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Occurrence and risk factors for Haemosporidian infections among pigeon (*Columba livia domestica*) populations in Maiduguri, Borno State, Nigeria

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Abstract

This study evaluated the occurrence of haemosporidian infections in exotic and indigenous pigeon (*Columba livia domestica*) populations in Maiduguri, Borno State, Nigeria, and also the risk factors associated with the infections. Three hundred pigeons from diverse locations, including live bird markets, breeder households and veterinary hospitals were sampled for the study. Blood samples were collected from each pigeon and examined microscopically. The overall occurrence of haemosporidian infections in the pigeons sampled was 21.0%. Four haemosporidian species were identified in the pigeons: *Haemoproteus*, *Plasmodium*, *Leucocytozoon*, and *Microfilariae* species. *Haemoproteus* had the highest occurrence (10.3%), followed by *Plasmodium* (5.0%). Co-infections of *Haemoproteus* and *Plasmodium* species were also detected (3%). The occurrence of the haemosporidian infections varied based on sampling locations, with veterinary hospitals showing the highest frequency of occurrence. Male pigeons had significantly ($p < 0.0001$) higher occurrence of infection than females; juveniles had significantly ($p = 0.0028$) more infection than adults, and exotic pigeons were significantly ($p = 0.0004$) more infected than the local breeds. The infections were significantly ($p < 0.0001$) more during the rainy season than the dry season, and clinically sick pigeons were at greater risk ($p < 0.0001$). Extensively reared pigeons, those in coops/lofts lacking arthropod screening nets, and those in improvised coop/lofts had higher frequency of occurrence. There was a lack of awareness among pigeon enthusiasts, breeders, and vendors regarding haemoparasites in pigeons. There is thus the need for public education to increase awareness of the occurrence of haemoparasites in pigeons.

Keywords: *Columba livia domestica*; Haemosporidian infections; Maiduguri Nigeria; Occurrence; Pigeons; Risk factors.

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Introduction

Pigeons (*Columba livia domestica*) have played a significant role in human history and culture for centuries (Podbielska and Radko, 2022). These avian species are appreciated not only for their unique beauty and diverse plumage but also for their utility in various aspects, including use as meat, use for sports and companionship (Carlen and Munshi-South, 2021). In Nigeria, as in many parts of the world, pigeon breeding and racing have become popular pastimes, and the industry has grown substantially in recent years (Ihedioha *et al*., 2016; Lawal *et al*., 2019; Wannaratana *et al*., 2021; Wang *et al*., 2023). However, this increasing demand for pigeons has raised several concerns, particularly regarding the health and well-being of these birds (Kastelic *et al*., 2021).

Just like any other avian species, pigeons are susceptible to various infectious diseases, among these are haemosporidian infections caused by various blood-borne pathogens such as protozoa and microfilariae (Schumm *et al*., 2021; Ehsani-Amerei *et al*., 2022). The occurrence of avian haemoparasites of the genera *Plasmodium*, *Haemoproteus*, and *Leucocytozoon* have been reported to lead to significant health challenges for infected pigeons, which include morbidity and mortality in both exotic and indigenous breeds of pigeons, resulting in considerable threat to the pigeon population as well as economic losses for pigeon breeders and potential public health concerns (Mirzaei *et al*., 2020; Tembe *et al*., 2023).

Avian haemosporidian infections are transmitted through the bites of infected insects, such as mosquitoes and biting flies, making them more prevalent in areas with high insect activity (Ilgūnas *et al*., 2019; Marzal *et al*., 2022). These parasites majorly invade the bird's red blood cells, leading mainly to anaemia and other potentially fatal consequences if left untreated (Marzal *et al*., 2022; Meister *et al*., 2022). Several factors have been reported to contribute to the risk of haemoparasitic infections in pigeons. Geographic location plays a vital role, as regions with a higher prevalence of disease-carrying insects have an increased likelihood of such haemoparasitic infections (Nebel *et al*., 2020). Additionally, the bird's immune status, age, and overall health have also been reported to influence their susceptibility to infection (Lawal *et al*., 2019; Parsa *et al*., 2023).

Haemoparasitic infections in pigeons present various clinical signs, including lethargy, decreased appetite, weakness, and anaemia (Ehsani-Amrei *et al*., 2022). Birds infected with haemoparasites may display reduced activity and grooming, and in severe cases, they might exhibit difficulty in breathing and neurological symptoms (Villalva-Pasillas *et al*., 2020; Pendl *et al*., 2022; Martín-Maldonado *et al*., 2023).

Preventing and controlling haemoparasitic infections in pigeons is essential for maintaining their health and well-being (Salem *et al*., 2022a; Tembe *et al*., 2023). Measures such as minimizing exposure to disease-carrying insects, regular veterinary check-ups, and providing a balanced diet can help strengthen the bird's immune system and reduce the risk of infection (Grace *et al*., 2024).

Understanding the occurrence and risk factors associated with haemoparasites in pigeons is of paramount importance for several reasons, including but not limited to the fact that pigeon breeding is a growing industry in Nigeria and offers significant economic opportunities (Scaglione *et al*., 2015; Lawal *et al*., 2019). Moreover, ensuring the health and welfare of pigeons is an ethical responsibility, especially given the increased interest in pigeon breeding as pets and for recreational purposes (Kastelic *et al*., 2021). The transition of live bird sellers and exotic bird breeders in developing countries to importing exotic pigeons, primarily for ornamental purposes and cross-breeding with local pigeons to enhance their quality, is driven by several factors, including growing demand for aesthetically pleasing avian pets and the potential for increased market value of the exotic breeds of pigeons (Wang *et al*., 2023). However, this shift in the exotic pigeon business presents significant implications for the transmission of trans-boundary infectious diseases to indigenous pigeon breeds and other poultry (Ellakany *et al*., 2019; Mia *et al*., 2022). Importation of exotic birds can introduce novel pathogens including avian haemoparasites, increasing the risk of disease transmission to local pigeon populations, leading to potential outbreaks of infectious diseases that could negatively impact the region's poultry industry (Perez-Sancho *et al*., 2020; Mia *et al*., 2022; Tembe *et al*., 2023). A better understanding of parasitic infections in pigeons can help develop effective management and treatment strategies (Salem *et al*., 2022b). Further, the knowledge will help in designing adequate biosecurity measures, and monitoring of imported birds, which is essential to mitigating these risks and safeguarding the health of indigenous pigeon breeds and the broader poultry sector (Samanta *et al*., 2018; Ismael *et al*., 2021). Haemoparasites that primarily affect pigeons can potentially spill over to other avian species and, in rare cases, humans. (Scaglione *et al*., 2015). Investigating the occurrence and risk factors for haemoparasitism in pigeons can help assess the zoonotic potential of these pathogens and inform measures to protect the health of the public (Mia *et al*., 2022).

While extensive research has been conducted on haemoparasites in domesticated poultry in Nigeria, limited attention has been given to the health status of pigeons, and currently, there is a limited body of research reports on haemoparasites in pigeons, specifically in the context of Maiduguri, Borno State, Nigeria. The present study evaluated the occurrence of haemoparasitic infections among both exotic and indigenous breeds of pigeon (*Columba livia domestica*) populations in Maiduguri Borno State, Nigeria, and the risk factors associated with the infections.

Materials and Methods

Study Area: The study was conducted in Maiduguri, Borno State, Nigeria (Figure 1). Maiduguri is the capital of and largest city in Borno State, Nigeria, which is located in northeastern Nigeria and situated at approximately 11.8451° N latitude and 13.1600° E longitude. Maiduguri occupies a strategic position within the Lake Chad Basin region. With an estimated area of around 50 square kilometres, Maiduguri is a bustling urban centre with a diverse population and a rich cultural heritage. The region has a tropical climate characterized by two distinct seasons - a wet season from April to October and a dry season from November to March. Maiduguri is known for its diverse population and a thriving pet bird trade, making it an ideal location for investigating the occurrence and risk factors for haemoparasite infections in exotic and local pigeon breeds.

Figure 1. Map of Maiduguri, Borno State, Nigeria, showing the study area. [Source: https://www.britannica.com/place/Maiduguri]

Study Design: This study employed a cross-sectional design, which allowed collection of data from a representative sample of exotic and local pigeons in Maiduguri. The data collected included both qualitative and quantitative information on the occurrence of haemoparasites and the associated risk factors.

Sampling Strategy: A multi-stage stratified sampling strategy was used to select the study sample area. Firstly, Maiduguri was divided into several zones based on geographical distribution. Next, live birds markets and households were randomly selected from each zone. Within each selected live birds market or household, all eligible exotic and local pigeons breeds present were included in the study.

Study Participants: Study participants encompassed a diverse array of exotic and local pigeon breeds sourced from live bird markets or households, spanning various ages and sex, with known health statuses or displaying symptoms of infectious diseases. Birds lacking complete origin records were excluded. Blood samples were collected from both apparently healthy and clinically ill pigeons of exotic and indigenous breeds, sourced from live bird markets, pigeon breeder households, and veterinary hospitals, including specific locations such as Monday and Custom markets, GRA, Mairi area, UniMaid staff quarters, UniMaid Veterinary Teaching Hospital, and SASUM Veterinary Hospital.

Sampling Period: Sampling was carried out between January and September 2023, within two seasonal periods that included the dry season (January – April) and rainy season (May – September).

Questionnaire Survey: A structured questionnaire was designed to gather information on various risk factors associated with haemoparasite infections in pigeons. The questionnaire covered topics such as bird specie, age, sex, source of acquisition, housing conditions, feeding practices, and health management. Informed consent was obtained from pigeon vendors or breeders before including their birds in the study. The purpose, procedures, and potential risks of the study were explained, and owners were assured of the confidentiality of their information.

Blood Sample Collection: After obtaining consent from pigeon breeders and sellers to sample their birds, the pigeons slated for blood collection were captured and placed in cages overnight to rest. Early the next morning, they were prepared for blood sample collection. For the blood collection, every apparently healthy pigeon sampled from homes, as well as sick ones from veterinary hospitals, was gently but securely restrained to minimize stress. The amount of blood collected depended on the bird's size and age. Blood was drawn from the brachial vein following the protocols outlined by Cheesbrough (2000) and Rukhsana (2005). A sterile 23-gauge needle and 2 ml syringe were used to collect approximately 0.5 – 1 ml of blood from each pigeon. The collected blood was then dispensed into labeled test tubes containing an anti-coagulant (EDTA). To prevent clotting, the tubes were gently rocked and rolled to ensure thorough mixing of the blood with the anti-coagulant. In cases where blood samples were collected from pigeons in live bird markets, the samples were obtained directly from the severed jugular vein during slaughter. Care was taken to handle the samples carefully to avoid haemolysis or contamination. Additionally, proper documentation procedures were followed to ensure accurate identification of each sample.

Blood Sample Analysis: Blood sample analysis involved microscopic examination of blood smears for the identification of haemoparasites.

Preparation of Blood Smears for Identification of Haemoparasites: Thin blood smear was prepared by placing a drop of blood at the edge of a slide which was pre-cleaned with alcohol, and a second slide was applied on top at an angle of 45° such that the blood running at the edge will touch the first. The slide was then pulled away along the first slide towards the opposite edges producing thin film of blood which reduced the thickness and increased the distance of the initial drop as described by Mello *et al*. (2014) and World Health Organization (WHO) (2016). Thin smears were made from each blood sample in duplicates on two different slides and were left for few minutes to air dry and then labeled appropriately. The slides were then fixed with methanol for five minutes, allowed to air dry, packaged and then transported to the University of Maiduguri Veterinary Teaching Hospital Research Laboratory, for staining with diluted 10% Giemsa stain according to the standard procedures described by Ribeiro *et al.* (2005) and Zajac and Conboy (2012). The slides were later viewed at low magnification (× 40) and at high magnification (× 100) using the light microscope under oil immersion for the presence of intracellular blood parasites and their gametocytes as previously described by Valkiûnas (2005), Valkiûnas *et al*. (2008) and Akinpelu (2008). Identification of parasites was based on their morphology, height and the pigmentation of endo-erythrocytic forms such as the halter-shaped appearance and presence of gametocyte within the erythrocytes in *Haemoproteus*, and the red-stained microgametocyte in *Leucocytozoon* as well as presence of merogony in erythrocytes and round to oval schizonts or deeply staining merozoites in *Plasmodium*. Photomicrographs were taken using a digital camera 20.1 MP (Sony, Tokyo, Japan DSC-W800/B *20 Megapixel*) and the printed copies were compared to standard plates (Taylor *et al*., 2007).

Buffy Coat Smear Preparation and Examination: For the microscopic detection of extracellular blood borne parasites, each blood sample was collected into heparinized micro-hematocrit capillary tube and centrifuged at 1,500 g for 5 minutes so as to concentrate the organisms in the buffy coat. The micro-hematocrit tube was cut just below the buffy coat above the packed RBCs, and the buffy coat was expressed from the cut end with a small amount of plasma to make a suspension, and then a thin smear was made on a clean dry glass slide, and allowed to air dry, then fixed with 70% methanol and allowed to air-dry for 5 minutes, labeled accordingly and stained with Giemsa stain for 45 minutes. The stained buffy coat smears on slides were later viewed at low magnification (× 40) and at high magnification (× 100) using the light microscope under oil immersion for the presence of extracellular blood parasites as previously described by Valkiûnas (2005) and Valkiûnas *et al*. (2008). Photomicrographs were then taken using digital camera 20.1 MP (Sony, Tokyo, Japan, DSC-W800/B *20 Megapixel*) for comparison with reference plates and keys.

Data Analysis: Statistical analysis of quantitative data generated in the study was performed using GraphPad Prism software (GraphPad Inc., San Diego, CA). Frequencies of occurrence were calculated. Chi-square or Fisher's exact tests was used to compare the proportions obtained for the presence or absence of infection according to age, sex, breed, season, health status and the study location, and differences were considered significant at $p < 0.05$. Descriptive statistics, in the form of frequencies and percentage, were also used to summarize the data generated from the questionnaire survey.

Results

A total of 300 blood samples were collected from the pigeons. Among these 300 samples, 63 pigeons were identified as being infected with one or more avian haemoparasites, giving an overall occurrence of 21.0% (Table 1). Pigeons sampled from veterinary hospitals exhibited the highest occurrence of infection (37%), followed by pigeons from households (15%), and then pigeons from live bird markets (11%) [Table 1].

Four different species of avian haemoparasites, namely *Haemoproteus* spp., *Plasmodium* spp., *Leucocytozoon* spp., and *Microfilariae* spp., were identified either as single infection or in mixed combinations (Figures 2, 3, 4 and 5), each with varying infection rates among the infected pigeons. The haemoparasite with the highest frequency of occurrence was *Haemoproteus spp*. (10.3%), followed by *Plasmodium* spp. (5.0%), then a combination of *Haemoproteus* spp. and *Plasmodium* spp. (3.0%), *Leucocytozoon* spp (1.7%) and lastly, *Microfilaria*e spp (1.0%) [Table 2].

Out of the 100 blood samples collected from pigeons at selected live bird markets, 11 (11.0%) were found to be infected with haemoparasites (Table 2). Further on the blood samples collected at the live bird markets, the most frequently encountered haemoparasite was *Haemoproteus* spp. (6.0%), followed by *Plasmodium* spp. (3.0%) and mixed *Haemoproteus* spp. + *Plasmodium* spp. infection (2.0%). Fifteen out of the 100 (15.0%) pigeon blood samples collected from households were found to be infected with haemoparasites (Table 2). *Haemoproteus* spp. (8.0%) was also the most frequently encountered haemoparasite in samples collected from households, followed by mixed *Haemoproteus* spp. + *Plasmodium* spp. co-infection (3.0%), *Plasmodium* spp. (2.0%), and *Leucocytozoon* spp. (2.0%) (Table 2). For samples collected from Veterinary Hospitals, out of the 100 blood samples, 37 (37.0%) were found to be infected with haemoparasites (Table 2). Just as was recorded at the live bird markets and households, *Haemoproteus* spp. (17.0%) also was the most frequently encountered haemoparasite, followed by *Plasmodium* spp. (10.0%), then mixed *Haemoproteus* spp. + *Plasmodium* spp. infection (4.0%), *Leucocytozoon* spp. (3.0%), and lastly *Microfilariae* spp. (3.0%) [Table 2].

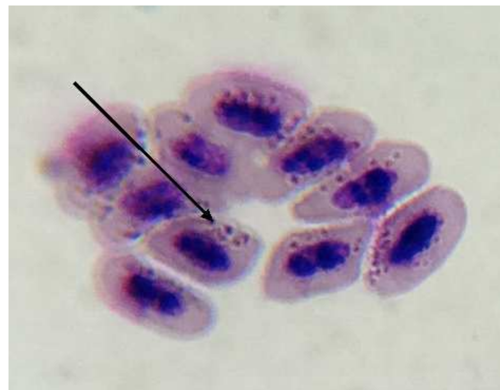

Figure 2: *Plasmodium* specie (black arrow) in stained blood smear of pigeons (*Columba livia domestica*).

Figure 3: *Haemoproteus* spp. (black arrow) in stained blood smear of pigeons (*Columba livia domestica*).

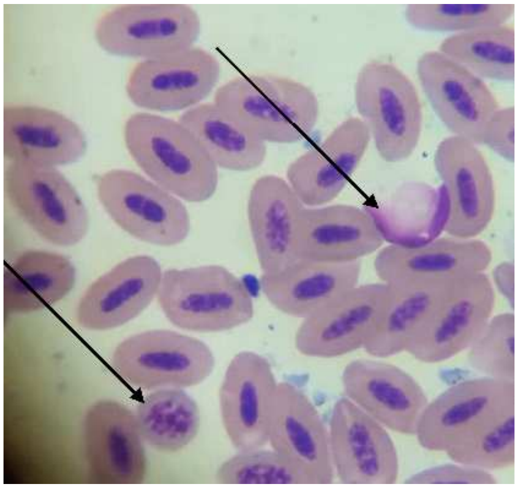

Figure 4: *Leucocytozoon* specie (black arrow) in stained blood smear of pigeons (*Columba livia domestica*).

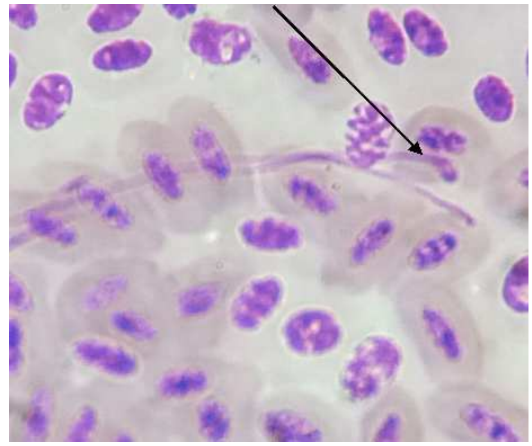

Figure 5: Microfilaria specie (black arrow) in stained blood smear of pigeons (*Columba livia domestica*).

Table 1. Occurrence and distribution of haemosporidian parasites in pigeon (*Columba livia domestica*) populations in Maiduguri, Borno State, Nigeria (n = 300).

Sample origin/ Study location	Study Units	Number of pigeons sampled	Number of pigeons infected (%)
Live birds' markets	Monday	62	9 (14.5%)
	Custom	38	2 (5.3%)
Total for Live bird markets		**100**	**11 (11.0%)**
Households	UniMaid staff Quarters	35	4 (11.4%)
	Mairi area	22	9 (40.9%)
	GRA	43	2 (4.7%)
Total for Households		**100**	**15 (15.0%)**
Veterinary Hospitals	SASUMVH	59	25 (42.4%)
	UMVTH	41	12 (29.3%)
Total for Veterinary Hospitals		**100**	**37 (37.0%)**
Overall		**300**	**63 (21.0%)**

[UniMaid VTH – University of Maiduguri, Veterinary Teaching Hospital; SASUMVH – Senator Ali Modu Sheriff Ultra-Modern Veterinary Hospital; GRA – Government Residential Area]

Table 2. Frequency of occurrence of specific haemoparasites in pigeon (*Columba livia domestica*) populations sampled at various locations in Maiduguri, Borno State, Nigeria.

Study location	Number of pigeons examined	Number of pigeons infected with the various haemoparasites (%).					Occurrence (%)
		HP	PM	HP + PM	LC	MF	
Live Bird Markets	100	6 (6.0%)	3 (3.0%)	2 (2.0%)	0 (0.0%)	0 (0.0%)	11 (11.0%)
Households	100	8 (8.0%)	2 (2.0%)	3 (3.0%)	2 (2.0%)	0 (0.0%)	15 (15.0%)
Veterinary Hospitals	100	17 (17.0%)	10 (10.0%)	4 (4.0%)	3 (3.0%)	3 (3.0%)	37 (37.0%)
Overall	300	31 (10.3%)	15 (5.0%)	9 (3.0%)	5 (1.7%)	3 (1.0%)	63 (21.0%)

[HP – *Haemoproteus* spp.; PM – *Plasmodium* spp.; HP + PM – *Haemoproteus* spp. + *Plasmodium* spp.; LC – *Leucocytozoon* spp.; MF – *Microfilariae* spp.]

Significantly higher (p < 0.0001) number of male pigeons (32.9%) were infected with haemoparasites when compared with females (10.2%) [Table 3]. Juveniles (28.3%) were significantly (p = 0.0028) more infected than the adults (14.2%) [Table 3]. Exotic pigeon breeds (29.3%) had a significantly (p = 0.0004) higher frequency of occurrence than the local breeds (12.7%), and there were significantly (p < 0.0001) higher frequency of haemoparasite infection occurrence in rainy season (34.7%) than in dry season (7.3%) [Table 3]. Pigeons that were not healthy (31.7%) had a significantly (p < 0.0001) higher frequency of occurrence than the apparently healthy ones (11.8%) [Table 3], and extensively reared pigeons (28.0%) had a significantly (p = 0.0004) higher frequency of occurrence than the intensively reared ones (14.0%). Pigeons kept in modern coop/loft (8.7%) had a significantly (p < 0.0001) lower occurrence of haemoparasite infections than those kept in improvised coop/loft (33.3%), and also pigeons kept in coop/loft that had a net (9.8%) had significantly (p < 0.0001) lower haemoparasite occurrence than those kept in coop/loft that had no net (29.9%) [Table 3].

The distribution of the frequency of occurrence of the specific haemoparasites in the pigeons based on sex, age, breed and season is presented in Table 4. For each of the parameters (sex, age, breed and season) and their variables (males or females, juveniles or adults, local or exotic breeds and dry or rainy season), *Haemoproteus* spp. was the most frequently encountered haemoparasite, followed by *Plasmodium* spp., then a combined infection with *Haemoproteus* + *Plasmodium*, then *Leucocytozoon* and finally *Microfilariae* spp., without any differences in patterns between the variables (Table 4). This same pattern of distribution was recorded for the occurrence of the specific haemoparasites based on health status (apparently healthy or not healthy), husbandry system (intensive or extensive), type of pigeon coop/loft (modern or improvised) and quality of netting of pigeon coop/loft (adequate or inadequate), with *Haemoproteus* spp. being the most frequently encountered haemoparasite, followed by *Plasmodium* spp., then a combined infection with *Haemoproteus* + *Plasmodium*, *Leucocytozoon* and finally *Microfilariae* spp., without any differences in patterns between the two variables each time (Table 5).

Out of the 60 respondents surveyed on their awareness of avian haemoparasite infections in pigeons, only 22 (36.7%) indicated that they were aware of the occurrence of haemoparasites in pigeons, while 38 (63.3%) reported that they were not aware (Table 6). Vendors at live bird markets were not aware (0%), and only 20% of pigeon breeders/enthusiasts in households were aware, but 90% of clinicians in veterinary hospitals were aware of the occurrence of haemoparasites in pigeons (Table 6).

Table 3. Distribution of pigeons (*Columba livia domestica*) infected with haemoparasites in Maiduguri, Borno State, Nigeria, based on sex, age, breed, season, health status, husbandry system, and type/adequacy of pigeon coop/loft.

Parameter	Risk factors	No. of pigeons examined	No. of pigeons infected (%)	P -value	RR	OR
Sex	Male	143	47 (32.9%)	< 0.0001	3.225	4.314
	Female	157	16 (10.2%)			
Age (months)	Juvenile (4 – 6 months)	145	41 (28.3%)	0.0028	1.992	2.383
	Adult (> 6 months)	155	22 (14.2%)			
Breed	Local	150	19 (12.7%)	0.0004	0.4318	0.3494
	Exotic	150	44 (29.3%)			
Season	Dry	150	11 (7.3%)	< 0.0001	0.2115	0.1491
	Rainy	150	52 (34.7%)			
Health status	Apparently healthy	161	19 (11.8%)	< 0.0001	0.3728	0.2889
	Not healthy	139	44 (31.7%)			
Husbandry system	Intensive	150	21 (14.0%)	0.0004	0.4318	0.3494
	Extensive	150	42 (28.0%)			
Type of Pigeon coop/loft	Modern	150	13 (8.7%)	< 0.0001	0.2600	0.1898
	Improvised	150	50 (33.3%)			
Pigeon coop/loft with net	Adequate	133	13 (9.8%)	< 0.0001	0.3265	0.2535
	Inadequate	167	50 (29.9%)			

[RR = Relative Risk; OR = Odd Ratio]

Table 4. Distribution of the frequency of occurrence of specific haemoparasites in pigeon (*Columba livia domestica*) populations sampled at Maiduguri, Borno State, Nigeria, based on sex, age, breed and season.

Parameters, with their variables		No. of pigeons examined	Number of pigeons infected with the various haemoparasites (%).					Occurrence (%)
			HP	PM	HP + PM	LC	MF	
Sex	Male	143	22 (15.8%)	11 (7.7%)	7 (4.9%)	4 (2.8%)	3 (2.1%)	47 (32.9%) [a]
	Female	157	9 (5.7%)	4 (2.5%)	2 (1.3%)	1 (0.6%)	0 (0.0%)	16 (10.2%) [b]
Age	Juveniles (4 – 6 months)	145	21 (14.5%)	9 (6.2%)	6 (4.1%)	3 (2.1%)	2 (1.4%)	41 (28.3%) [a]
	Adults (> 6 months)	155	10 (6.5%)	6 (3.9%)	3 (1.9%)	2 (1.3%)	1 (0.6%)	22 (14.2%) [b]
Breed	Local	150	12 (8.0%)	5 (3.3%)	1 (0.7%)	1 (0.7%)	0 (0.0%)	19 (12.7%) [a]
	Exotic	150	19 (12.7%)	10 (6.7%)	8 (5.3%)	4 (2.7%)	3 (2.0%)	44 (29.3%) [b]
Season	Dry	150	5 (3.3%)	3 (2.0%)	3 (2.0%)	0 (0.0%)	0 (0.0%)	11 (7.3%) [a]
	Rainy	150	26 (17.3%)	12 (8.0%)	6 (4.0%)	5 (3.3%)	3 (2.0%)	52 (34.7%) [b]

[a, b] Different superscripts on the variables for each parameter indicates significant ($p < 0.05$) difference in occurrence between the variables.

[HP – *Haemoproteus* spp.; PM – *Plasmodium* spp.; HP + PM – *Haemoproteus* spp. + *Plasmodium* spp.; LC – *Leucocytozoon* spp.; MF – *Microfilariae* spp.]

Discussion

The 21% overall occurrence of haemoparasites in the sampled pigeon population suggests that approximately one-fifth of the pigeons in the study area may be infected with haemoparasites. This overall frequency of occurrence is significant, and suggests that haemosporidian infections are common in pigeons in the study area. The overall frequency of occurrence recorded in this study is lower than the 41.8% reported in domesticated rock doves in a similar study at Gombe State, Nigeria, by Lawal *et al*. (2021a). The overall occurrence recorded in the present study is also lower than 96.6% reported by Nebel *et al*. (2020) in Cape Town South Africa, and 42.0% reported by Schumm *et al*. (2021) in feral and migratory pigeons from various parts of the world. The disparity in the prevalence rates might be due to the different diagnostic tools employed; the latter employed molecular tools, which seem to be more sensitive in the detection of haemoparasites compared to the microscopy employed in the present study. Moreover, results from previous studies suggested that migratory birds have a higher prevalence and diversity of blood parasites than resident or short-distance migratory species (Schumm *et al*., 2021). The recorded occurrence of four avian haemoparasites in pigeons in the present study implies the presence of suitable vectors in the study area and the susceptibility of pigeons to infection.

Table 5. Distribution of the frequency of occurrence of specific haemoparasites in pigeon (*Columba livia domestica*) populations sampled at Maiduguri, Borno State, Nigeria, based on health status, husbandry system, and type/adequacy of pigeon coop/loft.

Parameters, with their variables		No. of pigeons examined	Number of pigeons infected with the various haemoparasites (%).					Occurrence (%)
			HP	PM	HP + PM	LC	MF	
Health status	Apparently healthy	161	11 (6.8%)	4 (2.5%)	2 (1.2%)	2 (1.2%)	0 (0.0%)	19 (11.8%) [a]
	Not healthy	139	20 (14.4%)	11 (7.9%)	7 (5.0%)	3 (2.2%)	3 (2.2%)	44 (31.7%) [b]
Husbandry system	Intensive	150	13 (8.7%)	6 (4.0%)	2 (1.3%)	0 (0.0%)	0 (0.0%)	21 (14.0%) [a]
	Extensive	150	18 (12.0%)	9 (6.0%)	7 (4.7%)	5 (3.3%)	3 (2.0%)	42 (28.0) [b]
Type of Pigeon coop/loft	Modern	150	7 (4.7%)	5 (3.3%)	1 (0.7%)	0 (0.0%)	0 (0.0%)	13 (8.7) [a]
	Improvised	150	24 (16.0%)	10 (6.7%)	8 (5.3%)	5 (3.3%)	3 (2.0%)	50 (33.3) [b]
Pigeon coop/loft with net	Adequate	133	7 (5.3%)	5 (3.8%)	1 (0.8%)	0 (0.0%)	0 (0.0%)	13 (9.8%) [a]
	Inadequate	167	24 (14.4%)	10 (6.0%)	8 (4.8%)	5 (3.0%)	3 (1.8%)	50 (29.9%) [b]

[a, b] Different superscripts on the variables for each parameter indicates significant ($p < 0.05$) difference in occurrence between the variables.

[HP – *Haemoproteus* spp.; PM – *Plasmodium* spp.; HP + PM – *Haemoproteus* spp. + *Plasmodium* spp.; LC – *Leucocytozoon* spp.; MF – *Microfilariae* spp.]

Table 6. Level of awareness on avian haemoparasites amongst pigeon enthusiasts, fanciers, and breeders, live bird vendors and poultry clinicians in Maiduguri, Borno State, Nigeria.

Variables	Response	Number of respondents (%)			Total (%)
		Vendors / Live Bird Markets (n = 20)	Breeders and Enthusiasts / Households (n = 20)	Clinicians / Veterinary Hospitals (n = 20)	
Awareness of blood parasites in pigeons	Aware	0 (0.0%)	4 (20.0%)	18 (90.0%)	22 (36.7%)
	Unaware	20 (100.0%)	16 (80.0%)	2 (10.0%)	38 (63.3%)

χ^2 = Chi – square = 0.8533; p-value = 0.0035

Pigeons sampled from veterinary hospitals had the highest frequency of occurrence, followed by pigeons from households, and then pigeons from live bird markets; this variation in occurrence may be attributed to differences in husbandry practices, exposure to vectors, and the health status of the sampled pigeons. This finding is consistent with previous reports by Adhikari *et al*. (2022), who reported a lower prevalence of parasitic infections in pigeons sampled from households compared to other sampling sites. The higher frequency of occurrence of haemoparasite infections in pigeons sampled from veterinary hospitals in this study may possibly be linked to the immunosuppressive capabilities of haemosporidia parasites. This ability might contribute to making the host more susceptible to additional infections by secondary pathogens (Sol *et al*., 2003). These secondary infections could have prompted the birds to seek medical care at hospitals, where they happened to be sampled for this study. A moderately high frequency of occurrence of haemoparasitosis in pigeons sampled from live bird markets in the present study might be attributed to host interactions in the market scenario where different pigeons from varying regions were observed to be stocked in the same cage as they are presented for sale, and this practice may facilitate parasite transmission.

In terms of distribution of the specific haemoparasite species, *Haemoproteus* spp. had the highest occurrence, followed by *Plasmodium* spp. These two genera are well-known haemoparasites that are commonly found in pigeons, which agrees with the findings of Valkiunas (2005). Other earlier reports have also shown that the most common blood parasite found in pigeons is *Haemoproteus* species (Nebel *et al*., 2020; Lawal *et al*., 2021a). The intensity of *Haemoproteus* spp. infection in *Columbiformes* has been examined in various parts of Nigeria, with significant variations in frequency of occurrence across the different states: Opara *et al*. (2012) reported a high prevalence of 80% in Owerri, while Karamba *et al*. (2012) found a prevalence of 50% in Kano, and Lawal *et al*. (2021a) recorded a prevalence of 14.4% in Gombe State, Nigeria; all higher than what was observed in the current study. Similarly, Alkharigy *et al*. (2018) documented a prevalence of 76.0% in pigeons from Tripoli, Libya, whereas Nebel *et al*. (2020) observed a prevalence of 96.9% in Cape Town, South Africa. *Plasmodium* spp., recorded the second-highest frequency of occurrence in the present study, and this is consistent with the findings of Lawal *et al*. (2021a) in Gombe State, Nigeria. Co-infection of *Haemoproteus* spp. + *Plasmodium* spp. was detected in 3.0% of the pigeons; this was consistent with the reports of Scaglione *et al*. (2015), Lawal *et al*. (2021a), and Bakre *et al*. (2023) of similar co-infection of *Haemoproteus* spp. and *Plasmodium* spp. in feral pigeons and doves. *Leucocytozoon* spp. and *Microfilariae* spp. had lower frequencies of occurrence, suggesting that they are less common in pigeons in the study area. While Win *et al*. (2020) noted the existence of over 100 species of *Leucocytozoon* worldwide, only a few species have been recorded in poultry. The discovery of *Leucocytozoon* spp. in pigeons in the present study is not unexpected. Given that pigeons and chickens are raised together in close proximity in our study area, it is plausible that this co-habitation enables the transmission of haemoparasites between these bird species, especially in the presence of appropriate arthropod vectors. The findings in this present study that *Haemoproteus*, *Plasmodium* and *Leucocytozoon* were the predominant genera of avian haemosporidia infecting pigeons align with earlier reports by Okanga *et al*. (2013), Bakre *et al*. (2023), and Tembe *et al*. (2023). These studies similarly identified *Plasmodium*, *Haemoproteus*, and *Leucocytozoon* as the predominant genera of avian haemosporidia infecting birds. However, this present study is the first in Nigeria where the presence of *Microfilariae* spp. has been documented in domesticated pigeons. Previously, this nematode was reported in birds from the Caribbean slope of Costa Rica by Benedikt *et al*. (2009) and in the Lowveld, South Africa (Pori *et al*., 2023). The vectors involved in filarial nematode transmission are haematophagous arthropods. Microfilariae are sucked up by the vector when it ingests blood from an infected host. The microfilariae then develop into infective larvae in the vector and can in due course be transferred to another host through feeding by the vector (Garrido-Bautista *et al*., 2023). It is possible that the pigeons became infected while scavenging for food.

In the present study, male pigeons exhibited a significantly higher frequency of occurrence, when compared to females, and this is in agreement with earlier reports by Dakheel *et al*. (2022) on domestic and wild pigeons in Iraq. This sex-based variation suggests that there might be biological or behavioral aspects making male pigeons more vulnerable to haemoparasite infections. However, the findings of the present study are contrary to those of Scaglione *et al*. (2015) and Lawal *et al*. (2021a), who reported a higher prevalence in females compared to male doves. Further exploration into these sex-related differences is necessary to grasp the underlying mechanisms. It has been posited that various endogenous and exogenous factors could collectively influence the infection status of both sexes of pigeons regarding these parasites, including the host's hormones and humoral compounds, age, nutritional conditions, behavior, habits, as well as the seasonal and ecological characteristics of the regions (Al-Barwari and Saeed, 2012).

Young pigeons showed a higher frequency of occurrence, compared to adults; and this is in agreement with earlier reports by Atkinson and Samuel (2010) in forest birds in Hawai. This age based differences in occurrence may stem from the immunological status of the pigeons, as younger ones are more susceptible to infections. Young birds, like pigeons, have immune systems that are not as strong as those of adults, making them more prone to parasitic infections, especially haemoparasitosis (Harlin and Wade, 2009). It is believed that as pigeons grow older, their immune systems improve in recognizing and fighting pathogens, leading to a lower occurrence of haemoparasitosis in adults compared to juveniles (Radfar *et al*., 2012). Additionally, differences in behavior between young and adult pigeons, such as feeding habits, roosting places, and interactions with other birds, can affect their exposure to parasites. For example, young pigeons exploring various environments may come across different vectors or reservoirs of haemoparasites, while adults may display more cautious behaviors or have built immunity from previous exposures. The susceptibility of young pigeons to haemoparasitosis is also influenced by their nesting environment and maternal care. If the nesting area is contaminated or if parents carry parasites, young pigeons may contract infections early in life. Maternal antibodies passed from parent to offspring during feeding or through the egg provide temporary protection, but as young pigeons grow and are weaned, this maternal immunity wanes, leaving them more susceptible to parasitic infections (Niewiesk, 2014). These findings stress the importance of implementing age-specific management and control strategies.

Exotic pigeon breeds had a higher frequency of haemoparasite occurrence when compared to local breeds. This breed based variation could be attributed to genetic factors, differences in immune responses, or exposure to specific vectors. Various studies have highlighted different prevalence rates and reasons for variations in parasitic infections among breeds of domesticated birds (Schumm et al., 2021; Das *et al*., 2022; Salem *et al*., 2022b). One explanation is that indigenous breeds may have adapted to infections, rendering them more resistant and robust against infectious diseases compared to exotic breeds (Dakheel *et al*., 2022; Tembe *et al*., 2023). Hence, managing each breed differently might be necessary to mitigate the risk of haemoparasite infections. Despite limited information on breed-specific prevalence rates of haemoparasite infections in pigeons, one significant factor that may have contributed to the higher prevalence among exotic breeds is their potential lack of natural immunity and adaptation to local haemoparasites (Scaglione *et al*., 2015). These exotic breeds may have been introduced from regions with different parasite types, whereas local breeds have evolved over generations, developing more effective immune systems suited to combat endemic haemoparasites. Furthermore, the stressors associated with introducing exotic breeds to new environments (such as changes in climate, diet, and potential exposure to new pathogens) tend to weaken their immune systems, making them more prone to infections (Kastelic *et al*., 2021). In contrast, local breeds, having been raised in the same environment, are better adapted and less stressed, resulting in a lower prevalence of haemoparasite infections (Bakre *et al*., 2023).

Pigeons sampled during the rainy season showed a notably higher frequency of occurrence, when compared to those sampled in the dry season. This observation aligns with the findings of Pori *et al*. (2023), who also noted a greater prevalence of haemoparasites in feral birds during the wet season, attributing this to birds foraging near water bodies where haematozoa vectors breed. However, variations in vector abundance and bird behavior across seasons may also contribute to differences in the seasonal presence of avian haemoparasites. The rainy season is often associated with an increase in the population of arthropod vectors, such as mosquitoes and ticks, known carriers of haemoparasites. These vectors thrive in humid conditions, within stagnant water, which facilitates their life cycle, and parasites tend to have higher survival rates in moist environments, which are more prevalent during the rainy season. Pigeons may consequently encounter haemoparasite infected vectors more frequently during this period, raising the likelihood of haemoparasite transmission, thereby increasing infection risks in pigeons, as noted by Shearer and Ezenwa, (2020) and Salem *et al*. (2022a).

The higher occurrence of haemoparasite infections during the rainy season in this present study may also be linked to the rainy season's impact on bird migration and clustering, particularly pigeons, which tend to congregate in larger groups during this period, thus intensifying the risk of haemoparasite transmission due to increased proximity. In addition, the stress induced by migration or overcrowding may weaken the birds' immune defenses, heightening their susceptibility to infections, while the migration of infected birds to different regions can further facilitate the dissemination of haemoparasites within the pigeon population, as reported by Emmenegger *et al*. (2018). The finding in the present study of higher occurrence in rainy season is consistent with the reports of Lawal *et al*. (2021b), who also showed a higher prevalence of haemosporidian parasites during the rainy season in birds in Gombe State, Nigeria, but differs from that of Nath and Bhuiyan (2017), who reported a greater prevalence of haemosporidian parasites in the dry season in Bangladesh. The seasonal variability in prevalence underscores the importance of comprehending the ecology of vectors in the region and the timing of disease control interventions (Mawejje *et al*., 2021; Whittaker *et al*., 2023).

The higher frequency of occurrence recorded in this study in pigeons that were not healthy compared to apparently healthy ones suggests a potential link between haemoparasite infections and clinical illness in pigeons. Sick pigeons may have compromised immune systems due to underlying health issues or stress. A weakened immune system makes pigeons more vulnerable to various infections, including avian haemoparasites (Nebel *et al*., 2020; Salem *et al*., 2022a). Illness-related stress can further suppress their immune response, making it easier for haemoparasites to thrive and cause infections (Mirzaei *et al*., 2020). Additionally, sick pigeons might engage in behaviors that increase their exposure to haemoparasite vectors or sources. For instance, they may become less active and spend more time in areas where parasites or vectors are abundant (Schumm *et al*., 2021; Salem *et al*., 2022b; Martín-Maldonado *et al*., 2023). Moreover, their weakened condition might attract vectors, increasing the likelihood of transmission. It is also possible that some pigeons in the sick group had latent haemoparasite infections that became active or intensified under the stress of illness, contributing to the higher occurrence recorded. Monitoring the health of pigeons and providing targeted treatment for infected individuals could be crucial in reducing disease burden and mortality.

Pigeons raised in a free-range (extensive) system had a significantly higher prevalence of haemoparasites, when compared to those kept in cages (intensive). This difference may be due to the fact that free-range systems expose pigeons to a greater variety of environmental factors and potential carriers of haemoparasites, such as insects or other birds. The finding of the present study agrees with similar reports from previous studies by Radfar *et al*. (2012), Scaglione *et al*. (2015), and Alkharigy *et al*. (2018). In free-range system of husbandry, pigeons have unrestricted outdoor access, increasing their chances of encountering infected vectors. Conversely, caging (intensive system) of husbandry offer more controlled environments, limiting exposure to external factors which reduce their contact with potential haemoparasites infected vectors as noted by Alkharigy *et al*. (2018). Additionally, the social nature of pigeons means they often gather in large flocks, particularly in free-range systems, promoting close contact and potential transmission of haemoparasites. Proper management practices and vector control are crucial in free-range systems to mitigate the risk of haemoparasite infections.

The present study also found that pigeons housed in coops or lofts with open or partially open walls had a higher occurrence of avian haemoparasitosis, when compared to those in fully enclosed coops. The presence of open or partially open structures in coops may facilitate the entry of vectors, increasing the risk of infections. Pigeons in coops with open or partially open walls are likely to be more exposed to external vectors like mosquitoes or other biting insects, which can transmit avian haemoparasites. This finding concur with previous studies by Stuen (2020) and Tembe *et al*. (2023), who have reported that open environments make it easier for vectors to reach pigeons, thus increasing the chances of haemoparasite infection. The environmental conditions associated with open or partially open coops may support the survival and proliferation of haemoparasite vectors. In contrast, closed coops provide a controlled environment less favorable for haemoparasite-carrying vectors, thereby reducing the risk of infection among pigeons.

Results of the assessment of the level of awareness of haemoparasites among pigeon enthusiasts, fanciers, breeders, live bird vendors, and poultry clinician showed that a significant proportion of these individuals lacked awareness about avian haemoparasites and their potential effects on pigeon health. The lack of awareness is worthy of being concerned about, as it suggests that many individuals involved in pigeon rearing and pigeon-related activities do not know and thus may not be implementing proper preventive measures or seeking timely veterinary care for haemoparasite infections. This finding aligns with previous reports by Nebel *et al*. (2020) and Tembe *et al*. (2023), who found that lower levels of awareness were associated with higher prevalence of parasitic diseases in birds.

Conclusions: This study revealed an overall 21.0% frequency of occurrence for haemosporidian infections in pigeons at Maiduguri, Nigeria. *Haemoproteus*, *Plasmodium*, *Leucocytozoon* and *Microfilaria* species were the haemoparasites encountered, with *Haemoproteus* species being the most frequently occurring. Higher frequency of occurrence was recorded in pigeons sampled at veterinary hospitals (relative to those sampled at households and live bird markets). Significant sex, age, breed, seasonal, heath status and husbandry based differences in the frequency of occurrence of the haemoparasites were recorded. The level of awareness of the occurrence of these haemoparasites was generally low, especially in pigeon vendors, breeders and enthusiasts.

Recommendations: A surveillance system to regularly monitor the prevalence of avian haemosporidian infections in both exotic and indigenous pigeon breeds is recommended. Educational campaigns and workshops targeting pigeon enthusiasts, fanciers, breeders, live bird vendors, and poultry clinicians should be conducted. Pigeon breeders should be encouraged to implement biosecurity measures in their facilities to reduce the risk of infection. Routine health checkups for pigeons should be promoted, and strategies for controlling arthropod vectors in pigeon coops/lofts should be advocated and implemented. Collaboration between pigeon breeders, pigeon enthusiasts, and veterinary professionals in sharing information on avian haemosporidian infections and reporting of outbreaks is advocated. Further research on avian haemosporidian infections in pigeons, particularly in different regions of Nigeria is also recommended.

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Competing Interests

The authors declare that they have no competing interests.

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