German Journal of Microbiology

eISSN:2749-0149

Research article

Role of ornamental birds in the transmission of zoonotic pathogen and AMR: A growing public health concern

Rony I. Masud, Rownak Jahan, Zuhayr Bakhtiyar, Tabeer H. Antor, Dilruba A. Jany, Naeem A. I. Fahim and Md. Tanvir Rahman*

Department of Microbiology and Hygiene, Faculty of Veterinary Science, Bangladesh Agricultural University, Mymensingh-2202, Bangladesh

Article History:
Received: 3-Oct-2024
Accepted: 19-Dec-2024
***Corresponding author:**
Md. Tanvir Rahman
tanvirahman@bau.edu.bd

Abstract

Globally, ornamental birds are gaining popularity as exotic pets because of their high aesthetic value. Although keeping ornamental birds is a thousand-year-old tradition, in recent years, the market size has increased notably, and the population of ornamental birds is increasing tripinnately. However, serious public health concerns about their growing domestication and commerce exist. These birds may act as zoonotic pathogen reservoirs and vectors, allowing the spread of genes that cause antimicrobial resistance (AMR) in humans and the environment. Numerous variables, such as ornamental birds' extensive breeding, international trade, and intimate contact with people, contribute to the spread of zoonotic infections and AMR through these birds. Notably, these birds are frequently linked to certain infections, including *Salmonella* spp. and *Chlamydia psittaci*, which can be dangerous for pet owners and professionals handling them. Moreover, multidrug-resistant (MDR) bacteria are frequently found in ornamental birds, which helps disseminate AMR genes in the environment through their secretions and excrement. The part ornamental birds play in the spread of AMR still needs to be better understood despite mounting evidence. This analysis emphasizes the necessity of strong monitoring programs, enhanced diagnostic capabilities, and more stringent biosecurity protocols to reduce these hazards. It also highlights our limitations in understanding ornamental birds' microbiota and how it interacts with environmental resistance. Understanding these dynamics using cutting-edge molecular and metagenomic techniques should be the primary goal of future studies. The review's conclusions are essential for directing One Health initiatives to counteract zoonotic illnesses and AMR because human, animal, and environmental health are intertwined. Together, legislators, scientists, and the general public can mitigate the new risks that ornamental birds present while guaranteeing their safe assimilation into human society by tackling these problems.

Keywords: Ornamental birds, Antimicrobial resistance, Zoonosis, Public health

Citation: Masud, R. I., Jahan, R., Bakhtiyar, Z., Antor, T. H., Jany, D. A., Fahim, N. A. I., and Rahman, M. T. 2024. Role of ornamental birds in the transmission of zoonotic pathogen and AMR: A growing public health concern. Ger. J. Microbiol. 4 (3): 45-55. https://doi.org/10.51585/gjm.2024.3.0042

Introduction

Ornamental birds have a great connection with human beings and thus bear tremendous public health significance. People love to keep pets for their companionship, and decorative birds are one of the most beautiful pets among all pets. It is not a new culture, as birds and humans have been deeply connected since ancient times. Birds are frequently depicted in art (such as the Rime of the Ancient Mariner), a prevalent theme in Greek mythology and religion (such as the Egyptian gods with bird heads), and an integral part of traditional and cultural knowledge (Tidemann and Gosler, 2010). People love ornamental birds for different reasons: their pleasant voices, harmonious and beautiful body colors, source of financial income, and hybridization (Abd Rabou, 2022). People's typical nature is to stay in their comfort zone. Keeping pet birds can be a significant source of comfort for some people (Friedmann and Thomas, 2018). Some ornamental pets, like parrots and mynahs, are well-known for their ability to mimic speech and have lovely voices.

According to reports, decorative pets are the fourth most common companion animal kept as pets in the United States, behind fish, cats, and dogs. Even if a species is reared in captivity, birds are generally not considered domesticated animals, unlike other pets like cats and dogs. Because of this, when fish were not classified separately, "ornamental" birds were the third most popular pet in the EU (Peng and Broom, 2021). According to the European Pet Food Industry Federation (FEDIAF) data, 51.87 million ornamental birds were kept as pets in Europe in 2019—37.23 million were in the EU. After cats and dogs, songbirds and ornamental birds comprise the third-largest pet population on the continent (Bordun and Iegorov, 2022). Recent statistics show that the number of ornamental birds kept as pets varied by European Union country as of 2023. Italy led the pack with over 12.88 million pets, followed by France with roughly 5.8 million. In Australia, about 11% of all households owned 3.9 million pets (Stastistica, 2023).

Antimicrobial resistance (AMR) is becoming a significant concern in the running era, and more destruction is predicted to occur soon. The World Health Organization (WHO) states that AMR is among the most significant global development and public health challenges. Bacterial AMR was estimated to have directly caused 1.27 million deaths globally in 2019 and contributed to 4.95 million deaths. (Murray et al., 2022). AMR not only causes death and disability, but it also has high economic costs. According to World Bank projections, AMR may lead to US$ 1 trillion in higher healthcare expenses by 2050 and US$ 1 trillion to US$ 3.4 trillion in Gross Domestic Product (GDP) losses annually by 2030 (Jonas et al., 2017).

Keeping ornamental birds in houses is becoming popular across the globe. There is a growing public health concern as ornamental birds are closely connected with a human being, and many of these could be a potential source for multidrug-resistant (MDR) pathogens capable of causing human infection. Despite the recent increase in the number of studies on antimicrobial resistance patterns and the spreading of the AMR gene from human to animal or vice versa, no review on the role of ornamental birds in transmitting zoonotic pathogens and AMR is available to date. Therefore, this review focuses on the recent increase in the ornamental bird population, its global distribution, zoonosis potential, trends in using antimicrobials, and the possible transmission cycle of AMR.

Ornamental birds

Birds that have been tamed and domesticated by humans for ages are referred to as "ornamental birds" (Boichard et al., 2011). Some species are called ornamental birds because of their aesthetic attractiveness (Haukka et al., 2023). Naturally, the most well-known ornamental birds are the canaries, parakeets, parrots, and grays of Gabon. Ornamental birds have been domesticated and tamed by humans for centuries. The most common ornamental birds found worldwide include two prominent families, Passeriformes and Psittaciformes (Figure 1). The best known are the canaries, parakeets, parrots, and grey of Gabon. Often, players and speakers, those animals need foremost attention and affection from their owners. Domesticated fowls could undoubtedly be found in Iran by 800 B.C. The Persians spread them throughout Western Asia and to the shores of the Mediterranean by 600 B.C. They were introduced in Italy by 400 B.C. and in northern Europe by 100 B.C. Early European explorers and immigrants imported chickens into America and Australia. By the Renaissance, exotic birds became popular among European aristocracy. By the 17^{th} and 18^{th} centuries, as global exploration expanded trade, birds such as parrots and canaries were commonly kept in homes. The 19^{th} century saw a rise in middle-class bird ownership, especially canaries, due to improved transportation and the growing pet trade. By the 20^{th} century, pet birds like parrots, budgies, and cockatiels became widespread in homes, with advances in bird care and breeding making them more accessible and popular as household companions.

Zoonotic pathogens linked with ornamental birds

A significant worldwide public health concern is zoonotic illnesses, which may be characterized as infections that can transfer from animals to humans. The transmission can be either directly or indirectly. Specific zoonoses are transmitted through asymptomatic carriers, such as wild birds (Rahman et al., 2020a). The severity of the disease depends on the organism's virulence, transmission route, human immunity, and many other factors. This transmission often occurs between birds and animals, but inter-human transmission is infrequent (Heesterbeek et al., 2015). Certain groups, especially pregnant women, immunocompromised individuals, older adults above 65, and children under 5, are the permeable group for zoonoses. The interaction between humans, animals, and their shared environment plays a pivotal role in transmitting zoonoses. Feathers, feces, and secretions from ornamental pet birds (such as saliva, ocular discharge, tracheal, and other bodily fluids) eliminate the pathogen; even the habitat in which birds inhabit can also spread the pathogen. Pathogens that spread infection can linger in dirt that has long been contaminated with excrement (Hollingsworth et al., 2015). Birds, especially untamed ones, act as asymptomatic carriers for zoonotic pathogens and transmit them to humans without showing any sign symptoms. The summary of the most important zoonotic disease reported in Figure 2 represents the schematic diagram of zoonotic transmission dynamics from ornamental birds to humans and animals and vice versa. Ornamental bird species with primary clinical manifestations in birds and humans are presented in Table 1. Pet birds get affected by zoonosis from close contact with wild birds via contaminated water and feces, even through direct contact (Ebani and Mancianti, 2022). Ornamental birds play several roles in transmitting zoonotic diseases, either as carriers of pathogens or contributors to the spread of disease through human interaction (Boseret et al., 2013a).

Spread of AMR through ornamental birds

Using antibiotics carelessly and indiscriminately to treat ornamental birds is one of the leading causes of the rise in antibiotic resistance, which eventually spreads to the environment (De Marchi et al., 2024a). With or without the appropriate diagnosis and consultation from a veterinary physician, the bird's owner occasionally administered various antibiotics for therapeutic purposes. Antibiotic abuse and misuse in multiple domains, such as agriculture and human and animal health, lead to antimicrobial resistance. This reduces antimicrobial therapy's positive effects on human and animal health (Prouillac, 2021). However, when antibiotics are misused, they become less efficient at treating bacterial infections and help to promote resistance (De Marchi et al., 2024b). Misuse and overuse of existing antibiotics without veterinary doctor supervision can lead to AMR (Siddiky et al., 2021; WHO and IACG, 2019).

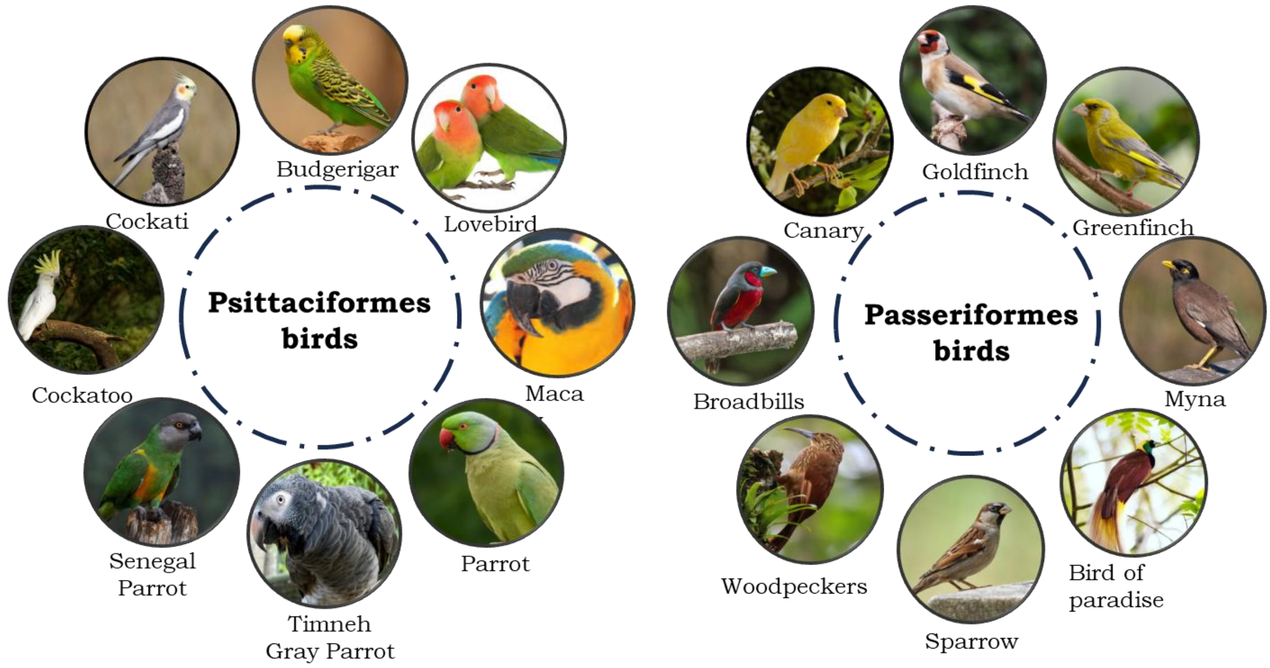

Figure 1: The most common ornamental birds found worldwide include two prominent families: Passeriformes and Psittaciformes.

Table 1: The summary of the most important zoonotic disease reported in Ornamental bird species with primary clinical manifestation in birds and human species (Boseret et al., 2013a).

Diseases	Sensitive host	Significant clinical signs in birds	Significant clinical signs in humans	OIE listed	Risk for humans
Salmonellosis	Canaries Finches Parrots Pigeons Doves Cockatoos	• Gastrointestinal signs • Lethargy and weakness • Respiratory symptoms and neurological signs (in severe cases) • Swollen joints and lameness	• Gastrointestinal distress • Fever like mild to moderate ranging from 37.8ºC-39.4ºC • Headache, muscle • Aches, fatigue, weakness, septicemia.	Yes	Moderate
Parrot fever	Macaws Cockatiels African greys Budgerigars Cockatoos Love birds	• Respiratory symptoms • Gastrointestinal symptoms • General signs like lethargy, ruffled feathers, weakness, and fluffed-up appearance	• Respiratory symptoms • Flu-like symptoms • Gastrointestinal symptoms. • Patients may experience lethargy and photophobia	Yes	High
Avian tuberculosis	Macaws African Grey Parrot Canaries Finches Budgerigars Cockatiels Pigeons	• Despite a good appetite, birds often lose significant weight • Lethargy • Chronic diarrhea • Respiratory distress (sneezing, wheezing) • Enlarged abdomen • Lameness or joint swelling • Sudden death	• Pulmonary symptoms include chronic cough, shortness of breath, chest pain, and fatigue • Skin lesions like ulcers or nodules • Gastrointestinal symptoms • Disseminated diseases	No	High
Listeriosis	Parrot African Grey parrot Cockatoos Macaws Canaries Finches	• Neurological signs (Most Common) • Gastrointestinal signs and general signs of illness • Reproductive issues like reduced fertility, egg production issues, or even embryonic death • Sudden death.	• Gastrointestinal symptoms • Flu-like symptoms • Neurological symptoms Septicemia - in case of widespread infection like fever, rapid heartbeat • Pregnancy-related complications like miscarriage and stillbirth.	No	Moderate
Staphylococcus/ bumble foot	Parrots Canaries Budgerigars Finches Cockatiels Pigeons Lovebirds Falcons	• Skin lesions or abscesses • Bumblefoot/Pododermatitis • Respiratory Problems • Digestive problems • General signs like lethargy and weakness • In chronic cases, septicemia • Behavioural changes.	• Staphylococcal dermatitis • Wound infections • Respiratory problems • Sepsis/Bloodstream infection • Endocarditis/Heart valve infection. • Bone and Joint infections • Toxic shock syndrome.	No	Low to moderate
Escherichia coli infection	Parrots Canaries Finches	• Colibacillosis • Air vasculitis • Omphalitis • Peritonitis • Enteritis • Cellulitis	• Gastrointestinal symptoms. • Haemolytic uremic syndrome • Urinary tract infections • Respiratory symptoms like cough and difficulty breathing.	Yes	Low to moderate

Campylobacteriosis	Parrots Finches Doves Canaries	• Gastrointestinal symptoms • General signs like lethargy, inappetence • Poor feather condition	• Gastrointestinal symptoms • Abdominal Cramps • General signs like fever, nausea, vomiting, fatigue and general malaise	No	Moderate
Avian influenza	Parrots (Psittacine) Canaries Finches Doves Pigeons Mynahs Toucans	• Respiratory symptoms • Digestive symptoms. • General symptoms include lethargy, ruffled feathers, decreased vocalization, and loss of production. • Neurological signs (more common with HPAI strains): tremors, ataxia, head tilt, seizures.	• Respiratory symptoms. • Systemic symptoms like high fever above 100.4˚F, muscle fever, fatigue, and chills. • Digestive symptoms • Pneumonia, Acute respiratory distress syndrome (ARDS), and organ failure. • Rare symptoms like conjunctivitis and confusion.	Yes	High
Newcastle disease	Parrots/ Psittacines Canaries Finches Dove Pigeons Mynahs	• Respiratory symptoms • Neurological symptoms • Greenish/watery diarrhea, anorexia, weight loss. • Ruffled feathers and decreased vocalization, especially in songbirds. • Sudden death.	• Conjunctivitis • Flu-like symptoms • Respiratory symptoms, but that may be rare.	Yes	Low
West Nile virus	Parrots/ Psittacine Canaries Finches Some exotic birds (mynahs, toucans, cockatoos)	• Neurological symptoms: tremors, weakness, incoordination, head tilt • Behavioral Changes: lethargy, depression, isolation from the flock	• Mild symptoms: fever, headache, fatigue, muscle and joint pain, nausea, vomiting • Neuro-invasive disease: high fever, stiff neck, confusion, seizures, paralysis of muscle	Yes	Moderate
Fungal disease	Parrots Canaries Finches Pigeons Candidiasis: Parakeets Lovebirds	• Breathing difficulty, coughing, nasal discharge, and change in vocalization. • In several cases, white patches in the mouth, poor appetite, weight loss, diarrhea, respiratory distress, lethargy, and neurological signs.	• Respiratory signs, allergic reactions. • Thrush, cutaneous candidiasis, invasive candidiasis • Pulmonary cryptococcosis, CNS involvement, cutaneous cryptococcosis, disseminated cryptococcosis, chronic pulmonary histoplasmosis (COPD), chronic cough	No	Low to moderate
Parasitic disease	Parrot Canaries Finches Pigeons Dove Chicken Duck	• Decreased appetite can result in weight loss, diarrhea, vomiting, lethargy and weakness, abdominal distension, Irritability or behavioral changes, ruffled feathers, respiratory issues, neurological signs, and jaundice.	• Abdominal pain, loss of appetite, headache, irritability, dizzin ess, anemia, fatigue, watery diarrhea (persistent or intermittent). • Flu-like symptoms, muscle aches, swelling of lymph nodes, sore throat.	Yes	Low to moderate

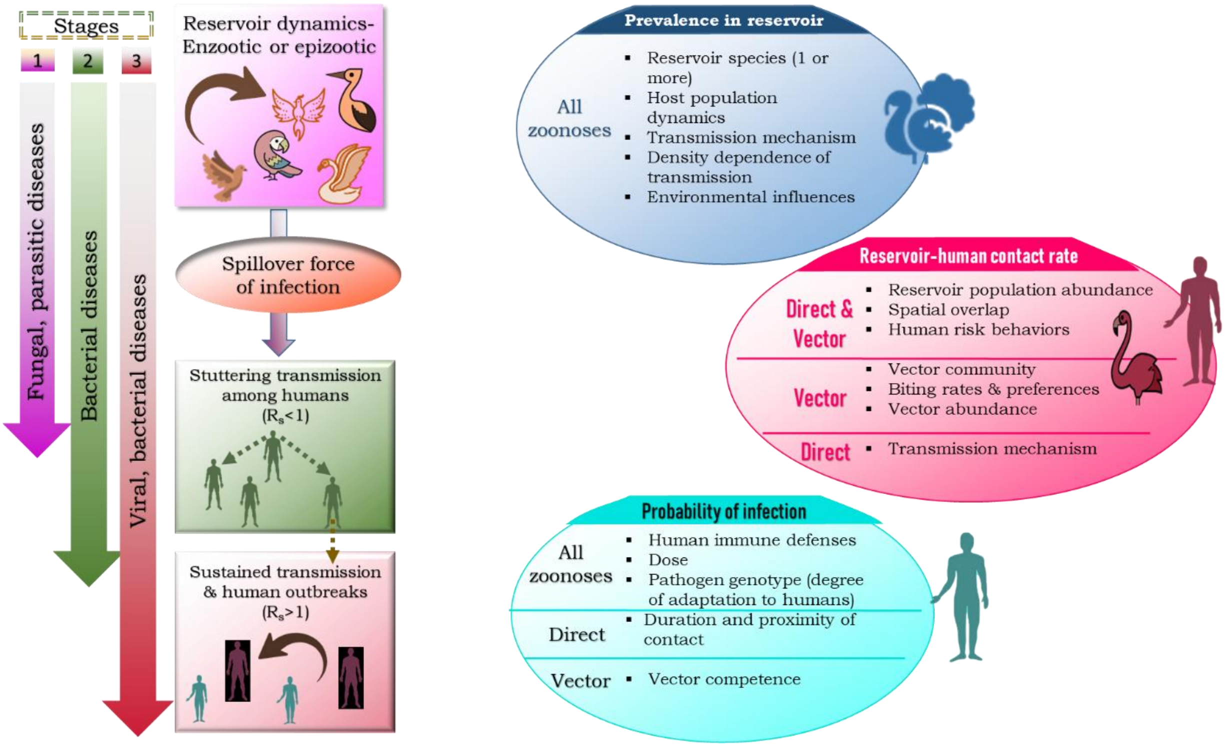

Figure 2: Schematic diagram of zoonotic transmission dynamics from ornamental birds to human and animal and vice versa.

Besides this, sometimes, owners need to complete the duration of the proper antibiotic. As a result of these events, there is a chance that bacteria can grow their resistance to these specific antibiotics, and these resistant genes also spread to wild ornamental birds.

Multiple studies have shown that antibiotics are sometimes used to prevent infections, such as before surgery, making the problem worse when taken as a preventative measure in ornamental birds. Surgical antimicrobial prophylaxis (AMP) may be defined as a very brief course of antimicrobial medicine initiated just before the initiation of an operation. AMP is not meant to sterilize tissues; instead, it is a carefully positioned adjuvant that reduces the microbial load of intraoperative contamination to a level that cannot overwhelm host defenses (Mangram et al., 1999a). Because of their preventive character, they are used when minimal microbial contamination of the surgical site is expected, such as clean Class I surgical wounds (Gordon, 2006; Li et al., 2014; Mangram et al., 1999b). AMR may develop as a result of this.

Wildlife species may come into contact with people and domesticated animals if they live or feed near homes and raise estates. For instance, if the food or feed is contaminated by mouse feces, people, their pets, and decorative birds might come into touch with it and eat it. Furthermore, manure and animal waste may be directly encountered by rodents that reside near residential areas and rearing estates. Moreover, people may have direct contact with wild animals when they hunt, trap, or treat them in their capacity as veterinarians. Nothing suggests that it could not be required in AMR bacteria exchanges (Stewart, 1996; Vittecoq et al., 2016).

AMR is dispersed and stored by wild birds, and the incidence of AMR has been linked to geographic proximity to human activity (Djuwanto, 2020). Birds can spread AMR bacteria to one another by direct contact, such as sharing food or water, or through their surroundings, including cages or bedding. The number of antibiotic-resistant genes in the feces of birds who feed in free landfills and waterfalls is much higher.

Antimicrobial-resistant bacteria can be found in different bird species, and waterbirds can occasionally transport antibiotic-resistant genes from one environment to another (from rice fields to landfills to water sources), which carries a danger of spreading to other birds, wildlife, and humans (Jarma et al., 2021). Sometimes, wild birds that may harbor antibiotic-resistant bacteria can come into touch with ornamental pet birds. As a result, AMR genes may spread throughout other species. AMR bacteria can be unintentionally transferred from birds to humans or vice-versa by direct contact or by handling contaminated ornamental pet bird items (such as food, drink, or equipment). By contact with human or livestock waste, ubiquitous birds may be exposed to anthropogenic influence and acquire resistant germs. Resistance in migratory bird species appears mainly caused by exposure to environmental pollutants and anthropogenic causes, such as manure, sewage treatment plant effluents, and human waste (Skarżyńska et al., 2021).

Possible mechanism of AMR transfer

Horizontal gene transfer is the most common way resistance genes are transferred from one bacterium to another. AMR bacteria have several methods for doing this. Therefore, AMR genes can spread rapidly among bacterial species, including those found in humans and birds. The transmission of resistance genes makes the bacteria more potent and effective against the antibiotic. Bacteria use three main methods to transmit their genes. It encompasses transformation, transduction, and conjugation. Conjugation is a central horizontal gene transfer mechanism; direct contact between bacterial cells (from a donor to a recipient bacterium) is required to share genetic material, including AMR genes. In various settings, including soil, plant surfaces, water, sewage, biofilms, and host-associated bacterial communities, conjugation is universally conserved among bacteria. By influencing the spread of numerous metabolic traits, such as virulence, biofilm formation, symbiotic living, resistance to heavy metals, and, most importantly, antibiotic resistance, conjugation propels bacterial strains' quick evolution and adaptability within these environments (Virolle et al., 2020).

Additionally, bacterial transformation is a typical method of horizontal gene transfer that might speed up adaptive evolution (Rathmann et al., 2023a). In transformation, bacteria can take AMR gene-containing DNA from their surroundings. Bacteria absorb DNA from their surroundings during transformation and then use homologous recombination to incorporate the newly acquired DNA segments into their chromosomes; by taking advantage of a gene pool that closely related species share, the transformation has a tremendous potential to accelerate adaption to changing environments (Dubnau and Blokesch, 2019; Maier, 2020; Rathmann et al., 2023b). Lastly, through the transduction process, bacteria can share AMR genes through bacteriophages, viruses that infect bacteria. During the lysogenic cycle, the prophage's excision from the host genome creates the hybrid DNA molecule connected to these particles. Whole genome sequencing of bacterial species demonstrates that phage or phage-like elements encode many bacterial virulence factors. The primary source of variation among bacterial strains is often seen in their proteome sequences (Schneider, 2021). The evidence of the AMR gene detected in various ornamental birds globally is presented in Table 2.

Given that budgerigars raised in homes have been shown to carry pathogenic germs, particularly strains that are resistant to multiple drugs, the results of this case indicate that frequent human contact with these animals may contaminate food, drink, and the environment (Okunlade et al., 2021b). In this case, the *E. coli* identified from the budgerigar bird was resistant to all the tried medications. This issue might be brought on by the overuse of antibiotics in avian medicine. *Chlamydophila psittaci* can be transmitted from pet birds to humans. *Salmonella* spp, although more commonly a foodborne zoonotic agent, can also be transmitted through pet birds. Allergic responses to pet birds, including pneumonitis and contact dermatitis, have also been documented. Bite wounds from pet birds are rarely reported but can cause trauma and develop infection. The possible transmission cycle of AMR genes from ornamental birds to human animals and environments Figure 3.

Table 2: Proof of AMR gene detected in different ornamental birds globally.

Organism name	Resistance gene name	Bird species	Location	References
Escherichia coli	*PMQR - qnrB*, *PMQR*, aminoglycoside resistance genes - *(aac(3)-IIa(aacC2), strA, strB, aadA (aadA1 or aadA2), aphA1, aphA2, and ant(2'')-Ia(aadB))*	Parrot Parakeets	Türkiye Türkiye	Diren Sigirci et al. (2020)
Staphylococcus aureus	*nuc* gene	Budgerigar, Cockatiel	Mymensingh, Bangladesh	Hossain Sigma et al. (2024)
Escherichia coli	*qnr*A	Budgerigar	Nigeria	Okunlade et al. (2021a)
Enterobacteriaceae	*tet*A, *tet*B	Parakeets, Parrots, Canaries, Indian nightingales, European goldfinches	Istanbul, Türkiye	Diren Sigirci et al. (2019a)
Enterobacteriaceae	*sul*1, *sul*2, *dfr*A5, *dfr*A17 *qnr*S, *mrx*, *mph* and *aad*A2, *aad*A4, *intI*1 $bla_{CTX\text{-}M\text{-}1}$, bla_{TEM}, bla_{ACT}, $bla_{OXA\text{-}1}$ and *rmt*A	Eurasian magpie, Common buzzard, Eurasian sparrowhawk, Grey heron, Common swift	Greece	Athanasakopoulou et al. (2022)
Salmonella spp.	*aac*(6')-*Iaa* *gyr*A, *gyr*B, *par*C, or *par*E	Greenfinch, House sparrow, Goldfinch	England and Wales	Mather et al. (2016)
Salmonella	Specific gene isn't detected.	House sparrows	Spain	Martín-Maldonado et al. (2020)

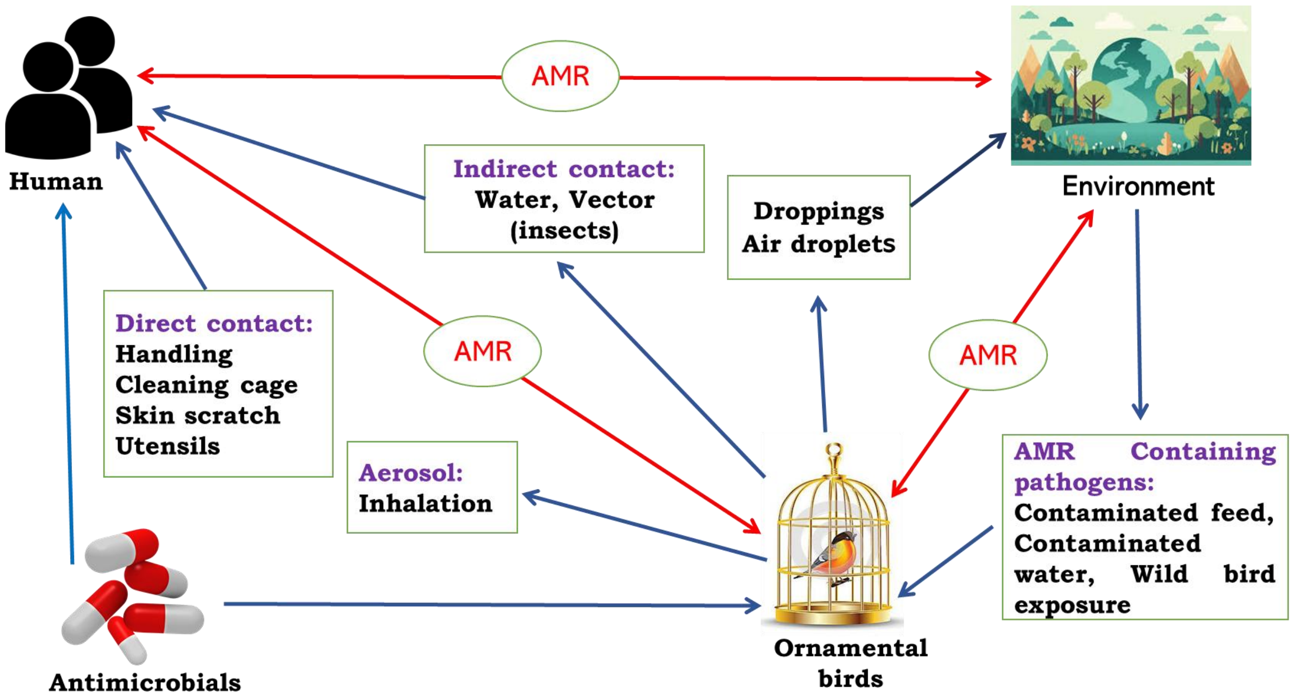

Figure 3: Possible transmission cycle AMR genes from ornamental birds to human animals and environments.

Another factor to be considered is that close contact between pet birds and people offers favorable conditions for bacterial transmission. Zoonoses like highly pathogenic avian influenza, salmonellosis, and chlamydiosis pose significant public health risks, particularly affecting those in close contact with pet birds, such as veterinarians, breeders, and owners (Boseret et al., 2013b). Foodborne zoonoses like salmonellosis and campylobacteriosis are notable for their transmission from pet birds to humans (Rahman et al., 2020b). Bacterial pathogens transmitted from birds include *Salmonella, Chlamydia, Mycobacterium, Listeria, E. coli, Campylobacter*, and *Staphylococcus* (Day, 2016). Diseases like chlamydiosis and salmonellosis are more prevalent in pet birds, presenting a risk of infection to their owners. Other less common zoonotic agents include *Yersinia, Pasteurella, Mycoplasma,* and *Klebsiella*. Specific strains like *E. coli* O157 and *Mycobacterium Avium* can also be transmitted from certain birds to humans. The most critical bacterial zoonoses in pet birds include chlamydiosis, salmonellosis, mycobacteriosis, campylobacteriosis, and Lyme disease (Hosseinian, 2022)

According to a study, pet birds pose serious health risks to the population by spreading *Salmonella* spp. Six isolates, including pathogenicity-associated serotypes, were found with a prevalence of 0.9%. Additional questions concerning infection treatment possibilities are brought up by the significant level of antibiotic resistance seen, especially to streptomycin (83.3%). Owners and others, particularly vulnerable people, are at risk from these birds because they can be asymptomatic carriers. To reduce the health hazards associated with pet birds, knowledge and preventive actions are essential due to the possibility of zoonotic transmission. Oksh et al. (2019) found that 83% of the *E. coli* isolates, 87.5% of the *Salmonella* isolates, 38.9% of the staphylococci isolates, and 100% of the *listeria* isolates recovered from pet birds showed MDR patterns against three antimicrobial drugs, according to an analysis of the isolates' AMR profiles. The presence of *E. coli* in the intestinal tract of psittacine is considered a sanitary risk. Public health is also dangerous because of strains that produce Shiga toxin (STEC), a strong cytotoxin that prevents eukaryotic cells from synthesizing proteins (Chiacchio et al., 2016). Extended-spectrum β-lactamases were discovered in *E. coli* from Turkish cage birds. There is a chance that these germs might spread and colonize people because birds and their caretakers frequently dwell nearby. This might pose a risk to public health (Yılmaz and Dolar, 2017).

Conclusion and recommendations

The role that ornamental birds play in spreading zoonotic diseases and the emergence of antimicrobial resistance (AMR) is a growing public health issue that needs greater attention. This study has highlighted ornamental birds as potential vectors for spreading infectious diseases, especially antibiotic-resistant ones, due to their global distribution and interactions with humans, other animals, and the environment. Ornamental birds are becoming increasingly common in urban areas and the pet trade, but they are also being connected to the development of zoonotic illnesses like avian influenza, *Salmonella*, and *Campylobacter,* as well as antibiotic resistance. These risks are further increased by the overuse and misuse of antibiotics in veterinary care and the pet trade.

A multimodal strategy is needed to address the threat of ornamental birds in light of zoonotic illnesses and AMR. Crucial measures include heightened public awareness campaigns about proper handling and care of ornamental birds, tighter laws in the pet trade, and more surveillance. Furthermore, reducing the increasing hazards requires more significant research on ornamental bird ecology and pathogen transmission and creating sustainable, alternative approaches to ornamental bird health management.

By being proactive, we can lessen the risks ornamental birds bring to public health and the worldwide burden of zoonotic diseases and antibiotic resistance, making the environment safer for both people and animals. In addition, we recommend implementing one health approach to combat antimicrobial resistance and to create awareness among the community's people.

Article Information

Funding. This research received no external funding

Conflicts of Interest. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments. Department of Microbiology and Hygiene, Faculty of Veterinary Science, Bangladesh Agricultural University.

Authors contribution. Conceptualization: M.T.R., R.I.M., Draft Writing; R.I.M., R.J., Z.B., M.T.H.A., D.A.J. N.A.I.F, Review and editing; M.T.R., R.I.M., Visualization: R.I.M., R.J., Z.B., M.T.H.A., D.A.J., N.A.L.F., Supervision: MTR, all authors read and approved the final version of the manuscript

Publisher's Note. The claims and data contained in this manuscript are solely those of the author(s) and do not represent those of the GMPC publisher, editors, or reviewers. GMPC publisher and the editors disclaim the responsibility for any injury to people or property resulting from the contents of this article.

References

Abd-Rabou, A.N., 2022. The Goldfinch (*Carduelis Carduelis*

Linnaeus, 1758) in Palestine: An appreciated bird and a threatened species. Biomedical Journal of Scientific & Technical Research, 47. https://doi.org/10.26717/bjstr.2022.47.007437

Athanasakopoulou, Z., Diezel, C., Braun, S.D., Sofia, M., Giannakopoulos, A., Monecke, S. et al., 2022. Occurrence and characteristics of ESBL-and carbapenemase-producing *Escherichia coli* from wild and feral birds in Greece. Microorganisms 106, 1217. https://doi.org/10.3390/microorganisms10061217

Tixier-Boichard, M., Bed'Hom, B. and Rognon, X., 2011. Chicken domestication: from archeology to genomics. Comptes Rendus. Biologies 334, 197-204. https://doi.org/10.1016/j.crvi.2010.12.012

Bordun, T., Iegorov, B., 2022. Innovative approaches in the formation of compound feed recipes for decorative birds and singing birds and technology of compound feed production for them. Grain Products and Mixed Fodder's 21, 29–37. https://doi.org/10.15673/gpmf.v21i3.2231

Boseret, G., Losson, B., Mainil, J.G., Thiry, E., Saegerman, C., 2013. Zoonoses in pet birds: Review and perspectives. Veterinary Research 44. https://doi.org/10.1186/1297-9716-44-36

Chiacchio, R.M.G.Di., Cunha, M.P.V., Sturn, R.M., Moreno, L.Z., Moreno, A.M., Pereira, C.B.P. et al., 2016. Shiga toxin-producing *Escherichia coli* (STEC): Zoonotic risks associated with psittacine pet birds in home environments. Veterinary Microbiology 184, 27–30. https://doi.org/10.1016/j.vetmic.2016.01.004

Day, M.J., 2016. Pet-Related Infections. http://www.wsava.org/educational/

De Marchi, L., Vernaccini, M., Meucci, V., Briganti, A., Lippi, I., Marchetti, V. et al., 2024. Six-year prescription pattern of antimicrobial use in cats at the veterinary teaching hospital of the University of Pisa. Animals 14, 3. https://doi.org/10.3390/ani14030521

Diren Sigirci, B., Celik, B., Başaran Kahraman, B., Bagcigil, A.F., Ak, S., 2019. Tetracycline resistance of Enterobacteriaceae isolated from feces of synanthropic Birds. Journal of Exotic Pet Medicine 28, 13–18. https://doi.org/10.1053/j.jepm.2017.12.003

Diren Sigirci, B., Celik, B., Halac, B., Adiguzel, M.C., Kekec, I., Metiner, K. et al., 2020. Antimicrobial resistance profiles of *Escherichia coli* isolated from companion birds. Journal of King Saud University - Science 32, 1069–1073. https://doi.org/10.1016/j.jksus.2019.09.014

Djuwanto, B.A., 2020. Wild Bird as a reservoir of antimicrobial resistance (AMR) in the Environment. University of Edinburgh. https://doi.org/10.17869/enu.2021.2808666

Dubnau, D., Blokesch, M., 2019. Mechanisms of DNA uptake by naturally competent bacteria. In Annual Review of Genetics 53, 217–237. https://doi.org/10.1146/annurev-genet-112618-043641

Ebani, V.V., Mancianti, F., 2022. Potential role of birds in the epidemiology of *Coxiella burnetii*, Coxiella-like Agents, and *Hepatozoon* spp. Pathogens 11, 3. https://doi.org/10.3390/pathogens11030298

Eid, S., El-Oksh, A.S., 2019. Pet birds, their role in the transmission of some bacterial pathogens. Nature and Science 17. https://doi.org/10.7537/ marsnsj170419.10

Friedmann, E., Thomas, S.A., 2018. Health benefits of pets for families. Pets and the Family, 191–204. Routledge. https://doi.org/10.4324/9781315784656-14

Gordon, S.M., 2006. Antibiotic prophylaxis against postoperative wound infections. Cleveland Clinic journal of medicine 73. https://doi.org/10.3949/ccjm.73.Suppl_1.S42

Haukka, A., Lehikoinen, A., Mammola, S., Morris, W., Santangeli, A., 2023. The iratebirds Citizen Science Project: a dataset on birds' visual aesthetic attractiveness to humans. Scientific Data 10, 1–12. https://doi.org/10.1038/s41597-023-02169-0

Heesterbeek, H., Anderson, R.M., Andreasen, V., Bansal, S., DeAngelis, D., Dye, C. et al., 2015. Modeling infectious disease dynamics in the complex landscape of global health. Science. 347, 6227. https://doi.org/10.1126/science.aaa4339

Hollingsworth, T.D., Pulliam, J.R.C., Funk, S., Truscott, J.E., Isham, V., Lloyd, A.L. et al., 2015. Seven challenges for modelling indirect transmission: vector-borne diseases, macroparasites and neglected tropical diseases. Epidemics 10, 16–20. https://doi.org/10.1016/j.epidem.2014.08.007

Hossain Sigma, S., Nahid Ashraf, M., Sultana, S., Hassan, J., Sultana Royal, S., Sultana Rimi, S. et al., 2024. Isolation and molecular detection of antibiotic resistant *Staphylococcus aureus* from pet birds of Mymensingh City corporation areas, Bangladesh. American Journal of Microbiological Research 12, 1–6. https://doi.org/10.12691/ajmr-12-1-1

Hosseinian, S.A., 2022. Zoonotic diseases associated with pet birds. Journal of Zoonotic Diseases 6, 91–112. https://doi.org/10.22034/jzd.2022.15461

Jarma, D., Sánchez, M.I., Green, A.J., Peralta-Sánchez, J.M., Hortas, F., Sánchez-Melsió, A. et al., 2021. Faecal microbiota and antibiotic resistance genes in migratory waterbirds with contrasting habitat use. Science of the Total Environment 783, 146872. https://doi.org/10.1016/j.scitotenv.2021.146872

Jonas, O.B., Irwin, A., Berthe, F.C.J., Le Gall, F.G., Marquez, P.V., 2017. Drug-resistant infections: A threat to our economic future. World Bank Report 2, 1–3. https://www.researchgate.net/publication/317235163

Li, G.H., Hou, D.J., Fu, H.D., Guo, J.Y., Guo, X.B., Gong, H., 2014. A review of prophylactic antibiotics use in plastic surgery in China and a systematic review. International Journal of Surgery 12, 1300–1305. https://doi.org/10.1016/j.ijsu.2014.10.029

Maier, B., 2020. Competence and transformation in *Bacillus subtilis*. Current Issues in Molecular Biology 37, 57–76. https://doi.org/10.21775/CIMB.037.057

Mangram, A.J., Horan, T.C., Pearson, M.L., Silver, L.C., Jarvis, W.R., 1999. Guideline for prevention of surgical site infection, 1999. Centers for Disease Control and Prevention (CDC) Hospital Infection Control Practices Advisory Committee. American Journal of Infection Control 27. https://pubmed.ncbi.nlm.nih.gov/10196487/

Martín-Maldonado, B., Vega, S., Mencía-Gutiérrez, A., Lorenzo-Rebenaque, L., de Frutos, C., González, F. et al., 2020. Urban birds: An important source of antimicrobial resistant *Salmonella* strains in central Spain. Comparative Immunology, Microbiology and Infectious Diseases 72, 101519. https://doi.org/10.1016/j.cimid.2020.101519

Mather, A.E., Lawson, B., de Pinna, E., Wigley, P., Parkhill, J., Thomson, N.R. et al., 2016. Genomic analysis of *Salmonella enterica serovar* Typhimurium from wild passerines in England and Wales. Applied and Environmental Microbiology 82, 6728–6735.

https://doi.org/10.1128/AEM.01660-16

Murray, C.J., Ikuta, K.S., Sharara, F., Swetschinski, L., Robles Aguilar, G., Gray, A. et al., 2022. Global burden of bacterial antimicrobial resistance in 2019: A systematic analysis. The Lancet, 399, 629–655. https://doi.org/10.1016/S0140-6736(21)02724-0

Okunlade, A.O., Esan, O.O., Ogunleye, A.O., 2021. Multidrug-resistant *E. coli* recovered from household reared female budgerigar pet bird (*Melopsittacus undulatus*) in Ibadan, Oyo State Nigeria: A case report. Bulletin of the National Research Centre 45, 1–4. https://doi.org/10.1186/s42269-021-00617-8

Peng, S., Broom, D.M., 2021. The sustainability of keeping birds as pets: Should any be kept? Animals 11, 1–14. https://doi.org/10.3390/ani11020582

Prouillac, C., 2021. Use of antimicrobials in a french veterinary teaching hospital: A retrospective study. Antibiotics 10. https://doi.org/10.3390/antibiotics 10111369

Rahman, M.T., Sobur, M.A., Islam, M.S., Ievy, S., Hossain, M.J., Zowalaty, M.E.E. et al., 2020. Zoonotic diseases: Etiology, impact, and control. Microorganisms 8, 1–34. https://doi.org/10.3390/microorganisms8091405

Rathmann, I., Förster, M., Yüksel, M., Horst, L., Petrungaro, G., Bollenbach, T. et al., 2023. Distribution of fitness effects of cross-species transformation reveals potential for fast adaptive evolution. ISME Journal 17, 130–139. https://doi.org/10.1038/s41396-022-01325-5

Schneider, C.L., 2021. Bacteriophage-Mediated Horizontal Gene Transfer: Transduction. Bacteriophages: Biology, Technology, Therapy 2, 151–192. https://doi.org/10. 1007/978-3-319-41986-2_4

Siddiky, N.A., Sarker, M.S., Khan, M.S.R., Begum, R., Kabir, M.E., Karim, M.R. et al., 2021. Virulence and antimicrobial resistance profiles of *Salmonella* enterica serovars isolated from chicken at wet markets in Dhaka, Bangladesh. Microorganisms 9, 952. https://doi.org/10.3390/ microorganisms9050952

Skarżyńska, M., Zając, M., Bomba, A., Bocian, Ł., Kozdruń, W., Polak, M. et al., 2021. Antimicrobial resistance glides in the sky—free-living birds as a reservoir of resistant *Escherichia coli* with zoonotic potential. Frontiers in Microbiology 12, 656223. https://doi.org/10.3389/fmicb .2021.656223

Stastistica, 2023. Ornamental bird population in the EU by country 2023. Statista. https://www.statista.com /statistics /515421/ornamental-bird-population-european -union-eu-by-country/

Stewart, S.J., 1996. Tularemia: Association with hunting and farming. FEMS Immunology & Medical Microbiology 13, 197–199. https://doi.org/10.1111/j.1574-695x.1996. tb00236.x

Tidemann, Sonia, Gosler, Andrew, 2010. Ethno-ornithology: birds, Indigenous peoples, culture and society. Routledge: Earthscan, London 346. https://www.researchgate. net/publication/255172902_Ethno Ornithology_Birds_ Indigenous_Peoples_Culture_and_Society

Virolle, C., Goldlust, K., Djermoun, S., Bigot, S., Lesterlin, C., 2020. Plasmid transfer by conjugation in Gram-negative bacteria: From the cellular to the community level. Genes 11, 1–33. https://doi.org/10.3390/genes11111239

Vittecoq, M., Godreuil, S., Prugnolle, F., Durand, P., Brazier, L., Renaud, N. et al., 2016. Antimicrobial resistance in wildlife. Journal of Applied Ecology 53, 519–529. https://doi.org/10.1111/1365-2664.12596

WHO. IACG, 2019. No time to wait: Securing the future from drug-resistant infections report to the secretary-general of the United Nations. https://www.who.int/publications /i/item/no-time-to-wait-securing-the-future-from-drug-resistant-infections

Yılmaz, E.Ş., Dolar, A., 2017. Detection of Extended-Spectrum β-Lactamases in *Escherichia coli* from cage birds. Journal of Exotic Pet Medicine 26, 13–18. https://doi.org/10.1053/j.jepm.2016.10.008