






DETECTION AND PREVALENCE OF *Leucocytozoon* spp. IN LOCAL CHICKEN BREEDS IN AL MUTHANNA PROVINCE OF IRAQ

Iman K. M. ALABADI¹ , Zahraa Abd Alhamza ABBASS² , Sura S. ALKHUZAIE³ ,
Hussein Ali KHAYOON⁴  and Mohenned ALSAADAWI⁵ 

¹Department of Pathology and Poultry Diseases, Veterinary Medicine College, Al-Muthanna University, Iraq

²Department of Microbiology, Medicine College, Al-Muthanna University, Iraq

³Department of Parasitology, Veterinary Medicine College, Al-Qadissiyah University, Iraq

⁴Nursing Department, Al-Mustafa University College, Iraq

⁵Department of Parasitology, Veterinary Medicine College, Al-Muthanna University, Iraq

✉ Email: mohenned.hemza@mu.edu.iq

↳ Supporting Information

ABSTRACT: *Leucocytozoon* species are avian haemoparasites with economic impacts on poultry production. The present study investigates the presence of *Leucocytozoon* in chickens of Al Muthanna province, Iraq. Eighty one blood samples were collected from chickens in Samawah, Rumaitha, Warkaa, and Kidhre regions to examine the prevalence of *Leucocytozoon*. An infection rate of 6.1% was found among chicken breeds. The study highlighted that the main symptoms of infection were decreased egg production, anemia, and loss of appetite. Notably, infection was more prevalent in the Rumaitha, Khidr and Samawah regions, while no cases were reported in Warka. Treatment methods included primaquine and pyrimethamine alongside care to manage the condition effectively. It is important to mention that the observed prevalence rate in chickens was lower compared to studies on birds in Iraq, where an overall blood parasite prevalence of 15% was documented. This difference could be attributed to factors like habitat variations, vector presence, or differing susceptibility among bird species. Our suggestion for future work can be the application of new programs for diagnosing and controlling parasites in chickens.

Keywords: Al-Muthanna Province, Avian health, Flocks, Hemoparasite, *Leucocytozoon* spp.

INTRODUCTION

Leucocytozoon belongs to a group of alveolates in the phylum *Apicomplexa*, which is also home to malaria parasites. These parasites are recognized for their life cycle involving blackflies (*Simulium* species) or biting midges as hosts, and birds as intermediate hosts. There have been more than 100 *Leucocytozoon* species identified worldwide, infecting avian hosts (Adler, 2019). In the life cycle of *Leucocytozoon*, gametocytes are present in the blood of hosts. They are acquired by female blackflies. The parasite undergoes a process of malaria. It does not produce hemozoin deposits, as *Plasmodium* does. Instead, merogony takes place in organs such as the liver, heart, and kidneys (Adler, 2019).

Pathogenic avian blood parasites can cause harm to poultry farming (Zhou et al., 2020). Infections by these blood-dwelling parasites can result in issues like anemia, weight loss, stunted growth, decreased egg production, and high mortality rates in poultry flocks (Adamu, 2017). This widespread presence of haemoparasites poses a risk to poultry due to exposure to insect vectors and environmental contamination (Wamboi et al., 2020).

Infections by haemoparasites can lead to changes in hematologic parameters in chickens, might affect their productivity (Wamboi et al., 2020). For example, *Haemoproteus* infections have been found to lower blood glucose levels in chickens, significantly likely because the parasites consume glucose for their metabolic needs (Wamboi et al., 2020). Moreover, these parasitic infections are often asymptomatic, which makes them challenging to identify and manage without monitoring. Helminth infections are widespread in free-range chickens, at levels leading to hidden illnesses that impact health and productivity (Sharma et al., 2018). Hence it is vital to establish controlling measures and regularly monitor these parasites to uphold poultry well-being and enhance production outcomes in backyard environments (Wamboi et al., 2020). Major avian haemosporidian genera include the potentially dangerous *Plasmodium* spp., *Haemoproteus* spp., and *Leucocytozoon* spp. (Bennett et al., 1993). Birds can acquire leucocytozoonosis from numerous species of the genus *Leucocytozoon* that spread via vectors. While *Leucocytozoon* is abundant, only a small subset of species is known to cause disease in birds (Forrester and Greiner, 2008). Waterfowls, pigeons, galliforms, raptors, and ostriches are all vulnerable to the phylum *Apicomplexa*, order *Haemosporina*, family *Plasmodiidae*, genus *Leucocytozoon* (Bennett et al., 1993). There are at least 67 identified species, with 66 infecting birds (Hsu et al. 1973). *Leucocytozoon* is birds' biggest and the most prevalent haemoparasite (Ahmadov et al., 2019). *Leucocytozoon* has two subgenera: *Akiba* and *Leucocytozoon* (Ahmadov et al., 2019). In Al-Muthanna, different epidemiological studies used

physiological parameters to show more information on microbiological infections in animals (Hameed et al., 2022; Al-Yasari et al., 2024).

The aim of the present study was to compare our results with the previous epidemiological studies, including those carried out in Iraq, about *Leucocytozoon* in birds.

MATERIALS AND METHODS

Study area

The samples were collected from the Veterinary Teaching Hospital in four selected regions of Al-Muthanna Province, Iraq (Samawah, Rumaitha, Warkaa, and Kidhre).

Samples collection

Eighty one (5-13/month) blood samples were collected from local chicken flocks in different regions of Al-Muthanna Province (Samawah, Rumaitha, Warkaa, and Kidhre), Iraq. Fresh samples were transferred in sterile containers to the Protozoology Laboratory at the College of Veterinary Medicine/Al-Muthanna University and aliquoted into tubes with EDTA and without EDTA. The study period was nine months from October 2022 to June 2023. All the information about chickens including sex, region, date of collection, clinical signs, and treatment were recorded on the sample containers. Finally, the samples were evaluated by preparing thin and thick smears, stained with Giemsa, and examined under the light microscope.

Statistical analysis

After collecting the samples, the data, were recorded. These included clinical signs, sex, the main cities in Al-Muthanna Province, months of study, and treatment measurements (Graphs 1-4). These data were analyzed after the examination of samples. The analysis was done using GraphPad Prism 9, Chi-Square program ($P \leq 0.05$).

Ethical approval

This study was part of a bigger project that was technically approved by the Scientific Committee at the College of Veterinary Medicine at Al-Muthanna University (Registered code: REF-3-Iman K Alabadi).

RESULTS AND DISCUSSION

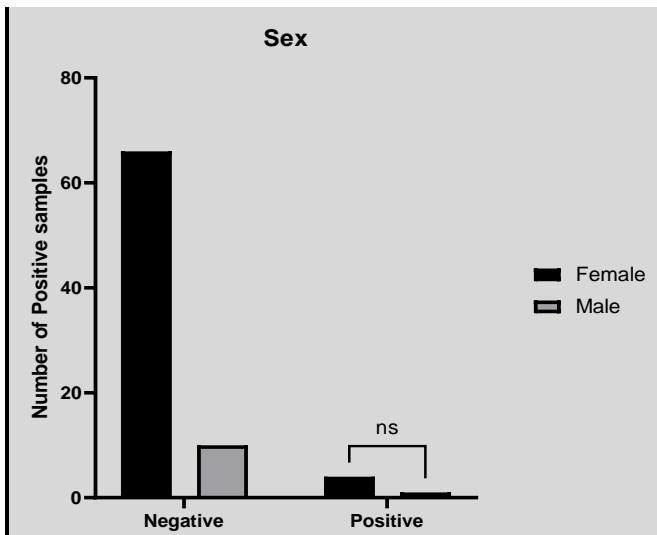
Epidemiology

Present results revealed that the total infection rate of *Leucocytozoonosis* was 6.1% in local Iraqi chicken breeds. Many host bird flocks have been infected with several *Leucocytozoon* species. *Leucocytozoon*'s gametogony takes place in leukocytes or erythrocytes, whereas its schizogony occurs in a wide variety of parenchymal and endothelial cells. *Leucocytozoon* gametocytes are pleomorphic, with certain species showing fusiform and exclusively spherical forms.

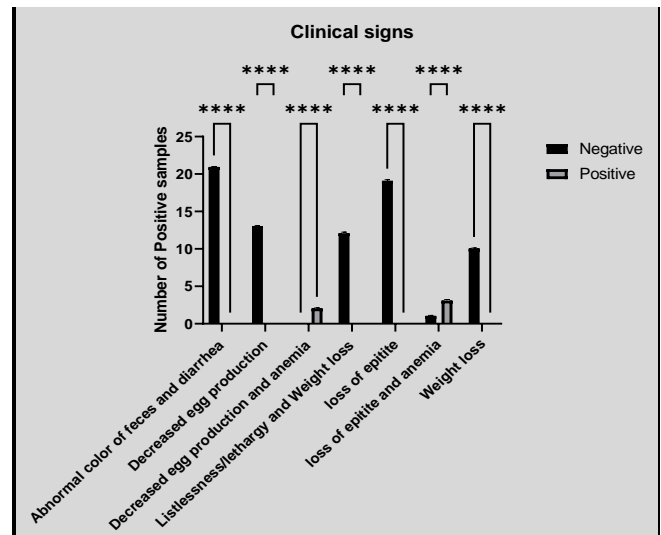
The life cycle of *Leucocytozoon* spp. involves two hosts. *Simuliid* black flies and *Culicoid* midges exhibit sporogony, after that sporozoites travel to the insect's salivary glands. Subsequently, the vertebrate host is infected, and internal organs such as the liver, brain, spleen, and lungs undergo schizogony. It is important to study intermediate hosts for both medicinal and veterinary purposes (Alkhuzai et al., 2019 and Shaker et al., 2024), as they can infect many organs such as the nasal cavities and sinuses (Alhayali et al., 2022). Our results revealed no significant differences between males and females infected with *Leucocytozoon* (Graph 1). Al-Biatee (2014) recorded *Leucocytozoon* spp. infection rates of 10.52% in quail in Baghdad City. They found out that female quails had a greater infection rate than males.

Pathogenesis and clinical signs

From present recordings, decreased egg production, anemia, and loss of appetite were the only significant signs (Graph 2). Different clinical signs were recorded such as anorexia, weight loss, feed conversion drawbacks, anemia, green feces, and frequent mortality. These can result from parasitic infections with *Plasmodium* and *Leucocytozoon* spp. Infections with *Leucocytozoon* spp. cause severe anemia. Pneumonia, lung congestion, and the resulting occlusion of alveolar capillaries are also all potential outcomes in turkey. Moreover, liver necrosis, enlarged spleen, lymphocytic infiltration of the liver and heart, and hemosiderosis may be present (Atkinson and Van Riper, 1991). Illness and mortality in young ducks, both domestic and wild, can be caused by *Leucocytozoon simondi*. Infection can be more prevalent in flocks of ducks, especially those close to lakes. Recovering ducklings may be permanently dwarfed. Adult birds are sometimes severely impacted to the point of death. Most of the time, they can make a full recovery, however, they continue to carry the parasite in their blood and spread it to other birds, especially young ones (Wehr and Farr, 1956).



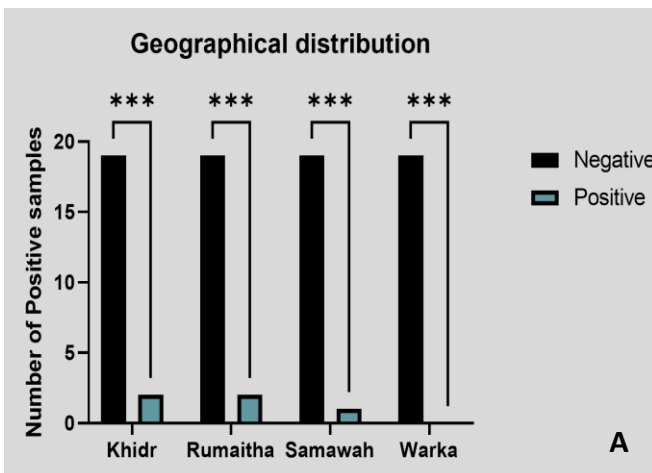
Graph 1 - Number of infected samples according to sex.



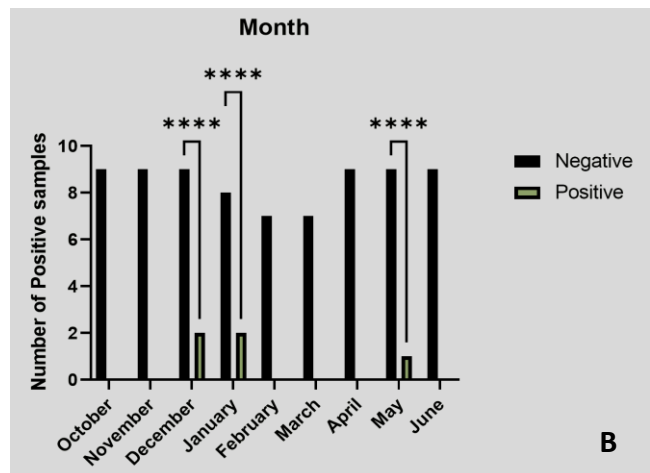
Graph 2 - Number of infected samples according to clinical signs.

Geographical distribution

The collected data showed that the infection was centered mainly in Rumaitha, then Khidr and Samawah. It is while there are no recorded positive results in Warka (Graph 3 A). These cities represent the main places in Al-Muthanna province. In addition, the researchers recorded positive results only in December, January, and May. This may be related to the nature of environmental conditions in Al-Muthanna, which could increase the growth rates of the transmission vector (Graph 3 B).



A



B

Graph 3 - Number of infected samples according to geographical distribution (A) and months (B).

Al-Shuaibi (2008) did not find the *Leucocytozoon* infection in chickens in Al Ramadi, about 110 kilometers west of Baghdad. *Leucocytozoon* spp. were the least common haemoparasite according to a study by Abdullah (2013), and their prevalence was low (13.5%), with no signs of sickness present among the chickens in the Qaradagh district of the Kurdistan region of Iraq, around 45 kilometers from Sulaimani Province. The prevalence of mixed hemoparasite infections in local chickens was 7.5% for *Plasmodium* spp. and *Leucocytozoon* spp., and 1.5% for *Leucocytozoon* spp. and *Haemoproteus* spp. (Abdullah, 2013). However, Hasson (2015) did not find any *Leucocytozoon* spp. record in adult chickens in Diyala. While mixed infection with the triple hemiparasites (*Plasmodium* spp., *Haemoproteus* spp., and *Leucocytozoon* spp.) was found in adult chickens at a 36.8% rate, *Leucocytozoon* species are widely dispersed in farmed chickens (*Gallus gallus domesticus*) in Baghdad city, with a higher infection rate of 30% (Ibrahim and Al-Rubaie, 2020). Additionally, mature chickens have a higher infection rate than young chickens, just as females compared to males. In Nineveh Villages, where geese were examined, Shamaun et al. (2007) found that the prevalence of *Leucocytozoon simondi* was 33.33%. Al-Shuaibi (2008) reported a 10.7% infection rate of *Leucocytozoon* spp. in geese in different areas of Al Ramadi. This rate was reported as 5.37% and a mixed infection with *Plasmodium* spp. + *Leucocytozoon* spp., and 14.1% in geese at Sulaimani Province (Mohammed, 2014a). 14.2% was the rate reported in different areas of Mosul Governorate in northern Iraq (Mohammed, 2020).

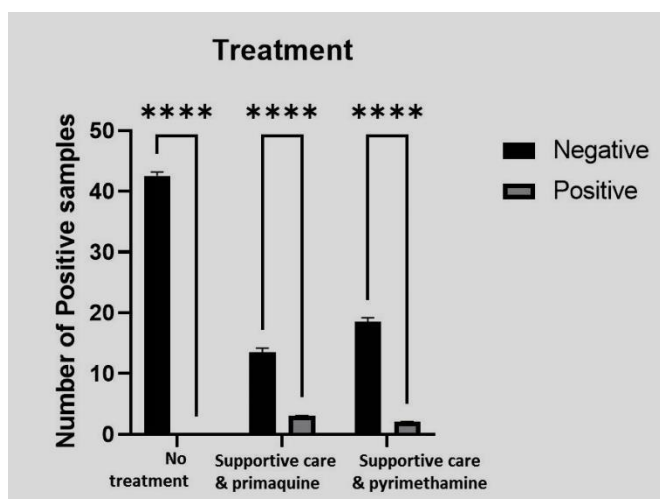
In the marbled teal from Al-Tharthar Lake, Salahuddin Province, in the northern part of the middle region, Mohammad (2014b) observed triple infection with *Leucocytozoon simondi*, *Epomidiostomum uncinatum*, and *Diploposthe*

laevis with total infection rates of 3% and *Leucocytozoon simondi* was the rarest among parasites. According to Mohammad (2015), ferruginous ducks were infected with *Leucocytozoon* spp. at the Dalmaj Lake, Al-Diwaniya Province, where the infection rate was 9.09%. At a few neighborhood markets in Baghdad, the infection rate was 10%, whereas it was 5.56% in Ferruginous ducks at the center of Iraqi territory (Mohammad, 2016). AL-Zurfi and AL-Rubaie (2016) discovered that *Leucocytozoon simondi* in mallards was prevalent in local markets of Baghdad City at 16.66%. It was reported as 5.06% in the middle of Iraq by Mohammad (2016). Phasianid birds from various locations in the north, middle, and south of Iraq recorded free of *Leucocytozoon* infection (Mohammad et al., 2001).

Treatment and control

Our data revealed that the main therapies used to treat *Leucocytozoon* in chickens were Primaquine and pyrimethamine. In addition, the supportive care plays a significant role in treatment measurements (Graph 4).

Primaquine was found to be effective against *Leucocytozoon* spp. gametocytes, however treatment with pyrimethamine mixed with sulfadimethoxine was reported to be partially successful in treating avian leucocytozoonosis (Zhao et al., 2016). According to Chiang et al. (2022), daily treatment of 0.5 g of *Artemisia annua* powder in chickens boosted body weight gain and decreased *Leucocytozoon caulleryi* parasite concentration, which in turn decreased mortality, pale comb, and the production of green feces. Based on present work, it's suggested to use both laboratory and field efforts for the control of *L. caulleryi* by immunization with an oil-adjuvanted rR7 vaccine (Recombinant R7 protein from second-generation *L. caulleryi* schizonts). These measures have yielded encouraging results (Ito and Gotanda, 2004; Saeed et al., 2022).



Graph 4 - Number of infected samples according to treatment measurements.

CONCLUSION

In conclusion, a total of 81 blood samples were taken from chickens in different areas of Iraq, like Samawah, Rumaitha, Warkaa, and Kidhre to investigate the presence of *Leucocytozoon*. 6.1% was the infection rate among the chicken breeds. The study highlighted signs of infection such as decreased egg production, anemia and loss of appetite. Infections were more prevalent in regions like Rumaitha, Khidr, and Samawah compared to Warka region, where no cases were found. Notably the observed prevalence of *Leucocytozoon* in chickens was lower than similar studies on birds in Iraq, which reported an overall blood parasite prevalence of 15%. This difference could be attributed to factors like habitat variations, availability of vectors or varying susceptibility among bird species, etc. it is suggested to conduct studies mapping out the distribution of *Leucocytozoon* comprehensively in Iraq, as well as identifying haemosporidian parasites which can vary significantly across different regions and bird species.

DECLARATIONS

Corresponding author

Correspondence and requests for materials should be addressed to Mohenned ALSAADAWI; E-mail: mohenned.hemza@mu.edu.iq; ORCID: <https://orcid.org/0000-0003-1087-015X>

Data availability

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

Author contributions

The designing of the study and writing the manuscript were done by Iman Aabadi. Sura Alkhuzei and Zahraa Abbas rewrote the article and revised the whole manuscript. HK revised the final version of the article.

Acknowledgment

Many thanks to the Veterinary Teaching Hospital and Veterinary Medicine College at Al-Muthanna University as we used the protozoal laboratory to examine our samples.

Funding

None.

Competing interests

The authors state that there is no conflict of interest regarding the publication of this article.

REFERENCES

- Abdullah SH (2013). Prevalence of Blood Parasites in Local Chickens in Qaradagh District, Sulaimani – Iraq. The Iraqi Journal of Veterinary Medicine, 37(1): 17-21. <http://dx.doi.org/10.30539/iraqijvm.v37i1.321>
- Abdullah SH, Mohammed AA, Saeid NM (2018). Study of ecto and haemo parasites in domestic pigeons (*Columba livia domestica*) in Sulaimani province, Kurdistan region/Iraq. Journal of Zankoy Sulaimani, 20(1) (Part-A):37-44. <https://phthiraptera.myspecies.info/sites/phthiraptera.info/files/94751.pdf>
- Adamu AN (2017). Epidemiology of haemoparasite infection and their effects on hematological parameters in scavenging chickens of west Gojjam administrative zone, Amhara region, Ethiopia, Doctoral dissertation, MSc. Thesis. University of Gondar, Ethiopia. <https://core.ac.uk/download/pdf/199937371.pdf>
- Adler PH and McCreddie JW (2019). Black flies (Simuliidae) In Medical and veterinary entomology, 1: 237-259. Academic Press, Elsevier. <https://doi.org/10.1016/B978-0-12-814043-7.00014-5>
- Ahmadov EI, Hasanova JV, Mammadova FZ, Samadova SO and Topchiyeva SA (2019). Leucocytozoonosis in Chickens (*Gallus Gallus Domesticus*). Acta Scientific Medical Sciences, 3 (2): 110-112. <https://actascientific.com/ASMS/pdf/ASMS-03-0198.pdf>
- Al-Biatee ST (2014). Detection of some protozoal infections in Quails in Baghdad city. Al-Anbar Journal of Veterinary Sciences, 7(2):35-38. <https://www.iasj.net/iasj/download/4dcc3d7ed1496648>
- Alhayali NS, Alsaadawi MA, Al-Fatlawi MA, and Alkhaled MJ (2022). Morphological and phylogenetic characterization of *Oestrus ovis* larvae in sheep: Al-Qadisiyah province, Iraq. Iraqi Journal of Veterinary Sciences, 36(1):133-137. <https://doi.org/10.33899/IJVS.2021.129231.1636>
- Al-Khafaji SA, Alsaadawi MA, Al-Yasari AM, and Al-Saadawe MA (2021). Article review: *Cordia myxa* L.: The gift of the nature, A Review. Basrah Journal of Agricultural Sciences, 34(2):267-77. <https://doi.org/10.37077/25200860.2021.34.2.20>
- Alkhuzaie SS, Al-Saadawe MA and Alsaadawi MA (2019). Studies on soil nematodes in al-muthanna province, Iraq. Indian Journal of Ecology, 46(3):640-642. <https://www.indianjournals.com/ijor.aspx?target=ijor:ije1&volume=46&issue=3&article=035>
- Alsaadawi MA, Alkaabi N, Alkhuzaie S and Kilvington S (2019). Ex vivo Cytopathic Effect Study of Human *Acanthamoeba* keratitis and Use of *E. coli* in Parasitic Culture. Indian Journal of Public Health Research & Development, 10(3):508-513. <http://dx.doi.org/10.5958/0976-5506.2019.00548.5>
- Al-Shuaibi MM (2008). Study of prevalence haemoparasites in different birds from Al-Ramadi city. Al-Anbar Journal of Agricultural Sciences, 6 (2): 288-292. (Arabic article) <http://dx.doi.org/10.32649/ajas.2008.33206>
- Al-Yasari AMR, Alsalih NJ and Alsaadawi MA (2024). Physiological and epidemiological study of some parasitic and viral enteric infections in dromedary camels in Al-Muthanna province. Tropical Biomedicine, 41(1):1-13. <https://doi.org/10.47665/tb.41.1.001>
- AL-Zurfi ANJ and AL-Rubaie HMA (2016). Prevalence of Haemoprotozoa of *Anas platyrhynchos* in Baghdad City. International Journal of Research and Development in Pharmacy & Life Sciences 5(1): 1904-1909. <https://www.ijrdpl.com/index.php/ijrdpl/article/view/199>
- Atkinson CT, van Riper C (1991). Pathogenicity and epizootiology of avian haematozoa: Plasmodium, Leucocytozoan, and Haemoproteus. In: Loye JE, Zuk M (Eds.), Bird-Parasite Interactions: Ecology, Evolution and Behavior. Oxford University Press, England, pp. 19-48.
- Bennett GF, Peirce MA, and Ashford RW (1993). Avian haematozoa: Mortality and pathogenicity. Journal of Natural History, 27: 993-1001. <http://dx.doi.org/10.1080/00222939300770621>
- Chiang Y, Lin Y, Wang S, Lee Y, and Chen C (2022). Effects of *Artemisia annua* on experimentally induced leucocytozoonosis in chickens. Poultry Science; 101(4) <https://doi.org/10.1016/j.psj.2021.101690>
- Forrester D J and Greiner E C (2008). Chapter 4 (Leucocytozoonosis). Parasitic Diseases of Wild Birds Edited by Carter TA, Nancy JT and Bruce HD. Wiley, UK. Pp. 54-107. <https://doi.org/10.1002/9780813804620.ch4>
- Hameed AK, Khudhur HR, Mahdi NA, Alsaadawi MA and Kareem AS (2022). Study of cholera in Al-Muthanna province. In AIP Conference Proceedings. 2398(1). AIP Publishing. <https://doi.org/10.1063/5.0095320>
- Hasson RH (2015). Haemosporidians parasites of *Gallus domesticus*, poultry in Iraq. International Journal of Advanced Research, 3(8): 1046-1054. <https://www.journalijar.com/article/5943/haemosporidians-parasites-of-gallus-domesticus-poultry-in-iraq/>
- Hsu CK, Campbell GR, Levine ND (1973). A checklist of the species of the genus *Leucocytozoon* (Apicomplexa, Plasmodiidae). Journal of Protozoology 20: 195-203. <https://doi.org/10.1111/j.1550-7408.1973.tb00862.x>

- Ibrahim RM and Al-Rubaie HMA (2020). Prevalence of Some Haemosporidians in Domesticated Chickens in Baghdad City. *Plant Archives*, 20 (S1):3444-3448. [http://www.plantarchives.org/SPECIAL%20ISSUE%2020-1/3443-3448%20\(415\).pdf](http://www.plantarchives.org/SPECIAL%20ISSUE%2020-1/3443-3448%20(415).pdf)
- Ito A, and Gotanda T (2004). Field efficacy of recombinant R7vaccine against chicken leucocytozoonosis. *Journal of Veterinary Medical Science*, 66:483–487. https://www.jstage.jst.go.jp/article/jvms/66/5/66_5_483/article
- Mohammed A. A. (2014a). Frequency rates of blood protozoa in geese in Slemani, Kurdistan region/ Iraq. *Journal of University of Duhok.*, 17(1) (Agri. and Vet. Sciences): 32-38. [Google Scholar](#)
- Mohammad, M. K. (2014b). The parasitic fauna of the marbled teal *Marmaronetta angustirostris* (Menetries, 1823) L. Reichenbach 1853 in the middle of Iraq. *International Journal of Recent Scientific Research*, 5 (1):54-56. [Google Scholar](#)
- Mohammad, M. K. (2015). The parasitic fauna of the Ferruginous duck *Aythya nyroca* (Güldenstädt, 1770 (collected in central Iraq. *International Journal of Advanced Research in Biological Sciences*, 2 (3): 62–65. [Google Scholar](#)
- Mohammad M. K. (2016). Haematozoa of the ducks in the middle of Iraq. *International Journal of Advanced Research in Biological Sciences*, 3(2): 243-246. [Google Scholar](#)
- Mohammed N.H. (2020). Study on the blood protozoa in geese. *Iraqi Journal of Veterinary Sciences*, 34 (1): 23-27. (Arabic article) <http://dx.doi.org/10.33899/ijvs.2019.125499.1028>
- Mohammad MK, Jasim MK and Al- Moussawi AA (2001). Haematozoa of the Avian family phasianidae in Iraq. *Bullutin Iraqi national Histology Museum* 9 (3): 57-61. <https://jnhm.uobaghdad.edu.iq/index.php/BINHMH/article/view/192>
- Saeed ZF, Kadhim BA, Al-Yasari AMR, Kheder RK, Abdulhussein SA, James H and Alsaadawi MA (2022). Proinflammatory activation of osteoclasts due to high prolactin level. *Iraqi Journal of Science*, 63(12):5166-5185. <http://dx.doi.org/10.24996/ij.s.2022.63.12.8>.
- Shaker DA, Abd MT, Alsalihi NJ, Mahdi SG, Alsaadawi M, Aakef IR and Aljandeel TJ (2024). A retrospective study of Crimean-Congo hemorrhagic fever in Iraq. *African Health Sciences*, 24(1): 59-68. <https://doi.org/10.4314/ahs.v24i1.8>
- Shamaun AA, Al-Taeef AF, Hasan MH (2007). Parasitological and histopathological studies of the natural infection with *Leucocytozoon simondi* in geese in Nineveh governorate. *Iraqi Journal of Veterinary Science*, 21(1):37-44. <http://dx.doi.org/10.33899/ijvs.2007.5634>
- Sharma N, Hunt PW, Hine BC, Sharma NK, Swick RA, and Ruhnke I (2018). Detection of *Ascaridia galli* infection in free-range laying hens. *Veterinary parasitology*, 256:9-15. <https://doi.org/10.1016/j.vetpar.2018.04.009>
- Wamboi P, Waruiru RM, Mbuthia PG, Nguhiu JM, and Bebora LC (2020). Haemato-biochemical changes and prevalence of parasitic infections of indigenous chicken sold in markets of Kiambu County, Kenya. *International journal of veterinary science and medicine*, 8(1):18-25. <https://doi.org/10.1080/23144599.2019.1708577>
- Wehr EE and Farr MM (1956). Parasites affecting ducks and geese. *Year Book of Agriculture* 500- 502. <https://www.cabidigitallibrary.org/doi/full/10.5555/19560802336>
- Zhao W, Pang Q, Xu R, Liu J, Liu S, Li J, and Culleton R (2016). Monitoring the prevalence of *Leucocytozoon sabraezesi* in southern China and testing tricyclic compounds against gametocytes. *PLoS One*, 11(8): e0161869. <https://doi.org/10.1371/journal.pone.0161869>
- Zhou Z, Shen B, and Bi D (2020). Management of pathogens in poultry. In *Animal agriculture*, Academic Press, Elsevier Inc. pp. 515-530. ISBN 9780128170526. <https://doi.org/10.1016/B978-0-12-817052-6.00030-6>

Publisher's note: Scienceline Publication Ltd. remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Open Access: This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <https://creativecommons.org/licenses/by/4.0/>.

© The Author(s) 2024