Journal of
Zoological and Botanical Gardens

MDPI

Article

Gastrointestinal Parasitic Infections in Non-Human Primates at Gabon's Primatology Center: Implications for Zoonotic Diseases

Krista Mapagha-Boundoukou [1,*], Mohamed Hassani Mohamed-Djawad [1,2], Neil Michel Longo-Pendy [1], Patrice Makouloutou-Nzassi [1,3], Félicien Bangueboussa [1], Mourad Ben Said [4,5], Barthélémy Ngoubangoye [3,6] and Larson Boundenga [1,7,*]

1 Health Ecology Research Unit (URES), Interdisciplinary Centre for Medical Research of Franceville (CIRMF), Franceville BP 769, Gabon; mhdjawad2020@gmail.com (M.H.M.-D.); longo2michel@gmail.com (N.M.L.-P.); patmak741@gmail.com (P.M.-N.); bangueboussafelicien040@gmail.com (F.B.)
2 Laboratory of Evolutionary Biology, Ecology and Ecosystem Management, Department of Animal Biology, Faculty of Science and Technology, Cheikh Anta Diop University, Dakar BP 5005, Senegal
3 Department of Animal Biology and Ecology, Tropical Ecology Research Institute (IRET/CENAREST), Libreville BP 13354, Gabon; genistha@hotmail.com
4 Department of Basic Sciences, Higher Institute of Biotechnology of Sidi Thabet, University of Manouba, Manouba 2010, Tunisia; bensaidmourad83@yahoo.fr
5 Laboratory of Microbiology, National School of Veterinary Medicine of Sidi Thabet, University of Manouba, Manouba 2010, Tunisia
6 Primatology Center, Interdisciplinary Centre for Medical Research of Franceville (CIRMF), Franceville BP 769, Gabon
7 Anthropology Department, University of Durham, South Road, Durham DH1 3LE, UK
* Correspondence: mapaghakrista@gmail.com (K.M.-B.); boundenga@gmail.com (L.B.)

Citation: Mapagha-Boundoukou, K.; Mohamed-Djawad, M.H.; Longo-Pendy, N.M.; Makouloutou-Nzassi, P.; Bangueboussa, F.; Ben Said, M.; Ngoubangoye, B.; Boundenga, L. Gastrointestinal Parasitic Infections in Non-Human Primates at Gabon's Primatology Center: Implications for Zoonotic Diseases. *J. Zool. Bot. Gard.* **2024**, *5*, 733–744. https://doi.org/10.3390/jzbg5040048

Academic Editor: Mariana Stancheva Panayotova-Pencheva

Received: 18 September 2024
Revised: 7 November 2024
Accepted: 13 November 2024
Published: 19 November 2024

Abstract: Parasites and infectious diseases pose significant threats to primate populations, especially in captive non-human primates (NHPs). This study aimed to assess the diversity and prevalence of intestinal parasites in NHPs at the CIRMF Primatology Center. A total of 97 fecal samples were analyzed using parasitological techniques, including sodium chloride flotation and modified Baermann sedimentation methods. An overall parasite prevalence of 93.81% (91/97) was observed. Sixteen groups of parasites with zoonotic potential were identified, comprising ten genera of nematodes (*Trichuris*, *Enterobius*, Hookworm, *Trichostrongylus*, *Mammomonogamus*, Spirure, *Oesophagostomum*, *Schistosoma*, *Ascaris*, and *Strongyloides*), three genera of protists (*Eimeria*, *Balantioides coli/Buxtonella*, and *Entamoeba*), one genus of cestodes (*Hymenolepis*), and two genera of trematodes (*Dicrocoelium* and *Paramphistomum*). High prevalences were noted for *Oesophagostomum* spp. (83.5%), *Strongyloides* spp. (52.58%), and *Trichostrongylus* spp. (50.52%). These findings underscore the potential role of the CIRMF Primatology Center in maintaining and facilitating the transmission of intestinal parasites with high zoonotic potential. The co-existence of human and NHP parasites in shared environments, such as zoos and research facilities, emphasizes the need for a holistic, One Health approach that addresses the interconnected health of humans, animals, and the environment. This study highlights the urgent need for collaborative strategies to mitigate the risks of zoonotic parasite transmission between NHPs and humans in captive settings.

Keywords: non-human primates; gastrointestinal parasites; prevalence; zoonotic diseases; CIRMF primatology center; one health approach

1. Introduction

Parasitic diseases pose a significant global health challenge [1–4]. Approximately 1.5 billion people are infected with intestinal parasites annually, leading to approximately 135,000 deaths [5]. This statistic highlights the critical need to address parasitic infections from both human and zoonotic perspectives. The close genetic similarity between humans

and great apes, coupled with increased interactions through activities such as hunting, agriculture, logging, ecotourism, urbanization, and the domestication of non-human primates (NHPs) significantly elevates the risk of cross-species transmission of parasites [6–8].

Great apes infected with intestinal parasites not only face serious health issues like malnutrition, anemia, and secondary infections but also represent a threat to human populations [1,9]. These health impairments directly affect their survival and reproductive success, exacerbating the conservation challenges faced by already endangered great ape populations [10,11]. In settings like the Primatology Center, where humans and various NHPs species interact closely, the risk of pathogen exchange is significantly heightened [12], unlike in the wild where natural barriers reduce such interactions [13].

The Primatology Center of the Interdisciplinary Center for Medical Research in Franceville (CIRMF) and Gabonese sanctuaries are dedicated to the care and rehabilitation of orphaned NHPs and those rescued from illegal private ownership [14–16]. A dedicated team of caretakers, veterinarians, and nurses work tirelessly to ensure the proper nutrition and overall welfare of these animals. Despite these efforts, NHPs at the center remain susceptible to a range of infections, including viral, fungal, bacterial, and parasitic diseases [17–21]. Among these, gastrointestinal parasites (GIPs) are particularly prevalent posing significant health risks such as growth retardation, gastrointestinal disorders, abortions, and neurological problems [22,23].

While the establishment of protected areas, sanctuaries, and primatology centers are essentials for NHP conservation [24,25], these confined environments also facilitate the zoonotic and anthropozoonotic transmission of pathogens [1,26–28]. The SARS-CoV-2 pandemic serves as a stark reminder of the risks posed by close human–animal interactions. Given the ongoing decline in great ape population [29], the CIRMF Primatology Center plays a critical role in understanding the impact of gastrointestinal parasites on NHP health and their conservation. This study aims to assess the diversity of intestinal parasites at the center, highlighting their potential effects on both primate and human health. By doing so, it seeks to provide valuable insights that can inform and improve conservation efforts, ultimately contributing to the long-term survival of these endangered species.

2. Materials and Methods

2.1. Study Site and Sample Collection

This study was conducted at the Primatology Center of CIRMF, located in southeastern Gabon (Figure 1). The center features enclosures with natural ground for free-ranging animals as well as aviaries with cemented floors. Sampling collection took place between February to April 2023, from 9 a.m to 1 p.m. A total of approximately 97 fecal samples were collected from five (5) primate species. Table 1 shows the distribution of the NHP species sampled, their characteristics, and status under the International Union for Conservation of Nature (UICN).

Figure 1. Location of the primatology center.

Table 1. Distribution of the population according to each sampled monkey species.

Common Name	Species	Habitat	Male	Female	UICN Status	Protection Status in Gabon	Total
Macaque	*Macaca rhesus*	aviary	7	3	last concern 2015	-	10
Nictitans	*Cercopithecus nictitans*	aviary	1	3	endangered 2020	-	4
Chimpanzee	*Pan t. troglodytes*	aviary	14	11	endangered 2016	fully protected	25
Mandrill	*Mandrillus sphinx*	enclosure	20	20	vulnerable 2016	fully protected	40
Solatus	*Allochrocebus solatus*	enclosure	2	16	near threatened 2019	fully protected	18
Total			44	53			97

To ensure the precise and uncontaminated fecal collection from NHPs, animals were sequentially captured in the feeding zone. Each individual was identified by their tattoo or ear tag. Fecal samples were collected immediately after defecation, avoiding ground contact, and placed in labeled coprology containers indicating species, sex, and collection date. Samples were either analyzed on the same day or stored at room temperature for a later analysis within 48 h. A microscopic examination of eggs and cysts was conducted using a Leica DM2000 LED microscope equipped with a Leica DFC450 digital camera for image capture.

2.2. Microscopic Analysis

Fecal samples were processed immediately using flotation and sedimentation methods as previously described [30,31]. An average of 2 g of fecal matter was used. This amount was added to a saline solution, the concentration of which varied according to flotation or sedimentation (40% and 9%, respectively). The staining step with bromothymol was omitted to enhance the visualization of parasite eggs and oocysts. Larval forms were extracted using the Baermann method. Parasite identification was based on morphological characteristics, color, and content, following the guidelines of [32,33]. In this study, to differentiate between *Necator* and *Ancylostoma* eggs, we focused on the biological behavior of the eggs. Notably, *Ancylostoma* eggs typically hatch within 24 h post-emission [34,35]. Thus, any eggs identified 48 h after collection were classified as *Necator* spp. However, as this distinction is still uncertain, we decided to refer to the worms *Ancylostoma* and *Necator* as 'hookworms'. Although larval forms belonging to the *Strongyloides* and Enterobius genera have been observed, it was not possible to identify the corresponding species precisely. To assess the parasitic load, the protocol by [36] was followed, using 2 g of fecal matter. The calculation of the parasitic load was calculated using the following formula:

EPG = (Total number of eggs counted/Number of grids counted) × (Total volume (mL)/Examined volume (mL) × 50 (Dilution factor).

2.3. Statistical Analysis

The data for this study were analyzed using R software (version 4.3.0). The prevalence of a given parasite was calculated as the ratio of the number of individuals positive for that parasite to the total number of individuals examined. To compare the prevalence of parasitic infections among different primate taxa, we employed the Kruskal–Wallis test, which is suitable for non-parametric continuous data. This test allowed us to determine if there were significant differences in infection rates between groups. Additionally, Fisher's exact test was applied to compare the number of infected and uninfected animals, providing a robust assessment of the impact of infections within various populations. The Shannon diversity index (H) and equitability (E) were also calculated to evaluate the parasitic diversity within the taxa, offering insights into the richness and evenness of the present parasitic species. Finally, a linear regression model was utilized to examine the influences of taxon, habitat, and sex on parasitic load, thereby identifying significant factors contributing to the variations in parasitic infections.

3. Results

3.1. Diversity and Distribution of Parasite Genera in Non-Human Primates at the CIRMF Primatology Center

This study identified 3 protists and 13 helminths in 5 examined NHP species (Figure 2 and Figure S1). All NHPs were infected with four common helminths: *Trichuris*, *Oesophagostomum*, *Trichostrongylus*, and *Strongyloides*. The distribution of the remaining nine helminths and three protists was as follows: Hookworm found in chimpanzee, macaque, mandrill, and solatus; *Schistosoma* in mandrill; *Mammomonogamus* in chimpanzee and mandrill; *Spirura* in macaque, mandrill, and solatus; *Enterobius* in chimpanzee, mandrill, and nictitans; *Hymenolepis* in solatus; *Dicrocoelium* in sacaque and solatus; *Paramphistomum* in solatus; *Balantioides coli*/*Buxtonella* in chimpanzee, macaque, mandrill, and solatus; *Eimeria* in mandrill; and *Entamoeba* in chimpanzee.

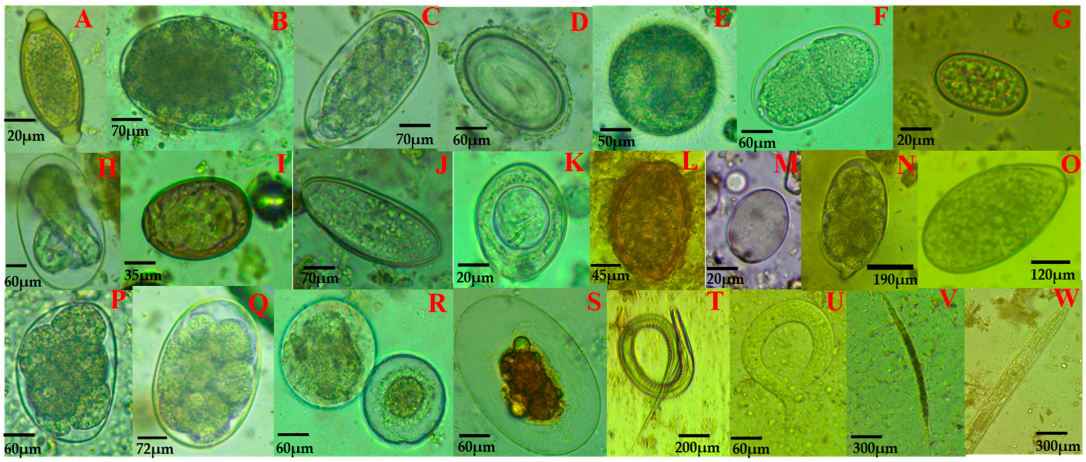

Figure 2. Parasitic structures identified in the feces of NHPs at the CIRMF Primatology Center (**A**), *Trichuris* sp. (**B**,**T**), *Oesophagostomum* sp. (**C**), *Trichostrongylus* sp. (**D**), Spirure (**E**), *Balantioides coli/Buxtonella* sp. (**F**), *Mammomonogamus* sp. (**G**), *Eimeria* sp. (**H**,**W**), *Strongyloides* sp. (**I**), *Dicrocelium* sp. (**J**,**U**), *Enterobius* sp. (**K**), *Hymenolepis* sp. (**L**), *Ascaris* sp. (**M**), *Entamoeba* sp. (**N**), *Schistosoma* sp. (**O**), *Paramphistomum* sp. (**P**,**V**,**Q**), Hookworm (**R**,**S**), unidentified eggs.

For all the parasites, species diversity, as reflected by Shannon's diversity index and equitability, indicated high parasite species diversity across all NHP species. However, the highest diversity (Shannon Index) and equitability were recorded in mandrills (H:2.92; E:1.81), followed by solatus (H:2.89; E:1.80), chimpanzee (H:2.47; E:1.53), and macaques (H:2.46; E:1.53) (Figure 3).

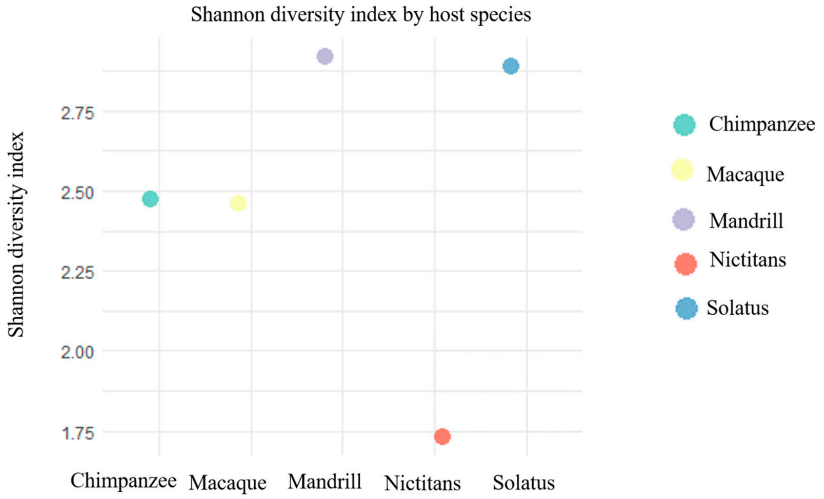

Figure 3. Shannon diversity index by host species.

3.2. Prevalence of Parasites in NHPs at CIRMF Primatology Center

The analysis of samples collected from non-human primates at the Primatology Center of CIRMF revealed an overall parasitic infection prevalence of 93.81%, providing an overview of the parasitic status within the studied population. The analysis of parasite prevalence revealed significant variations among different primate species, including chimpanzees, macaques, mandrills, nictitans, and solatus. In terms of overall prevalence, mandrills exhibited the highest rate (97.5%), followed by chimpanzees (96%), solatus (100%), nictitans (75%), and macaques (70%) (Table 2).

Table 2. Prevalence of parasite by host species.

Groups	Taxa	Chimpanzee	Macaque	Mandrill	Nictitans	Solatus	Means
Nematoda	*Trichuris* sp.	16	20	7.50	25	33.33	16.49
	Oesophagostomum sp.	88	50	90	50	88.89	83.50
	Trichostrongylus sp.	60	20	60	25	38.89	50.52
	Hookworm	33.33	20	32.5	0	24	29.03
	Schistosoma spp.	0	0	5	0	0	2.06
	Mammomonogamus sp.	4	0	2.5	0	0	2.06
	Strongyloides sp.	56	30	65	25	38.89	52.58
	Ascaris sp.	0	0	2.5	0	0	1.03
	Spirure	0	20	22.5	0	5.56	12.37
	Enterobius sp.	16	0	10.26	25	0	9.37
Cestoda	*Hymenolepis* sp.	0	0	0	0	11.11	2.06
Trematoda	*Dicrocelium* sp.	0	10	0	0	11.11	3.09
	Paramphistomum sp.	0	0	0	0	5.56	1.03
Protist	*Balantioides coli/Buxtonella* sp.	68	10	42.5	0	11.11	38.14
	Eimeria sp.	0	0	7.5	0	0	3.09
	Entamoeba sp.	8	0	0	0	0	2.06
Percentage (%) of animals with at least one parasite		96	70	97.5	75	100	-
p-value (Kruskal–Wallis)		0.406					

Upon closer examination, we also assessed the prevalence of each parasite species within each taxon (Table 2). Chimpanzees are distinguished by a particularly high prevalence of *Oesophagostomum* (88%) and *Balantioides coli/Buxtonella* (68%), indicating significant exposure to these parasites. In contrast, macaques show moderate prevalence levels for several parasites, including *Strongyloides* (30%) and Hookworm (20%). Mandrills also display high prevalence rates, particularly for *Oesophagostomum* (90%) and *Trichostrongylus* (60%). Nictitans exhibit varied prevalence, peaking at 25% for *Trichuris*. Finally, solatus are characterized by a notable prevalence of *Oesophagostomum* (88.89%) and *Strongyloides* (38.89%) (Table 2).

To identify the most prevalent parasite at the primatology center, we calculated the prevalence of each parasitic species in our study population sample without the distinction of taxon. *Oesophagostomum* spp. emerged as the most widespread parasite, infecting 83.51% of individuals. Other parasites, such as *Strongyloides* spp. (52.58%), *Trichostrongylus* spp. (50.52%), and *Balantioides coli/Buxtonella* (38.14%), were also detected at significant levels. Conversely, certain parasites, such as *Ascaris* spp. (1.03%) and *Mammomonogamus* spp. (2.06%), exhibited relatively low infection rates (Figure 4).

The following table illustrates the impact of gender, habitat, and host species on the degree of parasitism. The statistical analysis revealed no statistically significant differences ($p > 0.05$) in parasite infestation levels in relation to the factors under investigation. The infestation rate of females was similar to that of males (0.409), irrespective of habitat ($p = 0.082$) or host species ($p = 0.406$). The proportion of infected animals ranged from 70% to 100%, with the macaque group exhibiting the lowest level of infestation (50%), whereas all solatus were infected with at least one parasite (Table 3).

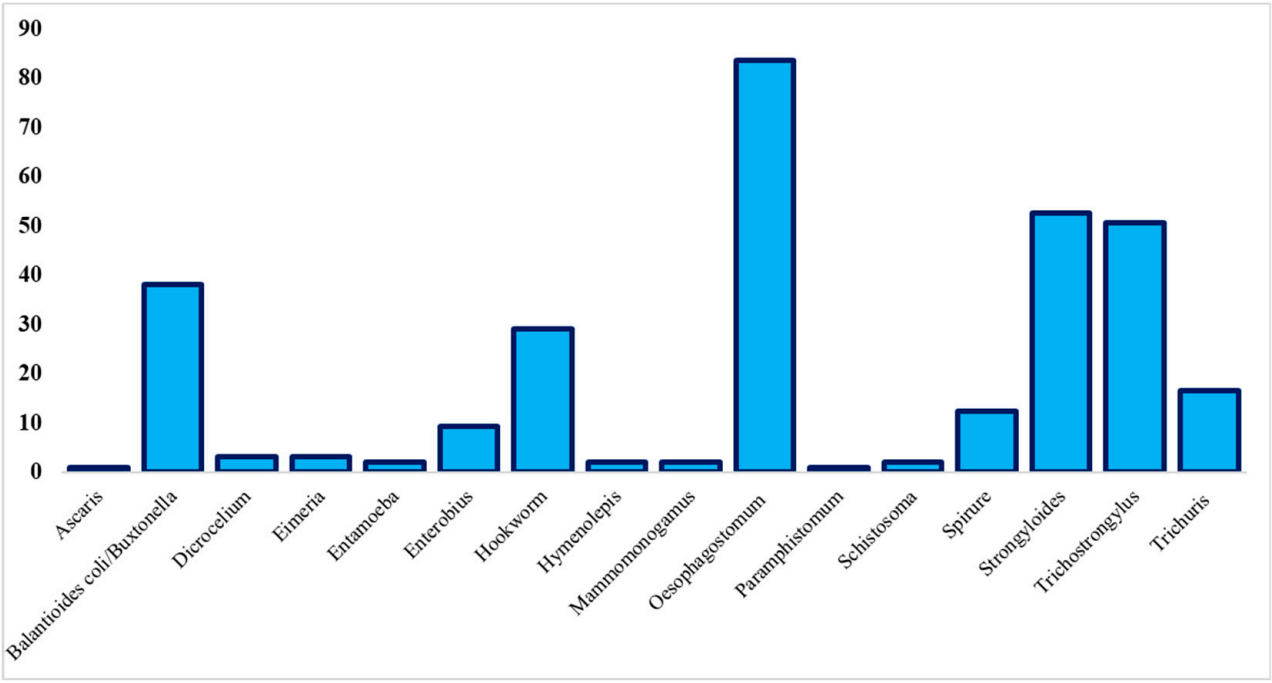

Figure 4. Prevalence of each parasite genera.

Table 3. Impact of gender and habitat factors on parasitism levels.

Factors	Classes	Sample (N)	Infected	Prevalence Rate (% ± Standard Deviation)	Df	*p*-Value
Living farm	Enclosure	57	56	98.25 ± 0.70	1	0.082
	Aviary	40	35	87.5 ± 3.54		
Sex	Male	44	41	93.18 ± 2.12	1	0.4096
	Female	53	50	94.33 ± 2.12		
Hosts	Chimpanzee	25	24	96 ± 0.70	4	0.406
	Macaque	10	7	70 ± 2.12		
	Mandrill	40	39	97.5		
	Nictitans	4	3	75 ± 0.70		
	Solatus	18	18	100		

3.3. Influence of Analyzed Variables on Parasite Load

The analysis of the linear regression model revealed significant influences of taxon and habitat on parasitic load.

The results indicate that mandrills and solatus exhibit significantly higher parasitic loads compared to chimpanzees, which serve as the reference group (Figure 5). Specifically, mandrills show a coefficient of 2510.2 (p = 0.00698), while solatus have a coefficient of 2139.9 (p = 0.02517). These findings suggest that these two taxa are more vulnerable to parasitic infections. Conversely, macaques display a significantly lower parasitic load, with a coefficient of −741.7 (p = 0.02851).

Regarding habitat, primates living in aviaries also demonstrate a high parasitic load, with a coefficient of 2882.6 (p = 0.00198). In contrast, the analysis did not reveal a significant effect of sex on parasitic load, as indicated by the coefficient of −322.4 (p = 0.10323) for males compared to females.

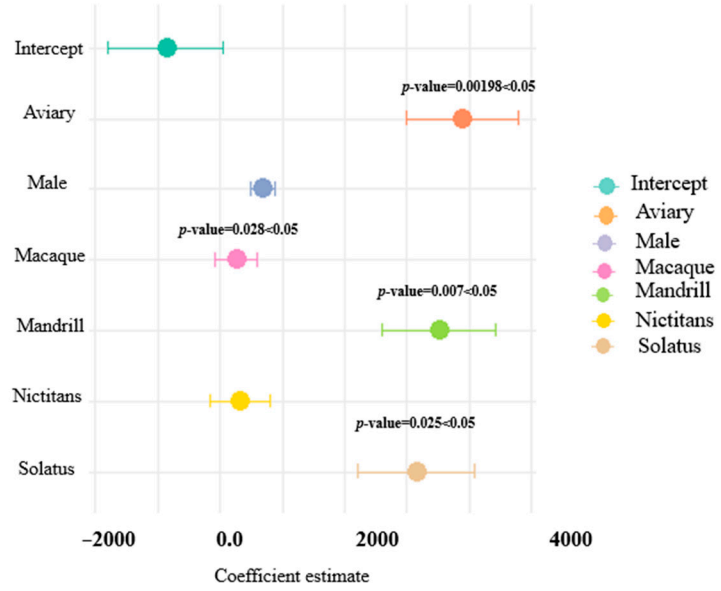

Figure 5. Influence of variables (hosts, sex, and species) on parasite load.

4. Discussion

Primatology centers are crucial for the understanding of parasite exchange dynamics, especially the transmission of parasites between primates and humans due to frequent interactions [27,37]. Our study aimed to elucidate the diversity of intestinal parasites in captive NHPs at CIRMF's Primatology Center. In the present study, we found a global parasite infestation prevalence of 93,81% (91/97) among the studied primates, which is notably higher than previous captive NHPs studied in Africa (67% to 76.2%) [18,38,39] and Asia (89.6%) [40]. This discrepancy may be attributed to a nearly two-year lapse in deworming at the CDP due to limited resources. This high prevalence highlights the increased susceptibility of NHPs to gastrointestinal parasites and remains consistent with the report, which reports a prevalence ranging from 22 to 100% in NHPs [15].

Our coprological analyses identified a total of 16 parasitic taxa infecting NHPs. The diversity of parasites observed varied across studies, largely due to the significant influence of environmental conditions on the dynamics of gastrointestinal parasites, as previously documented in the literature [15,41–43]. Since environmental factors differ from one location to another, they can substantially affect parasite diversity. Among the taxa identified in this study, some species belonging to *Oesophagostomum*, *Enterobius*, *Ascaris*, *Trichostrongylus*, *Strongyloides*, and hookworms are particularly known for their high zoonotic potential. Species of these genera have been implicated in bidirectional transmission in environments shared by NHPs and humans [44–46]. However, a reliance on microscopic analysis alone limits the ability to ensure accurate identification down to the species level. A notable instance is *Enterobius anthropopitheci*, the primary parasite of the *Enterobius* genus found in the chimpanzees [47]. This parasite is closely related to *Enterobius vermicularis* with which it shares similar morphological characteristics [48]. Documented instances of co-infection between these two species have been observed in environments where humans and primates coexist [49]. In light of this complexity, the utilization of molecular tools is imperative. These advanced techniques are of great importance for resolving the identification ambiguities associated with cryptic species and for gaining deeper insights into the dynamics of infection in areas of human–primate interaction. This finding underscores the need for rigorous feeding protocols to minimize pathogen exchange risks. Additionally, NHPs may act as reservoirs for human-infecting parasites, indicating that primatology centers could be sources of parasitic infections that pose significant health risks, particularly to young children [50].

The most prevalent parasitic genera identified were *Oesophagostomum* (83.5%), *Strongyloides* (52.58%), *Trichostrongylus* (50.52%), *Balantioides coli/Buxtonella* (38.14%), Hookworm (29. 03%), and *Trichuris* (16.49%). These findings are consistent with studies in sub-Saharan Africa, which often reported helminth infections as the most common among the NHP population [33,51,52]. The high prevalence of *Oesophagostomum* may be due to its low immunogenicity, allowing the effective colonization of host environments. Additionally, the promiscuity and reuse of the same soil in captive and semi-captive settings can facilitate the spread of intestinal parasites [12,18]. Nematodes from the *Oesophagostomum* genus are known to cause severe diseases in primates, including granulomas, caseous lesions, and abscesses in the intestinal wall, with some NHPs potentially acting as reservoirs for human oesophagostomosis [53].

The highest diversity and load of intestinal parasites were observed in mandrills, chimpanzees, and solatus, likely due to their direct contact with natural soil, which harbors a wider variety of parasites. Natural soil serves as a reservoir for infectious forms of intestinal parasites, promoting multi-parasitism in these animals [22,53,54]. Our study found similar infection rates in males and females, regardless of habitat or species, consistent with the findings of Eke et al. [55]. The absence of significant differences between sexes may be due to the communal living conditions of NHPs, where both males and females experience the same level of parasite exposure, as shown in other studies [55,56]. Differences in parasite infestation rates between sexes in NHPs are often associated with differences in home range and foraging behaviors. At our center, both sexes are housed together and receive equal food from caretakers [57,58]. Our results also show that individuals living in aviaries (cemented floor) had a much higher parasite burden than those living in pens (natural floor). Our observations are similar to those of Opeyemi et al. [59]. on helminth infections in captive birds, confirming the risks associated with aviary habitats. This finding may be explained by the fact that natural floors, in contrast to cemented ones, possess a capacity for self-regulation of parasite populations [59].

The potential for cross-species transmission, especially in captive settings with close contact between humans and NHPs, is a serious concern [18,60–63]. This issue would not only jeopardize the health of both primates and humans but also impacts the conservation of NHP populations. It is imperative to consider animal, human, and environmental factors to improve illness prevention at this interface. Effective measures should include improved hygiene, sanitation, and veterinary care.

The One Health approach is crucial to effectively addressing concerns related to intestinal parasites. This framework integrates efforts across human, animal, and environmental sectors, enhancing surveillance, improving environmental management, and fostering collaboration among stakeholders [6]. By recognizing the interconnectedness of these health domains, the One Health approach is essential for improving health outcomes and promoting sustainable coexistence between humans and NHPs. This holistic perspective is essential for combating intestinal parasites and advancing public health and conservation efforts.

5. Conclusions

The findings of this study highlight a significant risk of zoonotic disease transmission associated with the presence of gastrointestinal parasites in primatology centers in Gabon. The high prevalence and diversity of these parasites among non-human primates (NHPs) highlight the urgent need for enhanced surveillance and robust biosecurity measures. Our findings identified several genera of parasites, including *Strongyloides*, *Oesophagostomum*, Hookworm, and *Enterobius*, which harbor species with zoonotic potential that could present a risk to public health in cohabitation scenarios. Furthermore, these parasites may have a significant impact on the health of NHPs, potentially leading to increased morbidity and susceptibility to other infections. To gain a full understanding of the implications of these findings, further molecular analysis is essential to trace the origins and transmission pathways of these parasites. The close contact between humans and NHPs presents significant

health risks for both groups, reinforcing the necessity of a One Health approach to ensure the safety of all parties. This integrative framework acknowledges the interconnectivity between human, animal, and environmental health, which is essential for the effective management of zoonotic risks. To mitigate these threats, it is essential to implement a systematic monitoring program for potential parasitic infections and to restrict unauthorized contact between visitors and staff with NHP food and water sources. By implementing these preventive measures and adopting a One Health perspective, we can protect the health of both primates and humans, fostering a safer coexistence in shared environments while enhancing our collective capacity to address zoonotic threats comprehensively.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/jzbg5040048/s1, Figure S1: Various forms of larvae of observed gastrointestinal parasites.

Author Contributions: Conceptualization, L.B. and M.B.S.; methodology, K.M.-B.; software, K.M.-B., M.H.M.-D. and N.M.L.-P.; validation, L.B., N.M.L.-P. and P.M.-N.; formal analysis, K.M.-B., F.B. and M.H.M.-D.; investigation, K.M.-B., F.B. and M.H.M.-D.; resources, L.B., K.M.-B. and B.N.; data curation, N.M.L.-P., F.B. and P.M.-N.; writing—original draft preparation, K.M.-B.; writing—review and editing, L.B., P.M.-N., N.M.L.-P., M.H.M.-D. and M.B.S.; visualization, N.M.L.-P., P.M.-N. and MBS; supervision, L.B.; project administration, L.B.; funding acquisition, L.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: This study was approved by the scientific committee of our institute, the Centre Interdisciplinaire de Recherches Medicales de Franceville (CIRMF), in accordance with the ethical principles of animal research. All samples were collected with due regard to animal welfare, and, in this study, all samples were collected with the consent of the animal owners. In addition, animal sampling procedures were evaluated by the Institutional Committee for Animal Use and Care of the National CIRMF.

Data Availability Statement: All data generated or analyzed during this study are included in this published article.

Acknowledgments: We would like to express our gratitude to all members of Primatology center, the interdisciplinary medical research center in Franceville, for their assistance in learning coprological techniques. We would also like to acknowledge the various small ruminant breeders with whom we collaborated, as well as the interdisciplinary medical research center in Franceville for their technical support.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Medkour, H.; Amona, I.; Laidoudi, Y.; Davoust, B.; Bitam, I.; Levasseur, A.; Akiana, J.; Diatta, G.; Pacheco, L.; Gorsane, S.; et al. Parasitic Infections in African Humans and Non-Human Primates. *Pathogens* **2020**, *9*, 561. [CrossRef] [PubMed]
2. Altizer, S.; Nunn, C.L.; Lindenfors, P. Do threatened hosts have fewer parasites? A comparative study in primates. *J. Anim. Ecol.* **2007**, *76*, 304–314. [CrossRef] [PubMed]
3. El Kouni, M.; Chu, C. Purine metabolism in parasites: Potential targets for chemotherapy. In *Recent Advances in Nucleosides: Chemistry and Chemotherapy*; Chu, C.K., Ed.; Elsevier Science: Amsterdam, The Netherlands, 2002; pp. 377–416. [CrossRef]
4. Rondón, S.; Cavallero, S.; Di Filippo, M.M.; De Liberato, C.; Berrilli, F.; Capitani, N.; D'amelio, S. Intestinal parasites infecting captive non-human primates in Italy. *Front. Vet. Sci.* **2024**, *10*, 1270202. [CrossRef]
5. Organisation Mondiale de la Santé. Soil-Transmitted Helminth Infections. 2023. Available online: https://www.who.int/news-room/fact-sheets/detail/soil-transmitted-helminth-infections (accessed on 28 October 2024).
6. Boundenga, L.; Makouloutou-Nzassi, P.; Ngoubangoye, B. A review of Gabonese gorillas and their pathogens: Diversity, transfer and One Health approach to avoid future outbreaks? *Front. Parasitol.* **2023**, *2*, 1115316. [CrossRef]
7. Prugnolle, F.; Rougeron, V.; Becquart, P.; Berry, A.; Makanga, B.; Rahola, N.; Arnathau, C.; Ngoubangoye, B.; Menard, S.; Willaume, E.; et al. Diversity, host switching and evolution of *Plasmodium vivax* infecting African great apes. *Proc. Natl. Acad. Sci. USA* **2013**, *110*, 8123–8128. [CrossRef] [PubMed]
8. Jiang, X.; Fan, Z.; Li, S.; Yin, H. A Review on Zoonotic Pathogens Associated with Non-Human Primates: Understanding the Potential Threats to Humans. *Microorganisms* **2023**, *11*, 246. [CrossRef]

9. Obanda, V.; Maingi, N.; Muchemi, G.; Ng'ang'a, C.J.; Angelone, S.; Archie, E.A. Infection dynamics of gastrointestinal helminths in sympatric non-human primates, livestock and wild ruminants in Kenya. *PLoS ONE* **2019**, *14*, e0217929. [CrossRef]
10. Gillespie, T.R.; Lonsdorf, E.V.; Canfield, E.P.; Meyer, D.J.; Nadler, Y.; Raphael, J.; Pusey, A.E.; Pond, J.; Pauley, J.; Mlengeya, T.; et al. Demographic and ecological effects on patterns of parasitism in eastern chimpanzees (*Pan troglodytes schweinfurthii*) in Gombe National Park, Tanzania. *Am. J. Phys. Anthropol.* **2010**, *143*, 534–544. [CrossRef]
11. Hockings, K.J.; McLennan, M.R.; Carvalho, S.; Ancrenaz, M.; Bobe, R.; Byrne, R.W.; Dunbar, R.I.; Matsuzawa, T.; McGrew, W.C.; Williamson, E.A.; et al. Apes in the Anthropocene: Flexibility and survival. *Trends Ecol. Evol.* **2015**, *30*, 215–222. [CrossRef]
12. Boundenga, L.; Moussadji, C.; Mombo, I.M.; Ngoubangoye, B.; Lekana-Douki, J.B.; Hugot, J.-P. Diversity and prevalence of gastrointestinal parasites in two wild Galago species in Gabon. *Infect. Genet. Evol.* **2018**, *63*, 249–256. [CrossRef]
13. Daszak, P.; Cunningham, A.A.; Hyatt, A.D. Emerging infectious diseases of wildlife—Threats to biodiversity and human health. *Science* **2000**, *287*, 443–449. [CrossRef] [PubMed]
14. Sutherland, C.A.; Dicks, L.V.; Petrovan, S.O.; Smith, R.K. *What Works in Conservation. 2021*; Open Book Publishers: Cambridge, UK, 2020; p. 794.
15. Vonfeld, I.; Prenant, T.; Polack, B.; Guillot, J.; Quintard, B. Gastrointestinal parasites in non-human primates in zoological institutions in France. *Parasite* **2022**, *29*, 43. [CrossRef] [PubMed]
16. Calle, P.; Joslin, J.O. Singes du Nouveau Monde et singes de l'Ancien Monde. In *Fowler's Zoo and Wild Animal Medicine*; Elsevier: Amsterdam, The Netherlands, 2015; Volume 8, pp. 301–335.
17. Andrade, M.C.; Lemos, B.R.; Silva, L.M.; Pecotte, J.K. Eliminating potential effects of other infections during selection of nonhuman primates for COVID-19 research. *Comp. Med.* **2023**, *73*, 45–57. [CrossRef] [PubMed]
18. Boundenga, L.; Ngoubangoye, B.; Moukodoum, N.; Dibakou, S.-E.; Moussadji, C.; Hugot, J.P. Diversity of parasites in two captive chimpanzee populations in southern Gabon. *Infect. Genet. Evol.* **2021**, *91*, 104807. [CrossRef]
19. Ngoubangoye, B.; Boundenga, L.; Arnathau, C.; Mombo, I.M.; Durand, P.; Tsoumbou, T.-A.; Otoro, B.V.; Sana, R.; Okouga, A.-P.; Moukodoum, N.; et al. The host specificity of ape malaria parasites can be broken in confined environments. *Int. J. Parasitol.* **2016**, *46*, 737–744. [CrossRef] [PubMed]
20. Ngoubangoye, B.; Boundenga, L.; Dibakou, S.-E.; Tsoumbou, T.-A.; Kinga, C.M.; Prugnolle, F.; Fouchet, D.; Pontier, D. Surgical treatment of *Oesophagostomum* spp. nodular infection in a chimpanzee at the CIRMF primatology Center, Gabon. *Case Rep. Vet. Med.* **2021**, *2021*, 6617416. [CrossRef]
21. Ngoubangoye, B.; Fouchet, D.; Boundenga, L.A.; Cassan, C.; Arnathau, C.; Meugnier, H.; Tsoumbou, T.-A.; Dibakou, S.E.; Ekore, D.O.; Nguema, Y.O.; et al. *Staphylococcus aureus* host spectrum correlates with methicillin resistance in a multi-species ecosystem. *Microorganisms* **2023**, *11*, 393. [CrossRef]
22. Sirima, C.; Bizet, C.; Hamou, H.; Červená, B.; Lemarcis, T.; Esteban, A.; Peeters, M.; Ngole, E.M.; Mombo, I.M.; Liégeois, F.; et al. Soil-transmitted helminth infections in free-ranging non-human primates from Cameroon and Gabon. *Parasites Vectors* **2021**, *14*, 354. [CrossRef]
23. Nicolas, X.; Chevalier, B.; Simon, F.; Klotz, F. Traitement des parasitoses intestinales (amibiase et mycoses exclues). *Encycl. Méd. Chir.* **2002**, *1*, 1–14.
24. Brent, L. Life-long well being: Applying animal welfare science to nonhuman primates in sanctuaries. *J. Appl. Anim. Welf. Sci.* **2007**, *10*, 55–61. [CrossRef]
25. Feliu, O.; González-Zamora, A.; Riba, D.; Sauquet, T.; Sánchez-López, S.; Maté, C. The impact of sanctuary visits on children's knowledge and attitudes toward primate welfare and conservation. *PeerJ* **2023**, *11*, e15074. [CrossRef] [PubMed]
26. Senghore, M.; Bayliss, S.C.; Kwambana-Adams, B.A.; Foster-Nyarko, E.; Manneh, J.; Dione, M.; Badji, H.; Ebruke, C.; Doughty, E.L.; Thorpe, H.A.; et al. Transmission of *Staphylococcus aureus* from humans to green monkeys in the Gambia as revealed by whole-genome sequencing. *Appl. Environ. Microbiol.* **2016**, *82*, 5910–5917. [CrossRef] [PubMed]
27. Dawet, A.; Yakubu, D.; Butu, H. *Survey of Gastrointestnal Parasite of Non-Human Primates in Jos Zoological Garden*; University of Jos: Jos, Nigeria, 2013. Available online: https://dspace.unijos.edu.ng/jspui/bitstream/123456789/276/1/2167-6801-2-108(1).pdf (accessed on 28 October 2024).
28. Weingartl, H.M.; Embury-Hyatt, C.; Nfon, C.; Leung, A.; Smith, G.; Kobinger, G. Transmission of Ebola virus from pigs to non-human primates. *Sci. Rep.* **2012**, *2*, 811. [CrossRef] [PubMed]
29. Fritz, J. Using analytics to nudge student responsibility for learning. *New Dir. High. Educ.* **2017**, *2017*, 65–75. [CrossRef]
30. Lester, H.; Matthews, J. Faecal worm egg count analysis for targeting anthelmintic treatment in horses: Points to consider. *Equine Vet. J.* **2014**, *46*, 139–145. [CrossRef]
31. Dryden, M.W.; Payne, P.A.; Ridley, R.; Smith, V. Comparison of Common Fecal Flotation Techniques for the Recovery of Parasite Eggs and Oocysts. *Vet. Ther.* **2005**, *6*, 15–28.
32. Huffman, M.A.; Chapman, C.A. (Eds.) *Primate Parasite Ecology: The Dynamics and Study of Host-Parasite Relationships*; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2009.
33. Roland, K.W.Y.; Sylvie, P.; Fidèle, B.K.; Hilaire, B.K. Parasites Gastro-intestinaux des populations humaines du parc national de Taï, Côte d'Ivoire. *Eur. Sci. J.* **2019**, *15*, 27–44. [CrossRef]
34. Soulsby, E.J.L. Helminths, Arthropods and Protozoa of Domesticated Animals. 1968. Available online: https://www.cabidigitallibrary.org/doi/full/10.5555/19682902735 (accessed on 27 October 2024).

35. Hotez, P.J.; Brooker, S.; Bethony, J.M.; Bottazzi, M.E.; Loukas, A.; Xiao, S. Hookworm infection. *N. Engl. J. Med.* **2004**, *351*, 799–807. [CrossRef]
36. Vasconcelos-Nóbrega, C.; Santos, C.; Mega, C.; Coelho, C.; Cruz, R.; Vala, H.; Esteves, F.; Mesquita, J.R. *ABC Series on Diagnostic Parasitology Part 2: The McMaster Method*; MA Healthcare Limited: London, UK, 2017.
37. Adetunji, V. Prevalence of gastro-intestinal parasites in primates and their keepers from two zoological gardens in Ibadan, Nigeria. *Sokoto J. Vet. Sci.* **2014**, *12*, 25–30. [CrossRef]
38. Mbaya, A.; Udendeye, U. Gastrointestinal parasites of captive and free-roaming primates at the Afi Mountain Primate Conservation Area in Calabar, Nigeria and their zoonotic implications. *Pak. J. Biol. Sci.* **2011**, *14*, 709–714. [CrossRef]
39. N'da, K.M.; Dahourou, L.D.; Gbati, O.B.; Alambedji, R.B. Diversity and prevalence of gastrointestinal parasites with zoonotic potential of Green Monkeys in Bandia Reserve in Senegal. *Int. J. One Health* **2021**, *7*, 65–69. [CrossRef]
40. Adrus, M.; Zainuddin, R.; Ahmad Khairi, N.H.; Ahamad, M.; Abdullah, M.T. Helminth parasites occurrence in wild proboscis monkeys (*Nasalis larvatus*), endemic primates to Borneo Island. *J. Med. Primatol.* **2019**, *48*, 357–363. [CrossRef] [PubMed]
41. Mbora, D.N.; McPeek, M.A. Host density and human activities mediate increased parasite prevalence and richness in primates threatened by habitat loss and fragmentation. *J. Anim. Ecol.* **2009**, *78*, 210–218. [CrossRef] [PubMed]
42. Stoner, K.E.; González Di Pierro, A.M. Intestinal parasitic infections in Alouatta pigra in tropical rainforest in Lacandona, Chiapas, Mexico: Implications for behavioral ecology and conservation. In *New Perspectives in the Study of Mesoamerican Primates: Distribution, Ecology, Behavior, and Conservation*; Springer: Berlin/Heidelberg, Germany, 2006; pp. 215–240.
43. Gillespie, T.R.; Nunn, C.L.; Leendertz, F.H. Integrative approaches to the study of primate infectious disease: Implications for biodiversity conservation and global health. *Am. J. Phys. Anthropol.* **2008**, *137*, 53–69. [CrossRef] [PubMed]
44. Ota, N.; Hasegawa, H.; McLennan, M.R.; Kooriyama, T.; Sato, H.; Pebsworth, P.A.; Huffman, M.A. Molecular identification of *Oesophagostomum* spp. from 'village' chimpanzees in Uganda and their phylogenetic relationship with those of other primates. *R. Soc. Open Sci.* **2015**, *2*, 150471. [CrossRef]
45. Laidoudi, Y.; Medkour, H.; Latrofa, M.S.; Davoust, B.; Diatta, G.; Sokhna, C.; Barciela, A.; Hernandez-Aguilar, R.A.; Raoult, D.; Otranto, D.; et al. Zoonotic *Abbreviata caucasica* in Wild Chimpanzees *(Pan troglodytes verus*) from Senegal. *Pathogens* **2020**, *9*, 517. [CrossRef]
46. Nosková, E.; Sambucci, K.M.; Petrželková, K.J.; Červená, B.; Modrý, D.; Pafčo, B. Strongyloides in non-human primates: Significance for public health control. *Philos. Trans. R. Soc. B* **2024**, *379*, 20230006.
47. Hasegawa hideo Modry, D.; Tenora, F.; Vallo, P. Two nez subspecies of *Enterobius* (Nematoda: Oxyuridae) fromthe chimpanzee (*Pan troglodyes*) in equatorial Africa. *J. Parasitol.* **1992**, *78*, 676–684.
48. Hugot, J.-P.; Reinhard, K.J.; Gardner, S.L.; Morand, S. Human enterobiasis in evolution: Origin, specificity and transmission. *Parasite* **1999**, *6*, 201–208. [CrossRef]
49. Ghandour, A.; Zahid, N.; Banaja, A.; Kamal, K.; Bouq, A. Zoonotic intestinal parasites of hamadryas baboons Papio hamadryas in the western and northern regions of Saudi Arabia. *J. Trop. Med. Hyg.* **1995**, *98*, 431–439.
50. Ghislaine, O.D. Prévalence des Parasitoses Intestinales chez Lesenfants de 0 à 5, Dans la Communauté D'anonkoi 3. Ph.D. Thesis, Felix Houphouët Boigny University, Abidjan, Ivory Coast, 2015.
51. Setchell, J.M.; Bedjabaga, I.-B.; Goossens, B.; Reed, P.; Wickings, E.J.; Knapp, L.A. Parasite Prevalence, Abundance, and Diversity in a Semi-free-ranging Colony of Mandrillus sphinx. *Int. J. Primatol.* **2007**, *28*, 1345–1362. [CrossRef]
52. Kouassi, A.F.; Aké-Assi, E.; N'goran, K.S.B.; Ouattara, D.; Tiebré, M.S. Contribution de l'élevage urbain à la sécurité alimentaire: Stratégies d'adaptation des éleveurs de bovins dans le District d'Abidjan, Côte d'Ivoire. *Afr. Sci.* **2019**, *15*, 218–228.
53. Guillot, J.; Vermeulen, B.; Lafosse, S.; Chauffour, S.; Cibot, M.; Narat, V.; Masi, S.; Nieguitsila, A.; Snounou, G.; Bain, O.; et al. Les nématodes du genre Oesophagostomum. Un risque émergent pour l'homme et les grands singes en Afrique? *Bull. L'académie Natl. Méd.* **2011**, *195*, 1955–1963. [CrossRef]
54. Ghai, R.R. *Interactions Between Primates and Parasites in a Wild Community*; McGill University (Canada): Montréal, QC, Canada, 2014.
55. Eke, S.S.; Omalu, I.C.J.; Ochaguba, J.E.; Urama, A.C.; Hassan, S.C.; Otuu, C.A.; Okafor, I.D. Prevalence of gastrointestinal parasites of sheep and goats slaughtered in Minna Modern Abattoir, Niger State, Nigeria. *J. Anim. Sci. Vet. Med.* **2019**, *4*, 65–70. [CrossRef]
56. Brunet, S. Analyse des Mécanismes D'action Antiparasitaire de Plantes Riches en Substances Polyphénoliques sur les Nématodes du Tube Digestif des Ruminants. Ph.D. Thesis, Paul Sabatier University, Toulouse, France, 2008.
57. Folstad, I.; Karter, A.J. Parasites, bright males, and the immunocompetence handicap. *Am. Nat.* **1992**, *139*, 603–622. [CrossRef]
58. Oppliger, A.; Giorgi, M.; Conelli, A.; Nembrini, M.; John-Alder, H. Effect of testosterone on immunocompetence, parasite load, and metabolism in the common wall lizard (*Podarcis muralis*). *Can. J. Zool.* **2004**, *82*, 1713–1719. [CrossRef]
59. Opeyemi, O.; Shittu, O.; Abdulganiyu, K.; Ashaolu, A.; Lawal, A.; Kadir, R. Helminth Infections of Captive Animals and Management Practices at the University of Ilorin Zoo, North-Central, Nigeria. *Niger. J. Parasitol.* **2022**, *43*, 214. [CrossRef]
60. Adrus, M.; Zainudin, R.; Ahamad, M.; Jayasilan, M.; Abdullah, M.T. Gastrointestinal parasites of zoonotic importance observed in the wild, urban, and captive populations of non-human primates in Malaysia. *J. Med. Primatol.* **2019**, *48*, 22–31. [CrossRef]
61. Zanzani, S.A.; Gazzonis, A.L.; Epis, S.; Manfredi, M.T. Study of the gastrointestinal parasitic fauna of captive non-human primates (*Macaca fascicularis*). *Parasitol. Res.* **2016**, *115*, 307–312. [CrossRef]

62. Berrilli, F.; Prisco, C.; Friedrich, K.G.; Di Cerbo, P.; Di Cave, D.; De Liberato, C. *Giardia duodenalis* assemblages and *Entamoeba* species infecting non-human primates in an Italian zoological garden: Zoonotic potential and management traits. *Parasites Vectors* **2011**, *4*, 307–312. [CrossRef]
63. Köster, P.C.; Dashti, A.; Bailo, B.; Muadica, A.S.; Maloney, J.G.; Santín, M.; Chicharro, C.; Migueláñez, S.; Nieto, F.J.; Cano-Terriza, D.; et al. Occurrence and genetic diversity of protist parasites in captive non-human primates, zookeepers, and free-living sympatric rats in the Córdoba Zoo Conservation Centre, Southern Spain. *Animals* **2021**, *11*, 700. [CrossRef]