$/L) compared to German Shepherds with single infections. The NPD exhibited lower WBC counts, including German Shepherd NPD (10.00 ± 0.82 × 10^9/L), NIBD NPD (10.83 ± 0.98 × 10^9/L), and other breeds' NPD (10.83 ± 0.98 × 10^9/L) than parasitised dogs. Significant p-values for WBC (0.0332) and neutrophils (0.0059) confirmed a breed-dependent inflammatory response, with NIBD showing higher leukocyte responses.

Lymphocyte counts were significantly lower in parasitised dogs across breeds. The NIBD with multiple infections had the lowest lymphocyte value (0.65 ± 0.07 $\times 10^9$/L). German Shepherds with single infections (0.83 ± 0.10 $\times 10^9$/L) and multiple infections (0.90 ± 0.08 $\times 10^9$/L), as well as NIBD with single infections (0.75 ± 0.10 $\times 10^9$/L), and other breeds with single infections (0.80 ± 0.09 $\times 10^9$/L), all had significantly lower lymphocyte counts than NPD groups. The present results confirmed that lymphocyte suppression was breed-dependent ($p < 0.0001$).

Monocyte count in NIBD with multiple infections (1.45 ± 0.07 $\times 10^9$/L) and eosinophil count in NIBD with single infections (0.32 ± 0.04 $\times 10^9$/L) were significantly higher compared to other breeds of dogs. German Shepherds with multiple infections demonstrated significantly lower monocyte counts (0.90 ± 0.35 $\times 10^9$/L) than NIBD with multiple infections (1.45 ± 0.07 $\times 10^9$/L; $p < 0.05$).

Monocyte counts in NIBD with multiple infections (1.45 ± 0.07 $\times 10^9$/L) and eosinophil counts in NIBD with single infections (0.32 ± 0.04 $\times 10^9$/L) were significantly higher than those observed in other dog breeds (monocytes: 0.85 ± 0.49 $\times 10^9$/L in dogs with multiple infections; eosinophils: 0.20 ± 0.12 $\times 10^9$/L in dogs with single infections; $p < 0.05$). NIBD with single infections demonstrated elevated monocyte levels (1.43 ± 0.08 $\times 10^9$/L) compared to other dog breeds, but that was not significant ($p > 0.05$). German Shepherds with multiple infections exhibited significantly lower monocyte counts (0.90 ± 0.35 $\times 10^9$/L) compared to NIBD with multiple infections (1.45 ± 0.07 $\times 10^9$/L; $p < 0.05$). Monocyte counts in German Shepherds with single infections (1.18 ± 0.52 $\times 10^9$/L) were not significantly different from those in NIBD or other breeds ($p > 0.05$). Significant differences in monocytes ($p = 0.0355$) and eosinophils ($p = 0.0388$) indicated clear breed-related changes in these immune parameters. Therefore, the current findings demonstrated notable breed-related differences in leukocyte responses to hemoparasitic infections (Table 6).

Table 6. Leucogram parameters in dogs with parasitaemia and their changes in relation to breed

Breed	Parasitaemia	WBC ($\times 10^9$/L)	NEU ($\times 10^9$/L)	LYM ($\times 10^9$/L)	MON ($\times 10^9$/L)	EOS ($\times 10^9$/L)
German Shepherd	SI	13.00 ± 6.42^{b}	10.58 ± 5.28^{b}	0.83 ± 0.10^{b}	1.18 ± 0.52^{ab}	0.24 ± 0.13^{ab}
	MI	13.03 ± 5.84^{b}	10.15 ± 4.72^{b}	0.90 ± 0.08^{b}	0.90 ± 0.35^{b}	0.24 ± 0.15^{ab}
	NPD	10.00 ± 0.82^{c}	6.50 ± 0.41^{c}	2.45 ± 0.33^{a}	0.83 ± 0.05^{b}	0.23 ± 0.05^{ab}
NIBD	SI	17.08 ± 0.74^{a}	14.08 ± 0.74^{a}	0.75 ± 0.10^{b}	1.43 ± 0.08^{a}	0.32 ± 0.04^{a}
	MI	17.75 ± 0.35^{a}	14.75 ± 0.35^{a}	0.65 ± 0.07^{bc}	1.45 ± 0.07^{a}	0.30^{a}
	NPD	10.83 ± 0.98^{bc}	6.92 ± 0.49^{c}	2.72 ± 0.25^{a}	0.88 ± 0.10^{b}	0.32 ± 0.15^{a}
Other breeds of dogs	SI	13.00 ± 5.48^{b}	10.00 ± 4.70^{b}	0.80 ± 0.09^{b}	1.10 ± 0.51^{ab}	0.20 ± 0.12^{b}
	MI	11.00 ± 9.90^{bc}	9.00 ± 8.49^{b}	0.65 ± 0.07^{bc}	0.85 ± 0.49^{b}	0.17 ± 0.18^{b}
	NPD	10.83 ± 0.98^{bc}	6.92 ± 0.49^{c}	2.72 ± 0.25^{a}	0.88 ± 0.10^{b}	0.32 ± 0.15^{a}
F-ratio		2.3305	3.1966	108.0092	2.2982	2.2542
p-value		0.0332	0.0059	<0.0001	0.0355	0.0388

WBC: White blood cell, NEU: Neutrophil, LYM: Lymphocyte, MON: Monocyte, EOS: Eosinophil, SI: Single infection, MI: Multiple infections, NPD: Non-parasitised dogs. Other breeds of dogs: Russian shepherd, Lhasa, Siberian husky, Bull mastiff, Boerboel, and Neapolitan mastiff. Data are presented as mean ± SD. ^{a,b,c} Mean different superscript letters in a column are significant at $p < 0.05$.

3.5. Platelet changes

Parasitaemia was associated with thrombocytopenia in infected dogs. The lowest platelet counts were observed in other breeds with multiple infections (57.50 ± 10.61 × 10^9/L; Table 7). German Shepherds with multiple infections had platelet counts of 73.75 ± 11.09 × 10^9/L. In contrast, NPD maintained normal platelet levels across all breeds, with young dogs recording 215.00 × 10^9/L platelet counts. The current results indicated that the effect of parasitaemia on platelet counts (PLT, PDW, PCT) was breed-dependent, especially in other breeds of dogs with multiple infections, whereas sex ($p = 0.7981$) and age ($p = 0.5149$) did not have a significant effect on platelet counts, suggesting these factors exert minimal influence on platelet reduction.

The MPV was higher in male dogs with multiple infections (10.55 ± 0.49 fL) compared to female dogs with multiple infections (8.95 ± 0.94 fL), indicating a possible

compensatory response due to increased marrow production in reaction to thrombocytopenia ($p > 0.05$). However, MPV differences between breeds were not statistically significant ($p = 0.1200$). The PDW demonstrated mild but consistent significant increases in infected dogs, with the highest values observed in NIBD with multiple infections (16.50 ± 0.42%) compared to German Shepherds with multiple infections (16.03 ± 0.37%; $p < 0.05$). The PCT was lowest in other breeds with multiple infections (0.12 ± 0.02%), indicating reduced overall platelet mass. The significant breed-related differences in PCT confirmed that platelet distribution differed across breeds ($p = 0.0002$).

Table 7. Platelet changes in dogs with parasitaemia in relation to sex, age, and breed

Variable	Parasitaemia	PLT (×10^9/L)	MPV (fL)	PDW (%)	PCT (%)
Sex					
	SI	85.00 ± 8.79	9.62 ± 0.82	16.13 ± 0.37	0.19 ± 0.08
Female	MI	67.50 ± 12.14	8.95 ± 0.94	16.30 ± 0.31	0.14 ± 0.02
	NPD	198.00 ± 10.95	9.00 ± 0.00	16.00 ± 0.00	0.25 ± 0.02
	SI	85.00 ± 8.50	9.97 ± 0.73	16.26 ± 0.28	0.17 ± 0.02
Male	MI	80.00 ± 0.00	10.55 ± 0.49	16.05 ± 0.64	0.30 ± 0.20
	NPD	210.00 ± 10.00	9.10 ± 0.22	16.00 ± 0.00	0.28 ± 0.03
F-ratio		0.2268	1.0668	1.2011	2.5092
p-value		0.7981	0.3545	0.3123	0.0951
Age					
	SI	86.67 ± 9.07	9.87 ± 0.79	16.22 ± 0.34	0.18 ± 0.06
Adult	MI	70.00 ± 10.00	9.15 ± 0.87	16.25 ± 0.36	0.15 ± 0.03
	NPD	200.00 ± 10.00	9.00 ± 0.00	16.00 ± 0.00	0.26 ± 0.02
	SI	85.00 ± 10.00	10.00 ± 0.71	16.10 ± 0.42	0.17 ± 0.04
Puppy	MI	65.00 ± 7.07	10.50 ± 0.71	16.50 ± 0.28	0.14 ± 0.02
	NPD	205.00	9.00	16.00	0.27
Young	SI	88.00 ± 8.00	9.75 ± 0.67	16.15 ± 0.32	0.19 ± 0.05
	NPD	215.00	9.20	16.00	0.28
F-ratio		0.9739	1.1949	0.8191	2.0012
p-value		0.5149	0.3424	0.6589	0.0634
Breed					
	SI	83.75 ± 11.09^{b}	9.63 ± 1.11^{a}	16.25 ± 0.29^{ab}	0.17 ± 0.02^{b}
German Shepherd	MI	73.75 ± 11.09^{bc}	9.15 ± 1.34^{a}	16.03 ± 0.37^{b}	0.22 ± 0.15^{ab}
	NPD	197.50 ± 12.58^{a}	9.00 ± 0.00^{a}	16.00 ± 0.00^{b}	0.26 ± 0.02^{a}
	SI	85.00 ± 9.00^{b}	9.75 ± 0.82^{a}	16.30 ± 0.36^{ab}	0.18 ± 0.06^{b}
NIBD	MI	65.00 ± 7.07^{c}	10.50 ± 0.71^{a}	16.50 ± 0.42^{a}	0.14 ± 0.02^{bc}
	NPD	208.33 ± 9.83^{a}	9.08 ± 0.20^{a}	16.00 ± 0.00^{b}	0.27 ± 0.02^{a}
	SI	85.00 ± 9.00^{b}	9.60 ± 0.82^{a}	16.00 ± 0.36^{b}	0.10 ± 0.08^{c}
Other breeds of dogs	MI	57.50 ± 10.61^{c}	8.75 ± 0.35^{a}	16.50 ± 0.42^{a}	0.12 ± 0.02^{c}
	NPD	208.33 ± 9.83^{a}	9.08 ± 0.20^{a}	16.00 ± 0.00^{b}	0.27 ± 0.02^{a}
F-ratio		2.3305	1.7110	2.2982	5.1482
p-value		0.0332	0.1200	0.0355	0.0002

PLT: Platelet count, MPV: Mean platelet volume, PDW: Platelet distribution width, PCT: Plateletcrit, SI: Single infection, MI: Multiple infections, NPD: Non-parasitised dogs, NIBD: Nigerian indigenous breed, Other breeds of dogs: Russian shepherd, Lhasa, Siberian husky, Bull mastiff, Boerboel, and Neapolitan mastiff. Data are presented as mean ± SD. ^{a,b,c} Mean different superscript letters in a column are significant at $p < 0.05$.

3.6. Serum biochemical and mineral alterations

Serum biochemical parameters were assessed to evaluate the impact of haemoparasitic infections on hepatic and renal function, electrolyte balance, and protein metabolism across sex, age, and breed categories (Table 8). Parasitaemia was associated with significant reductions in sodium (Na), chloride (Cl), bicarbonate (HCO_3^-), and calcium (Ca^{2+}) concentrations in both sexes. While male dogs with multiple infections exhibited higher urea (31.50 ± 2.12 mmol/L) and creatinine levels (1.90 ± 0.14 µmol/L) compared to female dogs with multiple infections (Urea: 26.33 ± 2.80 mmol/L and creatinine: 1.62 ± 0.19 µmol/L), the differences were not significant ($p > 0.05$), suggesting greater renal compromise in male dogs. Liver enzymes, including ALP, ALT, and AST, along with bilirubin, were markedly elevated in parasitised dogs, with male dogs having higher enzyme values under multiple infections (AST: 68.50 ± 4.95 U/L) compared to female dogs with multiple infections (52.17 ± 9.99 U/L; $p > 0.05$). Most minerals and biochemical parameters, including potassium (K), ALP, ALT, AST, urea, creatinine, albumin, uric acid, total protein, total bilirubin, and conjugated bilirubin, indicated no significant sex-related differences ($p > 0.05$). However, electrolyte disturbances in Na, Cl, HCO_3^-, and Ca^{2+} differed significantly between sexes ($p < 0.05$), suggesting mild sex-specific susceptibility in electrolyte regulation.

Age had a pronounced influence on mineral indices. Puppies with multiple infections had significantly lower phosphorus (1.95 ± 0.07 mmol/L) and significantly higher Ca^{2+} (32.00 ± 1.41 µmol/L) levels compared to adult dogs with multiple infections (Phosphorus: 1.60 ± 0.17 mmol/L and Ca^{2+}: 26.17 ± 2.48 µmol/L), indicating significant differences in these parameters ($p < 0.05$).

Breed-related changes were evident. The NIBD with multiple infections had the highest creatinine level among breeds (6.00 ± 0.14 µmol/L). German Shepherds with multiple infections exhibited significantly lower elevations in liver enzymes (ALT: 97.50 ± 15.00 U/L) compared to NIBD with multiple infections (130.00 ± 7.07 U/L; $p < 0.05$).

The overall breed effect was significant for several parameters, including Na, Cl, HCO_3, Ca^{2+}, phosphorus, urea, creatinine, uric acid, total protein, albumin, ALP, ALT, total bilirubin, and conjugated bilirubin ($p < 0.05$). This finding confirmed that the biochemical changes caused by parasitaemia were breed-dependent, with NIBD being more negatively affected.

Table 8. Serum biochemical changes in dogs with parasitaemia in relation to sex, age, and breed

Variables	Parasitaemia	Na (mmol/L)	K (mmol/L)	Cl (mmol/L)	HCO_3 (mmol/L)	Ca^{2+} (mmol/L)	Phosphorus (mmol/L)	Urea (mmol/L)	Creatinine (µmol/L)	Uric Acid (mmol/L)	Total protein (g/dL)	Albumin (g/dL)	ALP (U/L)	ALT (U/L)	AST (U/L)	Tot.Bi (umol/L)	Conbil (umol/L)
Sex																	
Female	SI	137.11 ± 4.08^{b}	4.52 ± 0.38^{a}	102.67 ± 3.94^{b}	19.89 ± 1.69^{b}	8.88 ± 0.31^{b}	5.58 ± 0.37^{a}	26.17 ± 5.06	1.55 ± 0.36	1.33 ± 0.37	5.43 ± 0.54	2.41 ± 0.50	180.42 ± 26.50	99.17 ± 25.30	50.92 ± 15.29	10.73 ± 4.59	3.41 ± 1.68
	MI	138.83 ± 2.64^{b}	4.42 ± 0.26^{a}	104.00 ± 3.41^{b}	20.50 ± 1.38^{b}	8.98 ± 0.23^{b}	5.53 ± 0.28^{a}	26.33 ± 2.80	1.62 ± 0.19	1.43 ± 0.22	5.37 ± 0.37	2.32 ± 0.40	180.83 ± 18.28	100.00 ± 13.78	52.17 ± 9.99	10.95 ± 3.34	3.58 ± 1.20
	NPD	147.50 ± 1.29^{a}	4.53 ± 0.17^{a}	111.50 ± 1.29^{a}	23.75 ± 0.96^{a}	10.05 ± 0.13^{a}	3.85 ± 0.13^{b}	15.00 ± 5.24	0.96 ± 0.22	0.92 ± 0.08	6.44 ± 0.43	3.40 ± 0.40	102.00 ± 35.46	53.60 ± 20.79	29.40 ± 8.65	5.12 ± 1.19	1.06 ± 0.60
Male	SI	139.75 ± 1.26^{b}	4.33 ± 0.13^{a}	105.25 ± 1.71^{b}	21.00 ± 0.82^{ab}	9.15 ± 0.19^{b}	5.33 ± 0.17^{a}	25.00 ± 4.50	1.54 ± 0.29	1.33 ± 0.29	5.41 ± 0.39	2.35 ± 0.38	181.50 ± 18.86	96.00 ± 19.69	49.30 ± 12.39	10.53 ± 3.51	3.40 ± 1.24
	MI	139.50 ± 3.11^{b}	4.35 ± 0.30 ^{a}	105.25 ± 3.59^{b}	21.00 ± 1.41^{ab}	9.08 ± 0.22^{b}	5.43 ± 0.29^{a}	31.50 ± 2.12	1.90 ± 0.14	1.70 ± 0.14	4.85 ± 0.21	1.90 ± 0.14	207.50 ± 10.61	127.50 ± 10.61	68.50 ± 4.95	16.00 ± 1.41	5.35 ± 0.49
	NPD	147.00 ± 2.00^{a}	4.50 ± 0.10^{a}	111.00 ± 1.73^{a}	23.67 ± 1.15^{a}	10.03 ± 0.06^{a}	3.90 ± 0.17^{b}	14.20 ± 4.15	0.92 ± 0.16	0.94 ± 0.09	6.46 ± 0.48	3.42 ± 0.49	107.00 ± 41.47	50.60 ± 14.10	27.40 ± 4.98	5.24 ± 1.56	1.12 ± 0.78
F-ratio		3.5901	1.3943	3.2453	2.3305	6.4207	7.1470	0.0879	0.0026	0.0170	0.0019	0.0109	0.0326	0.0720	0.0842	0.0737	0.0230
p-value		0.0028	0.2283^{a}	0.0054	0.0332	<0.0001	<0.0001	0.9160	0.9974	0.9832	0.9982	0.9891	0.9679	0.9307	0.9194	0.9291	0.9773
Age																	
Adult	SI	137.11 ± 4.08^{b}	4.52 ± 0.38^{a}	102.67 ± 3.94^{b}	19.89 ± 1.69^{b}	26.89 ± 4.17^{b}	1.67 ± 0.23^{b}	8.88 ± 0.31^{b}	5.58 ± 0.37^{b}	1.46 ± 0.24^{ab}	5.24 ± 0.35^{b}	2.20 ± 0.30^{b}	189.44 ± 17.22^{b}	105.00 ± 19.36^{b}	54.67 ± 12.28^{b}	11.78 ± 3.68^{b}	3.82 ± 1.30^{b}
	MI	138.83 ± 2.64^{b}	4.42 ± 0.26^{a}	104.00 ± 3.41^{b}	20.50 ± 1.38^{b}	26.17 ± 2.48^{b}	1.60 ± 0.17^{b}	8.98 ± 0.23^{b}	5.53 ± 0.28^{b}	1.42 ± 0.19^{ab}	5.38 ± 0.35^{b}	2.33 ± 0.38^{b}	180.00 ± 17.03^{b}	99.17 ± 12.01^{b}	51.67 ± 9.07^{b}	10.78 ± 3.05^{b}	3.55 ± 1.14^{b}
	NPD	147.50 ± 1.29^{a}	4.53 ± 0.17^{a}	111.50 ± 1.29^{a}	23.75 ± 0.96^{a}	12.00 ± 0.82^{d}	0.83 ± 0.10^{d}	10.05 ± 0.13^{a}	3.85 ± 0.13^{d}	0.88 ± 0.05^{c}	6.60 ± 0.18^{a}	3.55 ± 0.13^{a}	86.25 ± 4.79^{d}	42.00 ± 3.56^{d}	24.25 ± 1.71^{d}	4.45 ± 0.13^{c}	0.73 ± 0.10^{d}
Puppy	SI	143.00 ± 1.41a^{b}	4.05 ± 0.07	109.00 ± 1.41^{ab}	23.50 ± 0.71^{a}	21.00 ± 0.00^{c}	1.15 ± 0.07^{c}	9.35 ± 0.21^{ab}	4.70 ± 0.00^{c}	1.05 ± 0.07^{bc}	5.80 ± 0.28^{ab}	2.75 ± 0.35^{ab}	167.50 ± 24.75^{bc}	80.00 ± 0.00^{c}	38.50 ± 2.12^{c}	7.65 ± 1.20b^{c}	2.35 ± 0.49^{c}
	MI	132.00 ± 1.41^{c}	5.00 ± 0.14^{a}	98.00 ± 1.41^{c}	17.50 ± 0.71^{c}	32.00 ± 1.41^{a}	1.95 ± 0.07^{a}	8.50 ± 0.14^{b}	6.00 ± 0.14^{a}	1.75 ± 0.07^{a}	4.80 ± 0.14^{bc}	1.85 ± 0.07^{b}	210.00 ± 7.07^{a}	130.00 ± 7.07^{a}	70.00 ± 2.83^{a}	16.50 ± 0.71^{a}	5.45 ± 0.35^{a}
	NPD	145^{ab}	4.4^{a}	110^{ab}	23^{a}	14^{cd}	1^{cd}	10^{a}	4^{cd}	1^{bc}	6.6^{a}	3.6^{a}	90^{d}	48^{cd}	28^{cd}	4.8^{c}	0.9^{d}
Young	SI	139.45 ± 5.63^{b}	4.35 ± 0.49^{a}	105.09 ± 5.56^{b}	21.45 ± 3.14^{b}	25.45 ± 5.24^{b}	1.52 ± 0.36^{b}	9.07 ± 0.45^{b}	5.27 ± 0.61^{b}	1.28 ± 0.38^{b}	5.49 ± 0.54^{b}	2.46 ± 0.51^{b}	176.36 ± 25.89^{b}	95.00 ± 25.30^{b}	48.64 ± 15.09^{b}	10.25 ± 4.49^{b}	3.25 ± 1.65^{b}
	NPD	144.80 ± 3.70^{ab}	4.40 ± 0.29^{a}	110.00 ± 2.92^{ab}	22.80 ± 1.64^{a}	16.80 ± 5.63^{c}	1.02 ± 0.22^{c}	9.80 ± 0.52^{ab}	4.24 ± 0.53^{c}	0.96 ± 0.09^{c}	6.30 ± 0.58^{a}	3.26 ± 0.58^{a}	122.00 ± 46.98^{c}	61.00 ± 20.54^{c}	31.80 ± 8.26^{c}	5.84 ± 1.66^{c}	1.42 ± 0.83^{c}
F-ratio		11.6759	0.6097	9.8544	5.6657	25.827	21.0857	24.1227	31.8282	11.5231	22.2392	24.0689	33.1005	21.5034	15.0854	11.1541	14.6761
p-value		0.0001	0.5489^{a}	0.0004	0.0071	<.0001	<.0001	<.0001	<.0001	0.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.0002	<.0001
Breed																	
GSD	SI	139.75 ± 1.26^{b}	4.33 ± 0.13	105.25 ± 1.71^{b}	21.00 ± 0.82^{b}	25.75 ± 0.96^{b}	1.53 ± 0.10^{a}	9.15 ± 0.19^{b}	5.33 ± 0.17^{b}	1.28 ± 0.13^{b}	5.58 ± 0.22^{b}	2.53 ± 0.28^{b}	170.00 ± 9.13^{c}	93.75 ± 6.29^{c}	48.75 ± 5.38^{c}	8.50 ± 1.47^{c}	2.53 ± 0.46^{c}
	MI	139.50 ± 3.11^{b}	4.35 ± 0.30	105.25 ± 3.59^{b}	21.00 ± 1.41^{b}	26.50 ± 3.11^{ab}	1.58 ± 0.21^{c}	9.08 ± 0.22^{b}	5.43 ± 0.29^{b}	1.35 ± 0.21^{b}	5.50 ± 0.38^{b}	2.48 ± 0.39^{b}	178.75 ± 21.75^{c}	97.50 ± 15.00^{c}	49.25 ± 10.59^{c}	9.93 ± 3.52^{c}	3.20 ± 1.28^{c}
	NPD	147.00 ± 2.00^{a}	4.50 ± 0.10	111.00 ± 1.73^{a}	23.67 ± 1.15^{a}	12.67 ± 1.53^{d}	0.87 ± 0.15^{e}	10.03 ± 0.06^{a}	3.90 ± 0.17^{e}	0.90 ± 0.10^{c}	6.60 ± 0.10^{a}	3.57 ± 0.06^{a}	88.33 ± 2.89^{e}	43.67 ± 5.13^{e}	25.33 ± 3.06^{e}	4.57 ± 0.25^{d}	0.77 ± 0.15^{d}
NIBD	SI	142.33 ± 2.34^{ab}	4.08 ± 0.17	108.00 ± 2.97^{ab}	22.83 ± 1.83^{a}	22.50 ± 1.22^{c}	1.35 ± 0.19^{d}	9.27 ± 0.31^{b}	5.07 ± 0.33^{c}	1.12 ± 0.18^{bc}	5.73 ± 0.34^{b}	2.68 ± 0.39^{b}	166.67 ± 20.90^{d}	83.33 ± 6.83^{d}	41.33 ± 4.32^{d}	8.27 ± 1.95^{cd}	2.60 ± 0.79^{c}
	MI	132.00 ± 1.41^{c}	5.00 ± 0.14	98.00 ± 1.41^{c}	17.50 ± 0.71^{c}	32.00 ± 1.41^{a}	1.95 ± 0.07^{a}	8.50 ± 0.14^{c}	6.00 ± 0.14^{a}	1.75 ± 0.07^{a}	4.80 ± 0.14^{d}	1.85 ± 0.07^{d}	210.00 ± 7.07^{a}	130.00 ± 7.07^{a}	70.00 ± 2.83^{a}	16.50 ± 0.71^{a}	5.45 ± 0.35^{a}
Others	SI	136.75 ± 5.69b^{c}	4.57 ± 0.51	102.42 ± 5.47^{bc}	20.08 ± 3.00^{bc}	27.17 ± 5.83^{ab}	1.65 ± 0.38^{b}	8.85 ± 0.42^{c}	5.49 ± 0.66^{b}	1.46 ± 0.38^{b}	5.21 ± 0.49^{c}	2.18 ± 0.43^{c}	191.67 ± 22.19^{b}	106.25 ± 27.06^{b}	55.08 ± 16.58^{b}	12.54 ± 4.49^{b}	4.10 ± 1.61^{b}
	MI	137.50 ± 0.71^{bc}	4.55 ± 0.07	101.50 ± 0.71^{bc}	19.50 ± 0.71^{bc}	25.50 ± 0.71^{b}	1.65 ± 0.07^{b}	8.80 ± 0.14^{c}	5.75 ± 0.07^{a}	1.55 ± 0.07^{ab}	5.15 ± 0.07^{c}	2.05 ± 0.07^{c}	182.50 ± 3.54^{bc}	102.50 ± 3.54^{bc}	56.50 ± 2.12^{b}	12.50 ± 0.71^{b}	4.25 ± 0.35^{b}
	NPD	145.43 ± 3.26^{a}	4.43 ± 0.27	110.43 ± 2.51^{a}	23.00 ± 1.41^{a}	15.43 ± 5.16^{d}	0.97 ± 0.20^{e}	9.87 ± 0.45^{a}	4.13 ± 0.48^{d}	0.94 ± 0.08^{c}	6.39 ± 0.51^{a}	3.34 ± 0.50^{a}	111.43 ± 42.50^{e}	55.71 ± 19.10^{e}	29.71 ± 7.63^{e}	5.44 ± 1.51^{d}	1.23 ± 0.75^{d}

F-ratio	3.5901	1.3943	3.2453	2.3305	6.289	5.2571	6.4207	7.147	3.2545	5.6249	5.9532	9.764	5.7823	4.0761	3.4795	4.0347
p-value	0.0028	0.2283	0.0054	0.0332	<0.0001	0.0002	<0.0001	<0.0001	0.0053	<0.0001	<0.0001	<0.0001	<0.0001	0.0012	0.0035	0.0013

SI: Single infection, MI: Multiple infection, GSD: German Shepherd, NIBD: Nigerian indigenous breed, NPD: Non-parasitised dogs, Na: Sodium, K: Potassium, Cl: Chloride, $HC0_3$: Bicarbonate, Ca^{2+}: Calcium, ALP: Alkaline phosphatase, ALT: Alanine aminotransferase, AST: Aspartate aminotransferase, Tot.Bi: Total bilirubin, Con bil: Conjugated bilirubin, Other breeds of dogs: Russian shepherd, Lhasa, Siberian husky, Bull mastiff, Boerboel, and Neapolitan mastiff. Data are presented as mean ± SD. [a,b,c,d,e] Mean different superscript letters in a column are significant at $p < 0.05$.

4. Discussion

The current findings highlighted the burden of haemoparasitic diseases in Jos North, Plateau State, Nigeria, reflecting global patterns while emphasizing local veterinary challenges.

Four haemoparasites were identified, with *Babesia* spp. being the most prevalent (52.5%), followed by *Anaplasma platys* (20%), *M. haemocanis* (20%), and *H. canis* (5%). The dominance of *B. canis* aligns with its global recognition as a major tick-borne pathogen, particularly in tropical and subtropical regions where Rhipicephalus sanguineus, its primary vector, thrives[10]. The favourable climate of Jos North, Nigeria, characterised by moderate temperatures and high humidity, likely promotes tick proliferation, which may explain the high prevalence of *Babesia* spp., consistent with previous findings in Nigeria[11]. The equal prevalence of *Anaplasma platys* and *M. haemocanis* in the present study underscores their importance in the local canine health landscape. *H. canis*, transmitted via ingestion of infected ticks, exhibited lower prevalence, likely due to its unique transmission route[10].

Parasitised dogs displayed marked haematological disturbances. The PCV and RBC counts were markedly reduced, particularly in puppies and NIBD, consistent with the findings of Happi et al.[11], and Vonkur et al.[12]. In contrast, Audu et al.[10] reported no significant haematological differences in infected dogs from Yobe State, Nigeria, possibly due to lower parasitaemia or chronic subclinical infections. Severe anaemia in puppies was likely due to *Babesia*-induced haemolysis and *M. haemocanis*-mediated immune destruction, consistent with the findings of Irwin and Hutchinson[13]. The elevated MCV, particularly in puppies, indicated compensatory reticulocyte release in response to bone marrow stress. Platelet counts were reduced, with thrombocytopenia most pronounced in NIBD and puppies, consistent with reports of *Anaplasma* platys-associated cyclic thrombocytopenia, similar to those of Kamani et al.[14] and Kolo[15]. Although *Anaplasma platys* is primarily responsible for cyclic thrombocytopenia, co-infection with *H. canis*, as identified in the current study, may additionally exacerbate hematological disturbances, such as anemia and thrombocytopenia, especially in cases involving multiple infections[16]. Substantial breed-specific differences for PCV and RBC suggested that NIBD might have possessed lower genetic resilience than breeds such as German Shepherds.

The biochemical results revealed elevated liver enzymes (ALT, AST, ALP) and bilirubin levels in parasitised dogs, especially puppies and NIBD with multiple infections, which is consistent with the findings of Turna et al.[17], and Mshelbwala et al.[18]. The ALP in puppies was likely induced by hepatobiliary stress, likely due to haemolytic byproducts. Renal markers, including urea and creatinine, were elevated, suggesting renal stress potentially from hypoxia or microthrombi[19]. Electrolyte imbalances, particularly reduced sodium and chloride levels, are particularly prevalent in puppies and males, indicating systemic fluid disturbances. Age- and breed-dependent effects for most biochemical parameters highlighted the vulnerability of younger dogs and NIBD, likely due to immature immune systems and higher parasite burdens associated with free-roaming lifestyles. This finding is consistent with the report of Adamu et al.[19], who identified age and management practices as potential determinants of haemoparasite occurrence in Nigerian dogs. In contrast, Zygner et al.[20] did not evaluate age- or breed-related susceptibility in their study on *Babesia canis*-infected dogs in Poland, as their analysis focused primarily on electrolyte imbalances rather than host-related risk factors.

According to the present findings, parasitemia strongly correlated with haematological and biochemical disturbances. Severe anaemia coincided with the high prevalence of *Babesia* spp.[19], which target RBCs, while thrombocytopenia was associated with *Anaplasma platys* infections[20]. Elevated WBC and neutrophil counts in parasitised dogs, particularly NIBD, reflected active inflammation, whereas lymphopenia in NIBD with multiple infections indicated immunosuppression, consistent with chronic haemoparasitic infections[17]. The findings of Turna et al.[17] are consistent with the present findings, confirming that lymphopenia is a frequent haematological finding in canine haemoparasitic infections and supporting the notion that these infections cause substantial haematological changes as part of the disease pathology. Breed-specific differences suggested that NIBD's heightened inflammatory response may exacerbate tissue damage, while German Shepherds' moderated response reflected more regulated immunity. The findings of Zygner et al.[20] are consistent with the present study, demonstrating that *Babesia canis* infection induced significant systemic metabolic disturbances, including strong monovalent electrolyte imbalances such as hyponatraemia, hypokalaemia, and hyperchloraemia, which align with the renal and inflammatory alterations reported in the present study and further underscore the multi-organ pathophysiology associated with canine haemoparasitic infections. The findings of Adamu et al.[21] are consistent with the present

study in confirming a high prevalence of *Babesia* spp. and frequent polymicrobial infections in canine populations, which contributed to systemic clinical manifestations. The haemobiochemical findings align with global studies but also highlight local challenges, including limited diagnostic facilities and low awareness, which exacerbate disease progression[18,11].

5. Conclusion

Haemoparasites were indicated to induce significant haemobiochemical alterations in dogs, particularly haemolytic anaemia, thrombocytopenia, and organ dysfunction (liver and kidney), with age and breed emerging as important influencing factors. The statistically significant distribution of haemoparasites suggested that ecological and host factors influence parasite occurrence, warranting further investigation into local vector dynamics. Puppies and NIBD were identified as the most vulnerable groups, emphasizing the need for region-specific preventive strategies to protect canine health. Babesia spp. was the most prevalent and impactful haemoparasite, driving marked haemobiochemical changes, especially in puppies and NIBD. The strong associations observed between parasitaemia and these biochemical alterations underscored the urgent need for targeted interventions to reduce the burden of these infections in Jos North, Nigeria. Puppies and NIBD, which were most affected, require targeted interventions, such as routine tick prevention and early diagnostic screening. While most biochemical parameters showed no significant sex-related differences, significant electrolyte disturbances (Na, Cl, HCO_3^-, Ca^{2+}) were observed between sexes ($p < 0.05$), suggesting mild sex-specific susceptibility in electrolyte regulation. Age- and breed-specific susceptibilities highlighted the need for tailored management. Puppies may require supportive therapies such as blood transfusions and immune supplementation, while NIBD owners should reduce free-roaming to minimise tick exposure. The present findings should motivate veterinarians, dog owners, and local authorities to collaborate to implement informed, practical solutions to safeguard canine health in this dynamic region of Nigeria.

Declarations

Ethical considerations

Prior to publishing the present study, the authors reviewed all ethical challenges, including plagiarism, consent to publish, and data fabrication, falsification, and no artificial intelligence was used in conducting and preparing the present study.

Competing interests

The authors have declared no conflict of interest.

Authors' contributions

Deborah Maigawu Buba conceptualised and drafted the main manuscript. George Yilzem Gurumyen reviewed the manuscript. Samuel Chukwudi Eze was involved with sample collection and literature search. Charibu Hurdison Dishon did the statistical analyses of the study. All authors have read and agreed to the published final edition of the manuscript.

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Availability of data and materials

All results presented here were generated by the authors and presented for publication.

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