

Factors associated with avian influenza infections in indoor commercial poultry farm settings: A systematic review

Elvira Meni Maria Gkrinia^{a,1}, Lisa Kohnle^{b,2}, Christina Joanne Atchison^{a,3}, Wendy Kwok^{a,*,4} 

^a School of Public Health, Imperial College, London, United Kingdom

^b European Food Safety Authority, Parma, Italy

ARTICLE INFO

Keywords:

Animal husbandry
Biosecurity
Influenza in birds
Protective factors
Risk factors
Systematic review

ABSTRACT

Avian influenza (AI) poses a significant threat to animal and human health, as well as to the poultry industry, with demonstrably pandemic potential. Intensive farming has been associated with conditions that may facilitate the emergence and spread of AI viruses with pandemic potential. To assess the risk and protective factors associated with AI infections in poultry within intensive production systems, a systematic literature review was conducted. Databases including Embase, PubMed/Medline, the Health Management Information Consortium, and Global Health were searched for publications from 2003 to 2023, with additional grey literature included. A total of 127 full-text studies were reviewed by two independent researchers, resulting in 27 studies being included. Quality appraisal of the included studies was performed using the Critical Appraisal Skills Programme and the Joanna Briggs Institute checklists, leading to the exclusion of four studies due to low quality. Ultimately, 23 studies were included in the final analysis. Study characteristics, as well as risk and protective factors were extracted, with most factors being related to the introduction of AI into commercial poultry farms. Biosecurity measures emerged as the most significant protective factor against AI. Environmental factors and the production system adopted also influenced a farm's risk of AI infections. Given AI's detrimental effect on ecosystems, economies, international trade, and both human and animal health, enhancing husbandry and biosecurity practices on commercial poultry farms is crucial to safeguard animal welfare, promote sustainable poultry production, and manage the risk of emerging pandemic AI strains.

1. Introduction

Avian Influenza (AI) is primarily a disease affecting bird populations, but certain AI viruses (AIV) demonstrably carry pandemic potential and are considered a threat to human health (Yamaji et al., 2020; Sutton, 2018; Kong et al., 2015; Peiris et al., 2007; Liu, 2006). AIV can have detrimental health and economic effects, particularly in regions reliant on animal husbandry (Hill et al., 2015; Basuno et al., 2010). Settings where people come into close contact with animals, such as live animal trade and commercial farming, are at high risk for zoonotic outbreaks (Sulaiman et al., 2021; Capua and Marangon, 2006).

Wild birds (Global Consortium for H5N8 and Related Influenza

Viruses, 2016), scavenging poultry (Badruzzaman et al., 2022), backyard flocks (Kwon et al., 2019), and non-avian species, such as swine, mink, domestic cats and dogs, and occasionally equids (De Vries and De Haan, 2023; Occhibove et al., 2024; Van Leeuw et al., 2025; Van Reeth et al., 2017) are reservoirs for low pathogenic AI (LPAI) strains. Some studies suggest that less industrialized or backyard poultry systems can be more vulnerable to AI due to lower biosecurity and greater exposure to wild birds (Biswas et al., 2009; Gilbert et al., 2006). However, certain husbandry practices in commercial poultry farming, such as number of birds and flocks per cycle and movement of farm workers, as well as the large number and density of poultry kept (Willyard, 2019; Smith and Dunipace, 2011; Gilchrist et al., 2006), can create conditions that

* Corresponding author.

E-mail addresses: elvira.gkrinia20@alumni.imperial.ac.uk (E.M.M. Gkrinia), lisa.kohnle@efsa.europa.eu (L. Kohnle), christina.atchison11@imperial.ac.uk (C.J. Atchison), w.kwok@imperial.ac.uk (W. Kwok).

¹ <https://orcid.org/0009-0002-1255-8653>

² <https://orcid.org/0000-0003-3181-0877>

³ <https://orcid.org/0000-0001-8304-7389>

⁴ <https://orcid.org/0000-0001-5200-7958>

facilitate AIV reassortment. This may contribute to the emergence of highly pathogenic avian influenza (HPAI) strains, some of which are of human pandemic potential (Shi et al., 2017; Wu et al., 2015; Gambotto et al., 2008). That said, reassortments of AIVs have also frequently occurred in wild birds, which serve as highly permissive hosts for viral genetic exchange, and also in mammals such as pigs and other wild or domesticated mammals, facilitating the emergence of novel strains and host range expansion (Peacock et al., 2024; Ganti et al., 2021). Workers on commercial poultry farms have a higher risk of contracting AI than the general population (Li et al., 2016; Qi et al., 2014; Wang et al., 2014a, 2014b), and AI is considered an occupational hazard (Fournié et al., 2017; MacMahon et al., 2008). Recently, a human case was reported in a poultry farm worker in the UK, while between May 2024 and March 7, 2025, US health authorities reported 12 cases of AIV infection in humans (European Food Safety Authority, 2025; Pan-American Health Organization, 2025). Furthermore, the first human death from H5N1 was confirmed in the US on January 6, 2025 (Centers for Disease Control and Prevention, 2025).

Most human HPAI infections are a result of contact with poultry (European Centre for Disease Prevention and Control, 2023) or contaminated environments, such as surfaces, soil, bird feces, and feathers (Miskiewicz et al., 2018). However, there have been sporadic human-to-human and human-to-animal transmission incidents (Shi et al., 2020; Sjurseth et al., 2017). Currently, the most predominant HPAI subtype in human infections is H5N1, which according to the World Health Organization (WHO) has a human mortality rate of around 50 %. Symptoms in humans include fever, cough and dyspnea, which gradually worsen, and deaths have been linked to organ failure (Rajabali et al., 2015; Chen et al., 2014; Hien, 2012). AI is considered a threat to public health because certain forms may cause severe illness in humans (Yang et al., 2013; Zhang et al., 2010) and outbreaks have spread more extensively in terms of geographical distribution and host range (Eisfeld et al., 2024; Kniss et al., 2023; Wille and Barr, 2022; Kaplan and Webby, 2013). As there are more places where AI circulates, as showcased by recent epidemics in intensive production systems in Europe, North America (US, Canada) and Asia (South Korea, Taiwan, Japan, India), there is more opportunity globally for the emergence of AIV with pandemic potential (Dupas et al., 2025; European Food Safety Authority, 2025; Department for Environment, Food & Rural Affairs, 2024; Centers for Disease Control and Prevention, 2022; World Health Organization, 2022). The escalating risk of AI has shifted the focus from prevention alone to advocating for a fundamental redesign of the food system (Wegner et al., 2022). Therefore, improving understanding of risk factors for avian influenza on commercial poultry farms, which are recognized as environments where novel strains may reassort and spread, potentially increasing human exposure, is essential for effective prevention and control.

Various factors affect commercial farms' risk for AI outbreaks. Research showed that flocks living under intensive farming conditions were at a high risk for emergence of and infection with reassorted AI strains, emphasising the need for biosecurity and surveillance measures (Melidou et al., 2024; Chang, 2016). Adequate biosecurity measures and educating poultry farm workers about their role in AI prevention have been successful in preventing outbreaks (Bos et al., 2010; Gray and Kayali, 2009; MacMahon et al., 2008). Prioritizing poultry farm workers in AI vaccination programs offers a demonstrated benefit in mitigating the risk of AI outbreaks by reducing the potential for viral reassortment and transmission between humans and poultry (Artois et al., 2018; Gray and Baker, 2007). That said, measuring the level of implementation of biosecurity and surveillance measures is not straightforward and difficult to do accurately, thus the quality of evidence available in literature needs to be carefully assessed.

The aim of this systematic review was to identify the key risk and protective factors for AI within commercial indoor poultry farms. Obtaining a thorough understanding of the associated factors may support policy-makers decide what changes should be made to protect

public health, particularly as certain AIV have become endemic in some regions and cases have risen globally.

2. Materials & methods

The review was conducted according to PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines and was registered in the PROSPERO database on January 15, 2024 (CRD42024463281).

2.1. Eligibility criteria

Inclusion and exclusion criteria (Table 1) were developed using the PECO search framework (Morgan et al., 2018) (Appendix A). Analytic observational studies, clinical trials and quasi-experimental field trials were eligible for inclusion.

2.2. Search strategy

The Embase, PubMed/Medline, Health Management Information Consortium and Global Health databases were searched for medical subjects, and Scopus was searched to include a multidisciplinary perspective. As AI is recognized as an occupational risk, the International Labour Organization website was searched, along with the websites of the World Organisation for Animal Health (WOAH) and the WHO for grey literature (Adam-Poupart et al., 2021). A systematic literature search was conducted separately on each database between the 20th and 27th July 2023, and to ensure comprehensive coverage of the available evidence, an additional manual search was performed in March 2025. MeSH terms were used to guarantee that no results would be lost due to different spelling or use of terms, as well as to ensure that the search strategy produced all suitable results. The comprehensive search strategy is presented in Appendix B.

2.3. Study selection

All identified references were uploaded onto Covidence (Veritas Health Innovation, 2024), where duplicates were automatically removed. The titles and abstracts of publications were screened by one reviewer (E.G.) based on the inclusion and exclusion criteria. Full-text screening for inclusion into the study according to the eligibility criteria was performed independently by two reviewers (W.K., E.G.) for studies deemed suitable at the title/abstract level or when the abstract was not informative enough to decide. There was 85 % agreement between the two reviewers. Any conflicts were resolved by consensus and if agreement could not be reached, a third reviewer (L.K.) made the final decision. Reasons for exclusion were recorded (including duplicates).

2.4. Data extraction

A standardised Excel template was used to collect information on study design characteristics and methodology along with baseline characteristics and key outcomes of interest regarding risk and protective factors for AI. The data extraction was undertaken by one reviewer (E.G.) and checked by a second reviewer (W.K.).

2.5. Quality assessment

To enhance the relevance and reliability of the review, the included studies were assessed for quality and bias. Firstly, the Critical Appraisal Skills Programme (CASP) checklist (Critical Appraisal Skills Programme, 2024), recommended by Cochrane, was used to assess the quality of the case-control studies and to allow prioritization of studies of higher quality during evidence synthesis. Secondly, the Joanna Briggs Institute (JBI) checklist (Joanna Briggs Institute, 2020) was used for cross-sectional studies. Each included study was scored based on these

Table 1
Inclusion and exclusion criteria used for the selection of studies in the systematic review.

Inclusion Criteria
• English language • Publication between 2003 (major outbreak among poultry farm workers in the Netherlands [Koopmans et al., 2004]) and February 2025 • AI (LPAI and HPAI strains, as they can both cause severe illness in humans and birds) • Commercial indoor farms where poultry is raised for meat / products / re-sell • Reported risk factors for AI within commercial indoor poultry farms • Reported protective factors against AI within commercial indoor poultry farms • Reported odds ratios for each risk / protective factor • Farms with chickens, ducks, quails, turkeys, geese, pheasants, doves, ostriches • Studies where the outcome is AI infection • Grey literature reports and publications by non-industry organizations
Exclusion Criteria
• Phylogenetic analyses, studies about serological evidence, seroprevalence studies, reviews, opinions, experimental studies (<i>in vitro</i> infections), economic studies, genome characterization, molecular epidemiology, genome sequencing, mathematic modelling • Backyard / household flocks. • Wild / migratory birds • Free-ranging / outdoor farms (unless they are compared to commercial farms and / or it is possible to differentiate the study's results about intensive and free-ranging farms) • Studies about live markets, zoos, game birds, cockfighting • Studies about non-avian species • Studies about other diseases

AI, avian influenza; HPAI, highly pathogenic avian influenza; LPAI, low pathogenic avian influenza

checklists and a threshold of 9/11 for the CASP checklist and 6/8 for the JBI checklist was set. If a study scored less than the threshold, it was excluded to ensure the inclusion of studies of high quality.

2.6. Data synthesis and analysis

Regarding evidence synthesis, since a variety of study types were included and the results were heterogenous and not readily comparable, a meta-analysis was not deemed appropriate (McKenzie and Brennan, 2019; Imrey, 2020). Extracted data were grouped and presented in separate tables and sections based on whether the risk/protective factor mentioned referred to the introduction or the spread of AI. For the measures and factors that applied to both, a separate paragraph and table were compiled. The risk factors in each table were sorted by odds ratio (OR), starting with OR higher than 1 and ending with OR lower

than 1.

3. Results

The database search identified a total of 16,120 records, of which 8704 duplicates were removed using Covidence Software. The study selection process, along with the rationale for inclusion and exclusion, is detailed in the PRISMA flow diagram (Fig. 1).

After applying the inclusion and exclusion criteria, a total of 27 studies were initially retained. However, four studies were subsequently excluded from the analysis due to low scores on the JBI and CASP checklists, leaving 23 studies for final inclusion. Of these, 20 were case-control studies and three were cross-sectional. All the studies conducted research on the premises of commercial poultry farms between 2003 and 2022, with study locations spanning Asia (n = 12), Africa (n = 5), North

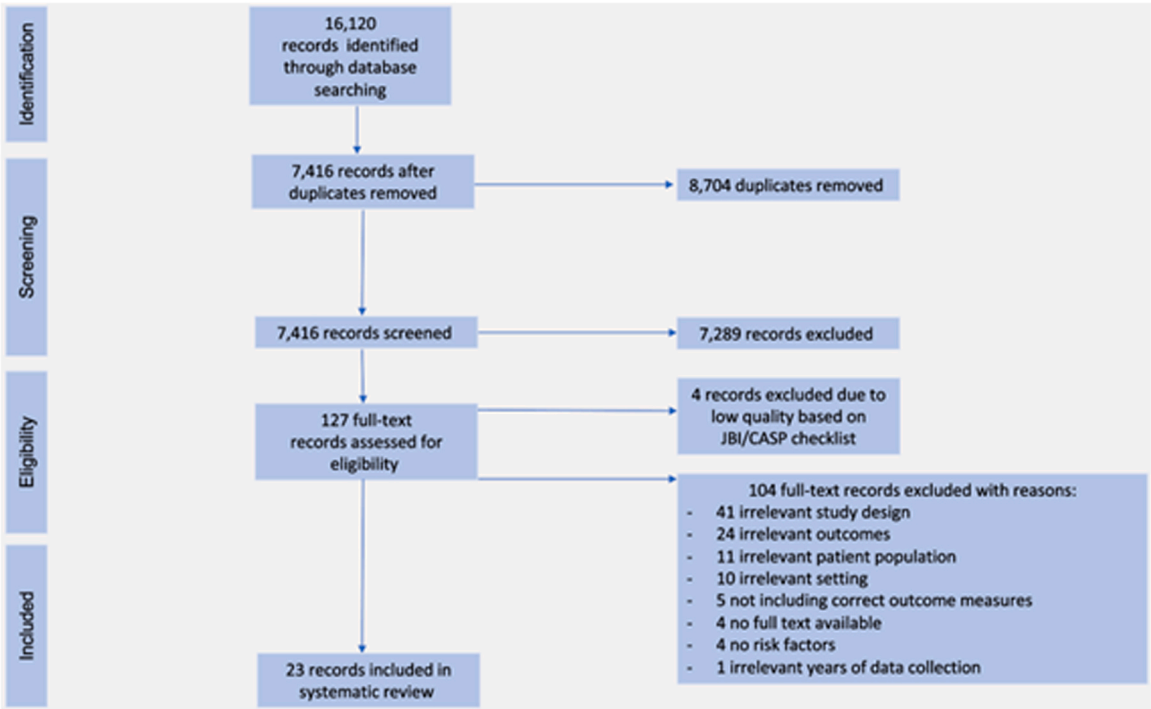


Fig. 1. PRISMA flow diagram depicting the process and rationale of study selection for this review.

America (n = 3), and Europe (n = 3). Fifteen studies reported data on farms affected by HP AI, while seven focused on LP AI, and one study included data on farms affected by both AI forms. Study characteristics are detailed in Table 2.

Questionnaires were administered on farms with laboratory-confirmed infection in 16 studies (#ID 3,4,6,7,8,9,11,12,13,14,15,16,17,19,21,22). Multivariable logistic regression was used in 14 of these studies, while binomial logistic regression was conducted in the remaining two. Site visits were conducted in seven studies (#ID 1,2,5,10,18,20,23). Additionally, nine studies employed polymerase chain reaction (PCR) (#ID 2,6,7,8,9,12,14,17,21) to confirm infection and three studies used enzyme-linked immunosorbent assay (ELISA) (#ID 5,11,20) to estimate seroprevalence.

3.1. Quality appraisal of included studies

The case-control and cross-sectional studies had a median score of 10 out of 11 and 7 out of 8 on the CASP and JBI checklists, respectively. The four studies that were excluded due to a low score did not account for bias and / or confounding factors. The results of the quality appraisal are included in Appendix C.

3.2. Studies investigating only factors associated with the introduction of AI

Finding a dead crow at or near the poultry farm was associated with the highest OR for the introduction of AI (OR 47.4; 95 % CI 4.7–480.3) (Biswas et al., 2011), followed by the farm being located close to other farms (OR 46.1; 95 % CI 5.96–357.55) (Wells et al., 2017), the farm

being in a control zone (OR 32.0; 95 % CI not reported) (Garber et al., 2016), sharing of farm equipment (OR 29.4; 95 % CI 4.2–207.5) (Nishiguchi et al., 2007), and rendering trucks being near the premises (OR 22.3; 95 % CI not reported) (Garber et al., 2016).

Conversely, factors associated with a protective effect against the introduction of AI into commercial poultry farms included visitors changing clothes when exiting or entering the farm (OR 0.08; 95 % CI not reported) (Garber et al., 2016), high worker biosecurity (OR 0.07; 95 % CI 0.01–0.96) (Wells et al., 2017), presence of a disinfection booth (OR 0.002; 95 % CI 0.000–0.025) (Yoo et al., 2021), and specific vehicles being designated for sending eggs to a vendor or market (OR 0.14; 95 % CI 0.02–0.88) (Biswas et al., 2009). In Wells et al., a cumulative score for worker biosecurity was created by summing the number of worker biosecurity protocols that were “always” or “nearly always” used by farm workers, which included requirement of showering before entering barn, assignment of different personnel to different barns, use of dry footbaths, use of disposable coveralls, requiring a change of clothes upon barn entry, requiring a change of shoes or shoe covers upon barn entry, and requiring footwear to be scrubbed with a bucket and brush (Wells et al., 2017).

Bouwstra et al. reported their findings in the form of relative risk (RR), with the production system being either meat-duck or duck-breeder yielding the highest RRs (39.5 [95 % CI 22.6–69.1] and 25.5 [95 % CI 14.2–45.9], respectively), while the production types layer-breeder, broiler, and broiler-breeder displayed a protective effect (RR 0.5 [95 % CI 0.3–0.8], 0.2 [95 % CI 0.1–0.8], and 0.4 [95 % CI 0.2–0.8], respectively) (Table 3).

Table 2

Summary of the main characteristics of studies included in the review.

#	Author, Year	Study type	Location	Species	Farm type / production system	AI strain [pathogenicity]
1	Ahmad et al. (2022)	Case-control	South Korea	Chickens / Ducks / Quails / Geese / Ostriches	Breeder / Broiler / Layer	H5N8/H5N6 [HPAI]
2	Artois et al. (2018)	Case-control	Egypt	Chickens / Ducks	Breeder / Broiler / Layer / Meat (duck)	H5N1 [HPAI]
3	Biswas et al. (2009)	Case-control	Bangladesh	Chickens	Breeder / Broiler / Layer	H5N1 [HPAI]
4	Biswas et al. (2011)	Case-control	Bangladesh	Chickens	Breeder / Broiler / Layer	H5N1 [HPAI]
5	Bouwstra et al. (2017)	Case-control	Netherlands	Ducks / Turkeys / Chickens	Breeder / Broiler / Layer / Layer-breeder / Meat (duck) / Meat (turkey)	NR [LP AI]
6	Chaudhry et al. (2015)	Case-control	Pakistan	Chickens	Broiler / Layer	H9N2 [LP AI]
7	Fasina et al. (2010)	Case-control	Nigeria	Chickens	NR	H5N1 [HPAI]
8	Garber et al. (2016)	Case-control	USA	Chickens	Layer / Pullet	H5N2 [HPAI]
9	Gompo et al. (2020)	Case-control	Nepal	Chickens / Ducks	Breeder / Broiler / Layer	H9 [LP AI]
10	Guinat et al. (2020)	Case-control	France	Ducks	Breeder / Force feeding / Mixed / Rearing*	H5N8 [HPAI]
11	Gupta et al. (2022)	Cross-sectional	Bangladesh	Chickens	Broiler / Layer	H5/H9 [HPAI/LPAI]
12	Kim et al. (2018)	Case-control	South Korea	Ducks	Broiler	H5N8 [HPAI]
13	Liu et al. (2015)	Case-control	China	Chickens	Layer	H5N1 [HPAI]
14	McQuiston et al. (2005)	Case-control	USA	Chickens / Turkeys	NR	H7N2 [LP AI]
15	Métras et al. (2012)	Case-control	Nigeria	Chickens / Turkeys	Broiler / Layer	H5N1 [HPAI]
16	Nishiguchi et al. (2007)	Case-control	Japan	Chickens	Layer	H5N2 [LP AI]
17	Osmani et al. (2013)	Case-control	Bangladesh	Chickens	Layer	H5N1 [HPAI]
18	Thomas et al. (2005)	Case-control	Netherlands	Chickens	Layer / Meat	H7N7 [HPAI]
19	Thompson et al. (2008)	Cross-sectional	South Africa	Ostriches	NR	H5 [HPAI]
20	Tombari et al. (2013)	Cross-sectional	Tunisia	Chickens / Turkeys	Breeder / Broiler / Layer	H9N2 [LP AI]
21	Wells et al. (2017)	Case-control	USA	Turkeys	Breeder / Meat	H5N2 [HPAI]
22	Woo and Park (2008)	Case-control	South Korea	Chickens / Ducks	Broiler / Layer	H9N2 [LP AI]
23	Yoo et al. (2021)	Case-control	South Korea	Chickens	Layer	H5N6 [HPAI]

*1-day old ducklings reared for around 3 weeks; AI, avian influenza; HP AI, highly pathogenic avian influenza; LP AI, low pathogenic avian influenza; NR, not reported

Table 3

Overview of results summarizing risk or protective factors for the introduction of AI into commercial poultry farms. The risk factors have been ranked by highest OR.

Author, Year	Country	Sample size (farms, n)	Sample size (n of birds per farm)	Risk factor	OR (95 % CI)	P-value
Biswas et al. (2011)	Bangladesh	60	520–9424 chickens	Dead crow seen at or near farm	47.4 (4.7–480.3)	0.001
Wells et al. (2017)	USA	63	Median size of case and control farms was 56,930 and 51,847 birds, respectively	Close proximity to poultry farms	46.14 (5.96–357.55)	< 0.01
Bouwstra et al. (2017)*	Netherlands	295	NR	Production type: meat-duck	39.5 (22.6–69.1)	< 0.00001
Garber et al. (2016)	USA	59	~20,000–6000,000 chickens	Farm is in an existing control zone†	32.0 (NR)	0.002
Nishiguchi et al. (2007)	Japan	73	~9000–500,000 chickens	Sharing of farm equipment	29.4 (4.2–207.5)	< 0.05
Bouwstra et al. (2017)*	Netherlands	295	NR	Production type: duck-breeder	25.5 (14.2–45.9)	< 0.00001
Garber et al. (2016)	USA	59	~20,000–6000,000 chickens	Rendering trucks near farm	22.3 (NR)	< 0.001
Biswas et al. (2011)	Bangladesh	60	520–9424 chickens	Exchanging egg trays with market vendors	20.4 (1.9–225.5)	0.014
Nishiguchi et al. (2007)	Japan	73	~9000–500,000 chickens	Distance to nearest case farm: 1000–1500 m	20.1 (3.0–142.9)	< 0.05
Biswas et al. (2011)	Bangladesh	60	520–9424 chickens	Mortality seen in backyard chickens reared nearby	19.4 (2.8–131.9)	0.002
Garber et al. (2016)	USA	59	~20,000–6000,000 chickens	Garbage trucks near farm	14.7 (NR)	< 0.001
Osmani et al. (2013)	Bangladesh	300	NR	Number of staff: 3–5 people	12.2 (1.1–4.3)	0.001
Bouwstra et al. (2017)*	Netherlands	295	NR	Production type: meat-turkey	12.0 (7.8–18.8)	< 0.00001
Fasina et al. (2010)	Nigeria	121	~300–3000 poultry	Purchases of live poultry	11.91 (3.11–45.59)	< 0.01
Bouwstra et al. (2017)*	Netherlands	295	NR	Production type: turkey-breeder	11.3 (2.8–46.2)	0.0008
Chaudhry et al. (2015)	Pakistan	266	NR	Selling of birds/eggs directly to the live bird retail stalls	10.6 (3.37–33.3)	< 0.001
Gompo et al. (2020)	Nepal	100	~100–3000 + poultry	Distance to next commercial farm: ≤ 1 km	10 (1.8–50.0)	0.007
Fasina et al. (2010)	Nigeria	121	~300–3000 poultry	Farm workers live outside the premises	8.98 (1.97–40.77)	< 0.01
Nishiguchi et al. (2007)	Japan	73	~9000–500,000 chickens	Distance to nearest case farm: 0–500 m	8.6 (1.2–61.8)	< 0.05
Fasina et al. (2010)	Nigeria	121	~300–3000 poultry	Farm receives visitors	8.32 (1.87–36.97)	< 0.01
Thompson et al. (2008)	South Africa	263	NR	White storks frequently seen amongst ostriches	7.51 (1.71–32.93)	0.007
Nishiguchi et al. (2007)	Japan	73	~9000–500,000 chickens	Incomplete hygiene measures of farm visitors	7.0 (1.2–42.6)	< 0.05
Guinat et al. (2020)	France	266	~100–1000 + ducks	Inadequate use of anteroom	6.5 (3.4–13.3)	≤ 0.05
Wells et al. (2017)	USA	63	Median size of case and control farms was 56,930 and 51,847 birds, respectively	Tilling near the farm in last 14 days	6.46 (1.36–30.78)	0.02
Bouwstra et al. (2017)*	Netherlands	295	NR	Production type: outdoor layer	6.3 (4.7–8.6)	< 0.00001
Kim et al. (2018)	South Korea	86	~1000–60,000 ducks	Farm is located within 500 m of another farm	6.30 (1.08–36.93)	0.041
Gupta et al. (2022)	Bangladesh	16 broiler flocks (H5/H9-positive); 53 layer flocks (H5/H9-positive)	NR	≥ 5 workers employed on the farm	5.8 (1.2–28.2)	0.013
Gupta et al. (2022)	Bangladesh	16 broiler flocks (H5/H9-positive); 53 layer flocks (H5/H9-positive)	NR	Vehicles enter the farm (excluding vehicles of traders who purchased chickens or eggs)	5.8 (1.5–22.4)	0.011
Biswas et al. (2009)	Bangladesh	132	~100–10,000 chickens	Farm is accessible to feral and wild animals	5.71 (1.81–18.0)	0.003
Liu et al. (2015)	China	87 (45 cases)	NR	Visitors within the past month	5.47 (1.97–15.64)	0.001
Osmani et al. (2013)	Bangladesh	300	NR	Number of staff: 6–65 people	5.1 (2.2–12.2)	0.001

(continued on next page)

Table 3 (continued)

Author, Year	Country	Sample size (farms, n)	Sample size (n of birds per farm)	Risk factor	OR (95 % CI)	P-value
Garber et al. (2016)	USA	59	~20,000–6000,000 chickens	Having a visit in the past 14 days by a company service person	5.0 (NR)	< 0.001
Gupta et al. (2022)	Bangladesh	16 broiler flocks (H5/H9-positive); 53 layer flocks (H5/H9-positive)	NR	3–4 workers employed on the farm	4.8 (1.4–16.3)	0.013
Gupta et al. (2022)	Bangladesh	16 broiler flocks (H5/H9-positive); 53 layer flocks (H5/H9-positive)	NR	Visits to other commercial poultry farms in the last month by farmers, workers, or family members who had access to the farm	4.7 (1.1–20.6)	0.039
Chaudhry et al. (2015)	Pakistan	266	NR	Distance from the main road: ≤ 500 m	4.59 (1.09–19.3)	0.038
Thompson et al. (2008)	South Africa	263	NR	Frequency of cleaning feed troughs: < 1x/week	4.49 (1.52–13.30)	0.007
Thompson et al. (2008)	South Africa	263	NR	Frequency of cleaning feed troughs: ~ 1x/week	4.02 (1.33–12.19)	0.014
Guinat et al. (2020)	France	266	~100–1000 + ducks	Presence of outdoor area	3.8 (1.9–8.1)	≤ 0.05
Tombari et al. (2013)	Tunisia	800 flocks	NR	Farm located in coastal area	3.51 (1.32–9.31)	0.01
Guinat et al. (2020)	France	266	~100–1000 + ducks	Inadequate protection of feed / facilities	3.5 (2.0–6.2)	≤ 0.05
Gompo et al. (2020)	Nepal	100	~100–3000 + poultry	Boots not applied when entering farm	3.48 (1.3–12.29)	0.016
Gupta et al. (2022)	Bangladesh	16 broiler flocks (H5/H9-positive); 53 layer flocks (H5/H9-positive)	NR	Access of stray dogs to the farm	3.1 (1.1–9.1)	0.040
Garber et al. (2016)	USA	59	~20,000–6000,000 chickens	Dead bird disposal within 27 m of poultry barn	2.8 (NR)	0.002
Artois et al. (2018)	Egypt	465 (chicken); 225 (duck)	NR	Presence of duck farms reporting abnormal mortality or egg losses nearby	2.31 (1.49–3.64)	0.001
Thompson et al. (2008)	South Africa	263	NR	Vehicle not cleaned/disinfected	2.28 (1.09–4.77)	0.029
McQuiston et al. (2005)	USA	350	~10,000–20,000 + turkeys or chickens	Non-family caretakers on farm	2.1 (1.1–4.1)	0.04
Thompson et al. (2008)	South Africa	263	NR	White storks seldom seen amongst ostriches	2.06 (1.00–4.27)	0.050
McQuiston et al. (2005)	USA	350	~10,000–20,000 + turkeys or chickens	Owner or family member of owner working off site	2.0 (1.1–3.7)	0.03
McQuiston et al. (2005)	USA	350	~10,000–20,000 + turkeys or chickens	Presence of raccoons, opossums, or foxes near the farm	1.9 (95 % CI 1.0–3.4)	0.04
Ahmad et al. (2022)	South Korea	NR	NR	Farm located ~900 m near body of water	NR (NR)	0.01–0.05
Yoo et al. (2021)	South Korea	243	~100–1000 + chickens	Presence of a disinfection booth	0.002 (0.000–0.025)	< 0.001
Wells et al. (2017)	USA	63	Median size of case and control farms was 56,930 and 51,847 birds, respectively	High worker biosecurity	0.07 (0.01–0.96)	0.05
Garber et al. (2016)	USA	59	~20,000–6000,000 chickens	Visitors change clothes when entering / exiting the farm	0.08 (NR)	0.01
Wells et al. (2017)	USA	63	Median size of case and control farms was 56,930 and 51,847 birds, respectively	Wild birds near dead bird disposal	0.12 (0.02–0.72)	0.02
Yoo et al. (2021)	South Korea	243	~100–1000 + chickens	Minimum distance to driveways (km)	0.124 (0.016–0.774)	< 0.001
Biswas et al. (2009)	Bangladesh	132	~100–10,000 chickens	Designated vehicles for sending eggs to a vendor / market	0.14 (0.02–0.88)	0.036
Woo and Park (2008)	South Korea	40	~20,000–40,000 + chickens or ducks	Renewal of the disinfectant at least once per 3–4 days	0.2 (0–0.7)	0.022
Bouwstra et al. (2017)	Netherlands	295	NR	Production type: broiler	0.2 (0.1–0.8)	0.02
Artois et al. (2018)	Egypt	465 (chicken); 225 (duck)	NR	Farm being closed§	0.22 (0.14–0.32)	< 0.001
Yoo et al. (2021)	South Korea	243	~100–1000 + chickens	Fence installation around the farm	0.277 (0.061–1.185)	< 0.001
Osmani et al. (2013)	Bangladesh	300	NR	Staff do not trade birds	0.3 (0.1–0.8)	0.02
Liu et al. (2015)	China	87 (45 cases)		Farm has a waste disposal system	0.37 (0.12–0.82)	0.011
Bouwstra et al. (2017)	Netherlands	295	NR	Production type: broiler-breeder	0.4 (0.2–0.8)	0.004

(continued on next page)

Table 3 (continued)

Author, Year	Country	Sample size (farms, n)	Sample size (n of birds per farm)	Risk factor	OR (95 % CI)	P-value
Bouwstra et al. (2017) *	Netherlands	295	NR	Production type: layer-breeder	0.5 (0.3–0.8)	0.008
Osmani et al. (2013)	Bangladesh	300	NR	No village chickens roaming on premises	0.6 (0.3–1.1)	0.05
Yoo et al. (2021)	South Korea	243	~100–1000 + chickens	Residential area within 3 km of farm	0.714 (0.51–0.979)	0.007
Nishiguchi et al. (2007)	Japan	73	~9000–500,000 chickens	Distance to nearest case farm: 500–1000 m	0.8 (0.08–9.3)	< 0.05
Yoo et al. (2021)	South Korea	243	~100–1000 + chickens	Minimum distance to H5N6 detection sites in wild birds (km)	0.943 (0.872–1.016)	< 0.001
Yoo et al. (2021)	South Korea	243	~100–1000 + chickens	Rice field within 3 km of farm	0.990 (0.940–1.042)	0.043

CI, confidence interval; NR, not reported; OR, odds ratio †A 10-km control zone was established around each infected premise, within which poultry, poultry products, and other materials required permitting before movement. Also, within these control zones, extensive surveillance of both commercial and backyard flocks was conducted; §In the closed farm system, ventilation is provided by electric fans or pad cooling systems

3.3. Studies investigating only factors associated with the spread of AI

Regarding the spread of AI within the farm premises, not replacing the litter during each production cycle, not using a feces removal service, > 2000 spent layers sold in the last batch of the farm, and the production type being chicken layer significantly increased the risk for AI (OR 28.3 [95 % CI 2.8–284.2], 27.7 [95 % CI 3.8–198.8], 24.0 [95 % CI 3.7–155.0], and 15.62 [95 % CI 4.7–71.6], respectively) (Gupta et al., 2022; Kim et al., 2018). In contrast, infrequent but scheduled veterinary visits, layer chickens being less than 18 weeks old, and changing of boots between sheds, were associated with a protective effect against the spread of AI (OR 0.6 [95 % CI 0.1–2.0], 0.16 [95 % CI 0.03–0.77], and 0.16 [95 % CI 0.02–0.85], respectively) (Yoo et al., 2021; Osmani et al., 2013; Tombari et al., 2013). The factors associated with the spread of AI within commercial poultry farms are included in Table 4.

3.4. Studies investigating factors associated with both the introduction and spread of AI

Farms that introduced end-of-lay chickens had a significantly higher risk for introduction and spread of AI within their premises, compared to farms that did not (OR 36.6; 95 % CI 2.4–558.6) (Nishiguchi et al., 2007). Other factors that increased the risk of introduction and/or spread of AI included inadequate management of vehicles’ and people’s movements (OR 9.3; 95 % CI 4.0–22.8) (Guinat et al., 2020), inadequate cleaning of facilities and surroundings (OR 6.6; 95 % CI 3.4–12.9) (Guinat et al., 2020), sharing a fence with another poultry farm (OR 5.23; 95 % CI 0.88–30.9) (Métras et al., 2012), and inadequate pest control (OR 5.1; 95 % CI 2.4–11.9) (Guinat et al., 2020). Conversely, poultry being vaccinated (OR 0.08; 95 % CI 0.05–0.13) (Artois et al., 2018) and traders staying at the farm gate (OR 0.23; 95 % CI 0.08–0.70) (Métras et al., 2012) limited the risk of introduction and/or spread of AI. The risk and protective factors for the introduction and/or spread of AI are included in Table 5.

4. Discussion

This systematic review identified several factors that contribute to commercial indoor poultry farms’ risk of AI infections and outbreaks, particularly related to location, husbandry practices, and biosecurity. Ecological and geographical factors, such as proximity to other farms, bodies of water, or wild bird populations, were consistently linked to an increased risk of AI. Location is particularly important, with AI becoming endemic on farms in certain regions, such as Pakistan (Channa et al., 2021). Proximity to other farms emerged as a major risk factor, aligning with previous research (Wang et al., 2014a,2014b). Reducing the density of poultry farms in close proximity is an effective mitigation strategy to limit avian influenza transmission, as it decreases

spatial contacts and the farm-level reproductive number, thereby lowering the risk of farm-to-farm spread (Le Menach et al., 2006). This risk was increased when inland bodies of water were nearby, as farms in coastal areas were found to be at higher risk for AI. Bodies of water attract waterfowl, known reservoirs of AI, thereby increasing the risk when wild bird populations are present around farms. There is consensus about wild and migratory birds significantly contributing to the introduction of AI into commercial poultry (Lisovski et al., 2018; Elmberg et al., 2017; Cappelle et al., 2014). While non-avian species on and around the farm also pose a risk, they are not as important as avian species (Liu et al., 2024; Martelli et al., 2023). However, non-avian species can still contract and spread AI to other animals and humans, as seen in the recent outbreak of AI in cattle in the US (Caserta et al., 2024), the confirmed case of AI in a sheep in the UK (Department for Environment, Food & Rural Affairs and Animal and Plant Health Agency, 2025), as well as the reported fatal cases of AI infection in species such as sea lions (Plaza et al., 2024), bears (Jakobek et al., 2023), and seals (Campagna et al., 2023). However, these factors are not easily modifiable and beyond the control of poultry farm workers, highlighting the need to focus on modifiable risk factors to better manage and mitigate AI outbreaks.

Husbandry practices significantly influenced a farm’s risk of AI. Artois et al. (2018) found that farms with fewer birds per cycle and the presence of windows had a lower risk of AI infection. In contrast, farms with more than seven flocks and owners with over 15 years of experience were identified as high risk. Additionally, keeping “other livestock on the same farm” was a recognised risk factor (Kim et al., 2018; Wang et al., 2014a,2014b). Farm type also played a crucial role, with breeder farms having a higher risk for AI outbreaks than layer and broiler farms. This higher risk was attributed to the larger bird population and the practice of raising breeder chickens on the floor, where fecal dust accumulates (Ahad et al., 2014). On the other hand, layer farms using cages and broiler farms typically keeping birds on-site for a shorter duration reduced the overall AI risk (Ahad et al., 2014). Regarding husbandry practices, a small number of birds and flocks was associated with lower AI risk (Channa et al., 2021; Artois et al., 2018). Movement of people and vehicles between farms facilitated inter-farm transmission of AI, highlighting the connection between trade practices and disease spread. While poultry demographics affected a farm’s risk for AI, their impact was smaller compared to environmental factors. Altering poultry demographics and farming systems is challenging, as it would require changes to food systems and socio-cultural norms.

Biosecurity measures, including the proper use of personal protective equipment, good hand hygiene, and regular, correct disinfection of premises, were identified as the most significant protective factors, in agreement with existing literature (Islam et al., 2024; Glass et al., 2019; Chang et al., 2016). There was also consensus that improper disposal of poultry carcasses is a risk factor for AI (Mao et al., 2017). Furthermore,

Table 4

Overview of results summarizing risk or protective factors for the spread of AI on commercial poultry farms. The risk factors have been ranked by highest OR.

Author, Year	Country	Sample size (farms, n)	Sample size (n of birds per farm)	Risk factor	OR (95 % CI)	P-value
Gupta et al. (2022)	Bangladesh	16 broiler flocks (H5/H9-positive); 53 layer flocks (H5/H9-positive)	NR	Not replacing litter or droppings during the current production cycle	28.3 (2.8–284.2)	0.013
Kim et al. (2018)	South Korea	86	~1000–60,000 ducks	Farm does not use a feces removal service	27.7 (3.8–198.8)	0.001
Gupta et al. (2022)	Bangladesh	16 broiler flocks (H5/H9-positive); 53 layer flocks (H5/H9-positive)	NR	> 2000 spent layers sold in the last batch of the farm	24.0 (3.7–155.0)	0.004
Artois et al. (2018)	Egypt	465 (chicken); 225 (duck)	NR	Production type: chicken layer	15.62 (4.7–71.6)	< 0.001
Wells et al. (2017)	USA	63	Median size of case and control farms was 56,930 and 51,847 birds, respectively	Rendering dead birds	9.80 (1.46–65.96)	0.02
Kim et al. (2018)	South Korea	86	~1000–60,000 ducks	Farm owner has ≥ 15 years of experience	7.91 (1.3–37.1)	0.009
McQuiston et al. (2005)	USA	350	~10,000–20,000 + turkeys or chickens	Disposal of dead birds via rendering	7.3 (3.3–15.9)	< 0.001
Kim et al. (2018)	South Korea	86	~1000–60,000 ducks	Farm has ≥ 7 poultry flocks	6.99 (1.3–37.04)	0.021
Gupta et al. (2022)	Bangladesh	16 broiler flocks (H5/H9-positive); 53 layer flocks (H5/H9-positive)	NR	> 950 to ≤ 2000 spent layers sold in the last batch of the farm	5.9 (1.2–29.1)	0.004
McQuiston et al. (2005)	USA	350	~10,000–20,000 + turkeys or chickens	Age of birds on the farm: 10–19 weeks	4.9 (2.5–9.6)	< 0.001
Gupta et al. (2022)	Bangladesh	16 broiler flocks (H5/H9 positive); 53 layer flocks (H5/H9-positive)	NR	Burying of dead birds near the farm	4.6 (1.2–17.3)	0.026
Gupta et al. (2022)	Bangladesh	16 broiler flocks (H5/H9 positive); 53 layer flocks (H5/H9-positive)	NR	Frequency of replacing litter or droppings during the current production cycle: fortnightly, monthly, or >monthly	4.6 (0.7–29.1)	0.013
McQuiston et al. (2005)	USA	350	~10,000–20,000 + turkeys or chickens	Age of birds on the farm: ≥ 20 weeks	4.3 (1.7–10.9)	< 0.001
Tombari et al. (2013)	Tunisia	800 flocks	NR	Layer chickens on farm	3.94 (2.41–6.43)	< 0.001
Tombari et al. (2013)	Tunisia	800 flocks	NR	Broiler breeder chickens on farm	3.72 (1.85–7.46)	< 0.001
Osmani et al. (2013)	Bangladesh	300	NR	Weekly veterinary visits	3.0 (1.2–7.3)	0.01
Gompo., 2020	Nepal	100	~100–3000 + poultry	Flock size of the farm: > 1500 birds	2.55 (1.02–6.37)	0.044
Thomas et al. (2005)	Netherlands	574	4–193,257 chickens	Presence of layer finisher chickens on farm	1.65 (1.06–2.56)	< 0.05
Thomas et al. (2005)	Netherlands	574	4–193,257 chickens	Only layer chickens on farm	1.23 (0.74–2.06)	< 0.05
Osmani et al. (2013)	Bangladesh	300	NR	Monthly veterinary visits	1.2 (0.4–3.1)	0.01
Yoo et al. (2021)	South Korea	243	~100–1000 + chickens	Flock size larger than 1000 birds	1.01 (1.00–1.01)	0.001
Tombari et al. (2013)	Tunisia	800 flocks	NR	Layer chickens aged less than 18 weeks	0.16 (0.03–0.77)	0.02
Yoo et al. (2021)	South Korea	243	~100–1000 + chickens	Change of boots between sheds	0.16 (0.02–0.85)	< 0.001
Osmani et al. (2013)	Bangladesh	300	NR	Infrequent but scheduled veterinary visits	0.6 (0.1–2.0)	0.01

CI, confidence interval; NR, not reported; OR, odds ratio

farms lacking feces removal services and disinfection procedures were found to be at high risk for AI, while cleaning reusable egg containers was considered a protective factor ([Kim et al., 2018](#); [Wang et al., 2014a, 2014b](#)). The implementation of biosecurity measures includes a behavioral component, and hygiene practices can be modified, which is important for applying these findings, highlighting the need for more qualitative research into barriers of implementation. However, some biosecurity measures, such as the frequency of changing boots, are difficult to quantify, and reporting bias poses a significant limitation in these studies. Additionally, the lack of comparable data makes it challenging to assess the impact of these factors. However, recent efforts have been made to standardize biosecurity measures, and toolkits are now available to assess biosecurity levels on farms ([Biocheck, 2025](#)).

Lastly, while only one study specifically examined the effects of poultry vaccination on AI ([Artois et al., 2018](#)), there is consensus on the

importance of vaccination as a preventative measure. This is reflected in recent initiatives, such as the Finnish government's recent decision to vaccinate fur farm workers against AI ([Global Center for Health Security, University of Nebraska, 2024](#); [Nohynek and Helve, 2024](#)) and the United States Department of Agriculture's approval for a field trial of two AI vaccines in cattle ([Animal and Plant Health Inspection Service, 2024](#)). A study in Bangladesh, using a multivariate modeling approach, found that vaccination led to a ten-fold decrease in the risk of AI outbreaks amongst poultry ([Islam et al., 2023](#)). Additionally, research is currently underway by the Spatial Epidemiology Lab at Université Libre de Bruxelles and the Institut National de Recherche pour l'Agriculture, l'Alimentation et l'Environnement examining the impact of poultry vaccination through the VIVACE project. However, as this research is ongoing, conclusive evidence is yet to be established ([Institut National de Recherche pour l'Agriculture, l'Alimentation et l'Environnement,](#)

Table 5

Overview of results summarizing risk or protective factors for the introduction and spread of AI on commercial poultry farms. The risk factors have been ranked by highest OR.

Author, Year	Country	Sample size (farms, n)	Sample size (n of birds per farm)	Risk factor	OR (95 % CI)	P-value
Nishiguchi et al. (2007)	Japan	73	~9000–500,000 chickens	Introduction of end-of-lay chickens	36.6 (2.4–558.6)	< 0.05
Guinat et al. (2020)	France	266	~100–1000 + ducks	Inadequate management of vehicles' / people's movements	9.3 (4.0–22.8)	≤ 0.05
Guinat et al. (2020)	France	266	~100–1000 + ducks	Inadequate cleaning of facilities / surroundings	6.6 (3.4–12.9)	≤ 0.05
Métras et al. (2012)	Nigeria	110	2000–6650 poultry	Share fence with another poultry farm	5.23 (0.88–30.9)	0.048
Guinat et al. (2020)	France	266	~100–1000 + ducks	Inadequate pest control	5.1 (2.4–11.9)	≤ 0.05
Biswas et al. (2009)	Bangladesh	132	~100–10,000 chickens	Footbath at entry to farm / shed	4.93 (1.61–15.1)	0.005
Chaudhry et al. (2015)	Pakistan	266	NR	History of infectious bursal disease in the flock	3.00 (1.44–6.24)	0.003
Tombari et al. (2013)	Tunisia	800 flocks	NR	Low biosecurity measures implemented	1.57 (1.01–2.43)	0.05
Thomas et al. (2005)	Netherlands	574	4–193,257 chickens	Presence of cattle on farm	1.13 (0.75–1.70)	< 0.05
Artois et al. (2018)	Egypt	465 (chicken); 225 (duck)	NR	Poultry are vaccinated	0.08 (0.05–0.13)	< 0.001
Métras et al. (2012)	Nigeria	110	2000–6650 poultry	Traders staying at the farm gate	0.23 (0.08–0.70)	< 0.001

CI, confidence interval; NR, not reported; OR, odds ratio

2024). It is also important to note France's pioneering AI vaccination campaign in poultry, now in its second year as the sole such initiative in Europe, which employs two recombinant H5 vaccines (Duck H5-SRV and Volvac B.E.S.T. AI+ND) that demonstrated to reduce HPAI H5N1 clade 2.3.4.4b viral transmission by 89–99 % in mallard ducks while maintaining surveillance through DIVA-compatible serological monitoring (Planchand et al., 2025; Grasland, 2023). Based on the findings of this systematic review, while vaccination shows potential for preventing AI outbreaks, implementing robust biosecurity measures could substantially reduce the risk of initial spillover events. Therefore, vaccination should be part of a comprehensive, multidisciplinary AI control strategy, which also includes enhanced biosecurity, surveillance, and monitoring (Acharya and Phuyal, 2024; Tseng et al., 2024).

4.1. Strengths and limitations

The main strength of this systematic review lies in the comprehensive process of study screening, selection, and quality appraisal. While the nature of the included studies allows for a higher risk of reporting bias, a rigorous critical appraisal of all studies was performed to reduce confounding and bias, thus supporting the validity of the results obtained. As each study was scored for its quality based on recommended tools and was ultimately excluded if deemed to be of low quality, selection bias might have been introduced to the review. However, a small number of studies (n = 4) were excluded through this process, with the reason being the authors not accounting for confounding and / or bias. Moreover, a meta-analysis was not deemed possible due to the heterogeneity of the data and how they were reported.

4.2. Significance and conclusions

A range of factors related to geography, husbandry practices, production type, and biosecurity were identified as increasing the risk of AI outbreaks on farms. Given AI's potential to affect both avian and non-avian species, its impact on livestock farm workers, and the recent human fatality in the US (Centers for Disease Control and Prevention, 2025, 2024; Kiley and Yun, 2024), addressing the risk AI poses to public health is critical. AI has also had severe consequences for the poultry industry, workers' livelihoods, international trade, and most notably, on ecosystems and animal health. Recently, over a half billion farmed birds were culled due to AI (Compassion in World Farming, 2023), while

millions of wild animals have died as a result (Gamarra-Toledo et al., 2023). Reducing the risk of AI on intensive farms, where conditions may promote infectious disease spread, is essential. Improving conditions in these farms, particularly through enhanced biosecurity measures and overcoming barriers to their implementation, will help protect both animal welfare and public health. Adopting a One Health approach to poultry farming is crucial, ensuring the health of animals while mitigating the risk of infectious diseases and zoonoses, including AI. These findings highlight the need for further research into biosecurity strategies and the most effective methods for measuring their implementation.

CRedit authorship contribution statement

Christina Joanne Atchison: Supervision, Methodology, Writing – review & editing, Investigation. **Wendy Kwok:** Supervision, Conceptualization, Formal analysis, Writing – review & editing, Investigation, Methodology. **Elvira Meni Maria Gkrinia:** Writing – original draft, Data curation, Writing – review & editing, Investigation, Project administration, Conceptualization. **Lisa Kohnle:** Supervision, Writing – review & editing, Investigation.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of Competing Interest

The co-author Lisa Kohnle is employed at the European Food Safety Authority (EFSA) in the ASSESS Department that provides scientific and administrative support to risk assessments, including risk assessments on animal health. However, the present article is published under the sole responsibility of the authors and may not be considered as an EFSA scientific output. The positions and opinions presented in this article are those of the authors alone and are not intended to/do not necessarily represent the views/any official position of EFSA. To know about the views or scientific outputs of EFSA, please consult its website under <http://www.efsa.europa.eu>.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.prevetmed.2025.106606](https://doi.org/10.1016/j.prevetmed.2025.106606).

Data availability

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

References

- Acharya, K.P., Phuyal, S., 2024. To vaccinate or not against highly pathogenic avian influenza? 100884 *Lancet Microbe* 5 (9), 100884. [https://doi.org/10.1016/s2666-5247\(24\)00107-1](https://doi.org/10.1016/s2666-5247(24)00107-1).
- Adam-Poupart, A., Drapeau, L.M., Bekal, S., Germain, G., Irace-Cima, A., Sassine, M.P., Simon, A., Soto, J., Thivierge, K., Tissot, F., 2021. Occupations at risk of contracting zoonoses of public health significance in Québec. *Can. Commun. Dis. Rep.* 47 (1), 47–58. <https://doi.org/10.14745/ccdr.v47i01a08>.
- Ahad, A., Thornton, R.N., Rabbani, M., Yaqub, T., Younus, M., Muhammad, K., Mahmood, A., Shabbir, M.Z., Kashem, M.A., Islam, Z., Mangtani, P., Burgess, G.W., Tun, H.M., Hoque, A., 2014. Risk factors for H7 and H9 infection in commercial poultry farm workers in provinces within Pakistan. *Prev. Vet. Med.* 117 (3–4), 610–614. <https://doi.org/10.1016/j.prevetmed.2014.10.007>.
- Ahmad, S., Koh, K.Y., Yoo, D.S., Lee, J.I., 2022. Impact of inland waters on highly pathogenic avian influenza outbreaks in neighboring poultry farms in South Korea. *J. Vet. Sci.* 23. <https://doi.org/10.4142/jvs.21278>.
- Artois, J., Ippoliti, C., Conte, A., Dhingra, M.S., Alfonso, P., Tahawy, A.E., Elbestawy, A., Ellakany, H.F., Gilbert, M., 2018. Avian influenza A (H5N1) outbreaks in different poultry farm types in Egypt: the effect of vaccination, closing status and farm size. *BMC Vet. Res.* 14 (1). <https://doi.org/10.1186/s12917-018-1519-8>.
- Badruzzaman, A.T.M., Rahman, M.M., Hasan, M., Hossain, M.K., Husna, A., Hossain, F. M.A., Giasuddin, M., Uddin, M.J., Islam, M.R., Alam, J., Eo, S.-K., Fasina, F.O., Ashour, H.M., 2022. Semi-scavenging poultry as carriers of avian influenza genes. *Life* 12 (2), 320. <https://doi.org/10.3390/10.3390/life12020320>.
- Basuno, E., Yusdja, Y., Ilham, N., 2010. Socio-economic impacts of avian influenza outbreaks on small-scale producers in Indonesia. *Transbound. Emerg. Dis.* 57 (1–2), 7–10. <https://doi.org/10.1111/j.1865-1682.2010.01121.x>.
- Biocheck, 2025. Keeping healthy animals healthy! (<https://biocheckgent.com/en>) (accessed 13 March 2025).
- Biswas, P.K., Christensen, J.P., Ahmed, S.S., Barua, H., Das, A., Rahman, M.H., Giasuddin, M., Hannan, A.S., Habib, A.M., Debnath, N.C., 2009. Risk factors for infection with highly pathogenic influenza A virus (H5N1) in commercial chickens in Bangladesh. *Vet. Rec.* 164 (24), 743–746. <https://doi.org/10.1136/vr.164.24.743>.
- Biswas, P.K., Rahman, M.H., Das, A., Ahmed, S.S., Giasuddin, M., Christensen, J.P., 2011. Risk for highly pathogenic avian influenza H5N1 virus infection in chickens in small-scale commercial farms, in a high-risk area, Bangladesh, 2008. *Transbound. Emerg. Dis.* 58 (6), 519–525. <https://doi.org/10.1111/j.1865-1682.2011.01235.x>.
- Bos, M.E., Te Beest, D.E., van Boven, M., van Beest Holle, M.R., Meijer, A., Bosman, A., Mulder, Y.M., Koopmans, M.P., Stegeman, A., 2010. High probability of avian influenza virus (H7N7) transmission from poultry to humans active in disease control on infected farms. *J. Infect. Dis.* 201, 1390–1396. <https://doi.org/10.1086/651663>.
- Bouwstra, R., Gonzales, J.L., De Wit, S., Stahl, J., Fouchier, R.A., Elbers, A.R., 2017. Risk for Low Pathogenicity Avian Influenza Virus on Poultry Farms, the Netherlands, 2007–2013. *Emerg. Infect. Dis.* 23, 1510–1516. <https://doi.org/10.3201/eid2309.170276>.
- Campagna, C., Uhart, M., Falabella, V., Campagna, J., Zavattieri, V., Vanstreels, R.E.T., Lewis, M.N., 2023. Catastrophic mortality of southern elephant seals caused by H5N1 avian influenza. *Mar. Mam. Sci.* 40, 322–325. <https://doi.org/10.1111/mms.13101>.
- Cappelle, J., Zhao, D., Gilbert, M., Nelson, M.I., Newman, S.H., Takekawa, J.Y., Gaidet, N., Prosser, D.J., Liu, Y., Li, P., Shu, Y., Xiao, X., 2014. Risks of avian influenza transmission in areas of intensive free-ranging duck production with wild waterfowl. *EcoHealth* 11, 109–119. <https://doi.org/10.1007/s10393-014-0914-2>.
- Capua, I., Marangon, S., 2006. Control of avian influenza infections in poultry with emphasis on vaccination. *Expert Rev. Anti Infect. Ther.* 4, 751–757. <https://doi.org/10.1586/14787210.4.5.751>.
- Caserta, L.C., Frye, E.A., Butt, S.L., Laverack, M., Nooruzzaman, M., Covalada, L.M., Thompson, A.C., Koscielny, M.P., Cronk, B., Johnson, A., Kleinhenn, K., Edwards, E. E., Gomez, G., Hitchener, G., Martins, M., Kapczynski, D.R., Suarez, D.L., Alexander Morris, E.R., Hensley, T., Beeby, J.S., Diel, D.G., 2024. Spillover of highly pathogenic avian influenza H5N1 virus to dairy cattle. *Nature* 634 (8034), 669–676. <https://doi.org/10.1038/s41586-024-07849-4>.
- Centers for Disease Control and Prevention, 2022. U.S. case of Human Avian Influenza A (H5) virus reported. (<https://www.cdc.gov/media/releases/2022/s0428-avian-flu.html#:~:text=To%20dat%2C%20H5N1%20viruses%20have>) (Accessed 13 March 2025).
- Centers for Disease Control and Prevention, 2024. CDC A(H5N1) Bird Flu Response Update October 18, 2024. (<https://www.cdc.gov/bird-flu/spotlights/cdc-bird-flu-response.html>) (Accessed 13 March 2025).
- Centers for Disease Control and Prevention, 2025. First H5 Bird Flu Death Reported in United States. (<https://www.cdc.gov/media/releases/2025/m0106-h5-bird-flu-deat.html>) (Accessed 13 March 2025).
- Chang, C.F., King, C.C., Wan, C.H., Chang, Y.C., Chan, T.C., David Lee, C.C., Chou, P.H., Li, Z.R., Li, Y.T., Tseng, T.J., Lee, P.F., Chang, C.H., 2016. Lessons from the largest epidemic of avian influenza viruses in Taiwan, 2015. *Avian Dis.* 60, 156–171. <https://doi.org/10.1637/11168-051915-reg>.
- Channa, A.A., Tariq, M., Nizamani, Z.A., Kalhor, N.H., 2021. Prevalence of avian influenza H5, H7, and H9 viruses in commercial layers in Karachi, Pakistan. *Iran. J. Vet. Res.* 22, 352–355. <https://doi.org/10.22099/ijvr.2021.41104.5964>.
- Chaudhry, M., Rashid, H.B., Thrusfield, M., Welburn, S., Bronsvort, B.M., 2015. A case-control study to identify risk factors associated with avian influenza subtype H9N2 on commercial poultry farms in Pakistan. *PLoS ONE* 10, e0119019. <https://doi.org/10.1371/journal.pone.0119019>.
- Chen, H., Yuan, H., Gao, R., Zhang, J., Wang, D., Xiong, Y., Fan, G., Yang, F., Li, X., Zhou, J., Zou, S., Yang, L., Chen, T., Dong, L., Bo, H., Zhao, X., Zhang, Y., Lan, Y., Bai, T., Dong, J., Shu, Y., 2014. Clinical and epidemiological characteristics of a fatal case of avian influenza A H10N8 virus infection: a descriptive study. *Lancet* 383, 714–721. [https://doi.org/10.1016/s0140-6736\(14\)60111-2](https://doi.org/10.1016/s0140-6736(14)60111-2).
- Compassion in World Farming, 2023. Bird flu: only major farm reforms can end it. (<https://www.ciwf.org.uk/research/animal-welfare/bird-flu-only-major-farm-reforms-can-end-it/>) (Accessed 13 March 2025).
- Critical Appraisal Skills Programme, 2024. Critical Appraisal Checklists. (<https://casp-uk.net/casp-tools-checklists/>) (Accessed 13 March 2025).
- De Vries, E., De Haan, C.A., 2023. Letter to the editor: Highly pathogenic influenza A (H5N1) viruses in farmed mink outbreak contain a disrupted second sialic acid binding site in neuraminidase, similar to human influenza A viruses. *Eur. Surveill.* 28. <https://doi.org/10.2807/1560-7917.es.2023.28.7.2300085>.
- Department for Environment, Food & Rural Affairs, 2024. Bird flu (avian influenza): latest situation in England. (<https://www.gov.uk>) (Accessed 13 March 2025).
- Department for Environment, Food & Rural Affairs and Animal and Plant Health Agency, 2025. Influenza of avian origin confirmed in a sheep in Yorkshire. (<https://www.gov.uk/government/news/influenza-of-avian-origin-confirmed-in-a-sheep-in-yorks-hire>) (Accessed 13 March 2025).
- Dupas, M.-C., Vincenti-Gonzalez, M.F., Dhingra, M., Guinat, C., Timothée, Vergne, Wint, W., Hendrickx, G., Marsboom, C., Gilbert, M., Dellicour, S., 2025. Global risk mapping of highly pathogenic avian influenza H5N1 and H5Nx in the light of epidemic episodes occurring from 2020 onward. *BioRxiv* (Cold Spring Harb. Lab.). <https://doi.org/10.7554/elife.104748.1>.
- Eisfeld, A.J., Biswas, A., Guan, L., Gu, C., Maemura, T., Trifkovic, S., Wang, T., Babujee, L., Dahn, R., Halfmann, P.J., Barnhardt, T., Neumann, G., Suzuki, Y., Thompson, A., Swinford, A.K., Dimitrov, K.M., Poulsen, K., Kawaoka, Y., 2024. Pathogenicity and transmissibility of bovine H5N1 influenza virus. *Nature* 633 (8029), 426–432. <https://doi.org/10.1038/s41586-024-07766-6>.
- Elmberg, J., Berg, C., Lerner, H., Waldenström, J., Hessel, R., 2017. Potential disease transmission from wild geese and swans to livestock, poultry and humans: a review of the scientific literature from a One Health perspective. *Infect. Ecol. Epidemiol.* 7, 1300450. <https://doi.org/10.1080/20080866.2017.1300450>.
- European Centre for Disease Prevention and Control, 2023. Facts about avian influenza in humans. (<https://www.ecdc.europa.eu/en/avian-influenza-humans/facts#:~:text=Transmission%20from%20birds%20to%20humans>) (Accessed 13 March 2025).
- European Food Safety Authority, 2025. Avian influenza overview December 2024 – March 2025. (<https://www.efsa.europa.eu/en/efsajournal/pub/9352>) (Accessed 13 March 2025).
- Fasina, F.O., Rivas, A.L., Bisschop, S.P., Stegeman, A.J., Hernandez, J.A., 2010. Identification of risk factors associated with highly pathogenic avian influenza H5N1 virus infection in poultry farms, in Nigeria during the epidemic of 2006–2007. *Prev. Vet. Med.* 98, 204–208. <https://doi.org/10.1016/j.prevetmed.2010.11.007>.
- Fournié, G., Høg, E., Barnett, T., Pfeiffer, D.U., Mangtani, P., 2017. A systematic review and meta-analysis of practices exposing humans to avian influenza viruses, their prevalence, and rationale. *Am. J. Trop. Med Hyg.* 97, 376–388. <https://doi.org/10.4269/ajtmh.17-0014>.
- Gamarra-Toledo, V., Plaza, P.I., Angulo, F., Gutiérrez, R., García-Tello, O., Saravia-Guevara, P., Mejía-Vargas, F., Epiquién-Rivera, Mírel, Quiroz-Jiménez, G., Martínez, P., Huamán-Mendoza, Deyvis, Inga-Díaz, Giancarlo, La, L.E., Luyo, P., Ventura, S., Lambertucci, S.A., 2023. Highly Pathogenic Avian Influenza (HPAI) strongly impacts wild birds in Peru. *Biol. Conserv.* 286, 110272. <https://doi.org/10.1016/j.biocon.2023.110272>.
- Gambotto, A., Barratt-Boyes, S.M., De Jong, M.D., Neumann, G., Kawaoka, Y., 2008. Human infection with highly pathogenic H5N1 influenza virus. *Lancet* 371, 1464–1475. [https://doi.org/10.1016/s0140-6736\(08\)60627-3](https://doi.org/10.1016/s0140-6736(08)60627-3).
- Ganti, K., Bagga, A., DaSilva, J., Shepard, S.S., Barnes, J.R., Shriner, S., Koelle, K., Lowen, A.C., 2021. Avian influenza A viruses reassort and diversify differently in mallards and mammals. *Viruses* 13 (3), 509. <https://doi.org/10.3390/v13030509>.
- Garber, L., Bjork, K., Patyk, K., Rawdon, T., Antognoli, M., Delgado, A., Ahola, S., McCluskey, B., 2016. Factors associated with highly pathogenic avian influenza H5N2 infection on table-egg layer farms in the Midwestern United States, 2015. *Avian Dis.* 60, 460–466. <https://doi.org/10.1637/11351-121715-reg>.
- Gilbert, M., Xiao, X., Domenech, J., Lubroth, J., Martin, V., Slingenbergh, J., 2006. Anatidae migration in the western Palearctic and spread of highly pathogenic avian influenza H5N1 virus. *Emerg. Infect. Dis.* 12 (11), 1650–1656. <https://doi.org/10.3201/eid1211.060223>.
- Gilchrist, M.J., Greko, C., Wallinga, D.B., Beran, G.W., Riley, D.G., Thorne, P.S., 2006. The potential role of concentrated animal feeding operations in infectious disease

- epidemics and antibiotic resistance. *Environ. Health Perspect.* 115, 313–316. <https://doi.org/10.1289/ehp.8837>.
- Glass, K., Barnes, B., Scott, A., Toribio, J., Moloney, B., Singh, M., Hernandez-Jover, M., 2019. Modelling the impact of biosecurity practices on the risk of high pathogenic avian influenza outbreaks in Australian commercial chicken farms. *Prev. Vet. Med.* 165, 8–14. <https://doi.org/10.1016/j.prevetmed.2019.02.002>.
- Global Center for Health Security, University of Nebraska, 2024. Finland to offer bird flu vaccine to select groups of people, a possible global first. (<https://www.unmc.edu/healthsecurity/transmission/2024/06/11/finland-to-offer-bird-flu-vaccine-to-select-groups-of-people-a-possible-global-first-2/>) (Accessed 13 March 2025).
- Gompo, T.R., Shah, B.R., Karki, S., Koirala, P., Maharjan, M., Bhatt, D.D., 2020. Risk factors associated with Avian Influenza subtype H9 outbreaks in poultry farms in Kathmandu valley, Nepal. *PLoS ONE* 15, e0223550. <https://doi.org/10.1371/journal.pone.0223550>.
- Grasland, B., Schmitz, A., Niqueux, E., Andraud, M., Busson R., Morin, N., Guillemot, C., Orsco, A., Souchaud, F., Briand, F.X., Martenot, C., Cherbannel, M., Massin, P., Louboutin, K., Pierre, I., Delpont, M., Pouvelle, L., Soubies, S., Rose, N., Amelot, M., Keita, A., Guérin, J.-L., Etteradossi, N., 2023. Expérimentation de vaccination des canards mulards en élevage contre un virus influenza aviaire hautement pathogène A (H5N1) clade 2.3.4.4b. ANSES. (https://www.anses.fr/fr/system/files/Rapport_evaluation_transmission_Vaccin.pdf) (Accessed 13 March 2025).
- Gray, G., Kayali, G., 2009. Facing pandemic influenza threats: The importance of including poultry and swine workers in preparedness plans. *Poult. Sci.* 88, 880–884. <https://doi.org/10.3382/ps.2008-00335>.
- Gray, G.C., Baker, W.S., 2007. The importance of including swine and poultry workers in influenza vaccination programs. *Clin. Pharm. Ther.* 82, 638–641. <https://doi.org/10.1038/sj.cpt.6100391>.
- Guinat, C., Comin, A., Kratzer, G., Durand, B., Delesalle, L., Delpont, M., Guérin, J., Paul, M.C., 2020. Biosecurity risk factors for highly pathogenic avian influenza (H5N8) virus infection in duck farms, France. *Transbound. Emerg. Dis.* 67 (6), 2961–2970. <https://doi.org/10.1111/tbed.13672>.
- Gupta, S.D., Fournié, G., Hoque, M.A., Henning, J., 2022. Farm-level risk factors associated with avian influenza A (H5) and A (H9) flock-level seroprevalence on commercial broiler and layer chicken farms in Bangladesh. *Front Vet. Sci.* 9. <https://doi.org/10.3389/fvets.2022.893721>.
- Hien, T., 2012. Clinical features and pathogenesis of H5N1 influenza in humans. *Int J. Inf. Dis.* 16, e41. <https://doi.org/10.1016/j.ijid.2012.05.104>.
- Hill, A.A., Dewé, T., Kosmider, R., Von Dobschuetz, S., Munoz, O., Hanna, A., Fusaro, A., De Nardi, M., Howard, W., Stevens, K., Kelly, L., Havelaar, A., Stärk, K., 2015. Modelling the species jump: towards assessing the risk of human infection from novel avian influenzas, 150173 R. Soc. Open Sci. 2 (9), 150173. <https://doi.org/10.1098/rsos.150173>.
- Imrey, P.B., 2020. Limitations of meta-analyses of studies with high heterogeneity. *JAMA Netw. Open* 3, e1919325. <https://doi.org/10.1001/jamanetworkopen.2019.19325>.
- Institut National de Recherche pour l'Agriculture, l'Alimentation et l'Environnement, 2024. Management of avian influenza in a vaccination context. (<https://www.inrae.fr/en/news/management-avian-influenza-vaccination-context>) (Accessed 13 March 2025).
- Islam, A., Munro, S., Hassan, M.M., Epstein, J.H., Klaassen, M., 2023. The role of vaccination and environmental factors on outbreaks of high pathogenicity avian influenza H5N1 in Bangladesh. *One Health* 17, 100655. <https://doi.org/10.1016/j.onehlt.2023.100655>.
- Islam, A., Rahman, M.Z., Hassan, M.M., Epstein, J.H., Klaassen, M., 2024. Farm biosecurity practices affecting avian influenza virus circulation in commercial chicken farms in Bangladesh. *One Health* 18, 100681. <https://doi.org/10.1016/j.onehlt.2024.100681>.
- Jakobek, B.T., Berhane, Y., Nadeau, M., Embury-Hyatt, C., Lung, O., Xu, W., Lair, S., 2023. Influenza A(H5N1) Virus Infections in 2 Free-Ranging Black Bears (*Ursus americanus*), Quebec, Canada. *Emerg. Infect. Dis.* 29. <https://doi.org/10.3201/eid2910.230548>.
- Joanna Briggs Institute, 2020. Critical Appraisal Tools. (<https://jbi.global/critical-appraisal-tools>) (Accessed 13 March 2025).
- Kaplan, B.S., Webby, R.J., 2013. The avian and mammalian host range of highly pathogenic avian H5N1 influenza. *Virus Res* 178 (1), 3–11. <https://doi.org/10.1016/j.virusres.2013.09.004>.
- Kiley, J.L., Yun, H.C., 2024. Avian influenza: an overview and clinical status. *Curr. Inf. Dis. Rep.* 27 (1). <https://doi.org/10.1007/s11908-024-00850-y>.
- Kim, W., An, J., Kim, J., Moon, O., Bae, S.H., Bender, J.B., Cho, S., 2018. Risk factors associated with highly pathogenic avian influenza subtype H5N8 outbreaks on broiler duck farms in South Korea. *Transbound. Emerg. Dis.* 65, 1329–1338. <https://doi.org/10.1111/tbed.12882>.
- Kniss, K., Sumner, K.M., Tastad, K.J., Lewis, N.M., Jansen, L., Julian, D., Reh, M., Carlson, E., Williams, R., Koirala, S., Buss, B., Donahue, M., Palm, J., Kollmann, L., Holzbauer, S., Levine, M.Z., Davis, T., Barnes, J.R., Flannery, B., Brammer, L., 2023. Risk for Infection in Humans after Exposure to Birds Infected with Highly Pathogenic Avian Influenza A(H5N1) Virus, United States, 2022. *Emerg. Infect. Dis.* 29. <https://doi.org/10.3201/eid2906.230103>.
- Kong, W., Wang, F., Dong, B., Ou, C., Meng, D., Liu, J., Fan, Z., 2015. Novel reassortant influenza viruses between pandemic (H1N1) 2009 and other influenza viruses pose a risk to public health. *Micro Pathog.* 89, 62–72. <https://doi.org/10.1016/j.micpath.2015.09.002>.
- Koopmans, M., Wilbrink, B., Conyn, M., Natrop, G., van der Nat, H., Vennema, H., Meijer, A., van Steenberghe, J., Fouchier, R., Osterhaus, A., Bosman, A., 2004. Transmission of H7N7 avian influenza A virus to human beings during a large outbreak in commercial poultry farms in the Netherlands. *Lancet* 363 (9409), 587–593. [https://doi.org/10.1016/s0140-6736\(04\)15589-x](https://doi.org/10.1016/s0140-6736(04)15589-x).
- Kwon, J., Bahl, J., Swayne, D.E., Lee, Y., Lee, Y., Song, C., Lee, D., 2019. Domestic ducks play a major role in the maintenance and spread of H5N8 highly pathogenic avian influenza viruses in South Korea. *Transbound. Emerg. Dis.* 67, 844–851. <https://doi.org/10.1111/tbed.13406>.
- Le Menach, A., Vergu, E., Grais, R.F., Smith, D.L., Flahault, A., 2006. Key strategies for reducing spread of avian influenza among commercial poultry holdings: lessons for transmission to humans. *Proc. Biol. Sci.* 273 (1600), 2467–2475. <https://doi.org/10.1098/rspb.2006.3609>.
- Li, S., Zhou, Y., Song, W., Pang, Q., Miao, Z., 2016. Avian influenza virus H9N2 seroprevalence and risk factors for infection in occupational poultry-exposed workers in Tai'an of China. *J. Med. Virol.* 88, 1453–1456. <https://doi.org/10.1002/jmv.24483>.
- Lisovski, S., Van Dijk, J.G.B., Klinkenberg, D., Nolet, B.A., Fouchier, R.M., Klaassen, M., 2018. The roles of migratory and resident birds in local avian influenza infection dynamics. *J. Appl. Ecol.* 55, 2963–2975. <https://doi.org/10.1111/1365-2664.13154>.
- Liu, H., Zhou, X.K., Zhao, Y.B., Zheng, D.N., Wang, J., Wang, X.F., Castellan, D., Huang, B., Wang, Z., Soares, R.J., 2015. Factors associated with the emergence of highly pathogenic avian influenza A (H5N1) poultry outbreaks in China: evidence from an epidemiological investigation in Ningxia, 2012. *Transbound. Emerg. Dis.* 64, 746–753. <https://doi.org/10.1111/tbed.12433>.
- Liu, J.P., 2006. Avian influenza—a pandemic waiting to happen? *J. Microbiol. Immunol. Infect.* 39, 4–10.
- Liu, Y., Kjær, L.J., Boklund, A.E., Hjulsgaard, C.K., Larsen, L.E., Kirkeby, C.T., 2024. Risk factors for avian influenza in Danish poultry and wild birds during the epidemic from June 2020 to May 2021. *Front Vet. Sci.* 11. <https://doi.org/10.3389/fvets.2024.1358995>.
- MacMahon, K.L., Delaney, L.J., Kullman, G., Gibbins, J.D., Decker, J., Kiefer, M.J., 2008. Protecting poultry workers from exposure to avian influenza viruses. *Public Health Rep.* 123, 316–322. <https://doi.org/10.1177/003335490812300311>.
- Mao, X., Wu, J., Lau, E.H.Y., Cheng, K.L., Zhong, Z., Song, Y., Ji, X., Zhou, L., Ke, C., Sriyal, J., Wang, H., Yen, H.-L., 2017. Monitoring avian influenza viruses from chicken carcasses sold at markets, China, 2016. *Emerg. Infect. Dis.* 23, 1714–1717. <https://doi.org/10.3201/eid2310.170679>.
- Martelli, L., Fornasiero, D., Scarton, F., Spada, A., Scolamacchia, F., Manca, G., Mulatti, P., 2023. Study of the interface between wild bird populations and poultry and their potential role in the spread of avian influenza. *Microorganisms* 11, 2601. <https://doi.org/10.3390/microorganisms11102601>.
- McKenzie J.E., Brennan S.E., 2019. Chapter 12: Synthesizing and presenting findings using other methods In: Higgins J.P.T., Thomas J., Chandler J., Cumpston M., Li T., Page M.J., Welch V.A. (eds). *Cochrane Handbook for Systematic Reviews of Interventions* version 6.5. (www.training.cochrane.org/handbook).
- McQuiston, J.H., Garber, L.P., Porter-Spalding, B.A., Hahn, J.W., Pierson, F.W., Wainwright, S.H., Senne, D.A., Brignole, T.J., Akey, B.L., Holt, T.J., 2005. Evaluation of risk factors for the spread of low pathogenicity H7N2 avian influenza virus among commercial poultry farms. *J. Am. Vet. Med. Assoc.* 226, 767–772. <https://doi.org/10.2460/javma.2005.226.767>.
- Melidou, A., Enkirch, T., Willgert, K., Adlhoeh, C., Alm, E., Lamb, F., Marangon, S., Monne, I., Stegeman, J.A., Delacourt, R., Baldinelli, F., Broglia, A., 2024. Drivers for a pandemic due to avian influenza and options for One Health mitigation measures. *EFSA J.* 22 (4). <https://doi.org/10.2903/j.efsa.2024.8735>.
- Métrás, R., Stevens, K.B., Abdu, P., Okike, I., Randolph, T., Grace, D., Pfeiffer, D.U., Costard, S., 2012. Identification of potential risk factors associated with highly pathogenic avian influenza subtype H5N1 outbreak occurrence in Lagos and Kano States, Nigeria, during the 2006–2007 epidemics. *Transbound. Emerg. Dis.* 60, 87–96. <https://doi.org/10.1111/j.1865-1682.2012.01322.x>.
- Miskiewicz, A., Kowalczyk, P., Oraibi, S.M., Cybulska, K., Misiewicz, A., 2018. Bird feathers as potential sources of pathogenic microorganisms: a new look at old diseases. *Antonie Van Leeuwenhoek* 111, 1493–1507. <https://doi.org/10.1007/s10482-018-1048-2>.
- Morgan, R.L., Whaley, P., Thayer, K.A., Schünemann, H.J., 2018. Identifying the PECO: a framework for formulating good questions to explore the association of environmental and other exposures with health outcomes. *Environ. Int.* 121, 1027–1031. <https://doi.org/10.1016/j.envint.2018.07.015>.
- Nishiguchi, A., Kobayashi, S., Yamamoto, T., Ouchi, Y., Sugizaki, T., Tsutsui, T., 2007. Risk factors for the introduction of avian influenza virus into commercial layer chicken farms during the outbreaks caused by a low-pathogenic H5N2 virus in Japan in 2005. *Zoonoses Public Health* 54, 337–343. <https://doi.org/10.1111/j.1863-2378.2007.01074.x>.
- Nohynek, H., Helve, O.M., 2024. One health, many interpretations: vaccinating risk groups against H5 avian influenza in Finland. *Eur. Surveill.* 29 (25). <https://doi.org/10.2807/1560-7917.es.2024.29.25.2400383>.
- Occhibove, Flavia, Knäuf, S., Sauter-Louis, C., Staubach, C., Allendorf, V., Anton, A., Barron, S., Bergmann, H., Brojer, C., Buzan, E., Cerny, J., Denzin, N., Gethoffer, F., Globig, A., Gethmann, J., Gonzalez, Moises, Garcia-Bocanegra, I., Harder, T., Jori, F., Keuling, O., 2024. The role of mammals in Avian Influenza: a review. *EFSA Sup Pub* 21 (3). <https://doi.org/10.2903/sp.efsa.2024.en-8692>.
- Osmani, M.G., Thornton, R.N., Dhand, N.K., Hoque, M.A., Milon, M.A., Kalam, M.A., Hossain, M., Yamage, M., 2013. Risk factors for highly pathogenic avian influenza in commercial layer chicken farms in Bangladesh during 2011. *Transbound. Emerg. Dis.* 61, e44–e51. <https://doi.org/10.1111/tbed.12071>.
- Pan-American Health Organization, 2025. *Epidemiological Update: Avian Influenza A (H5N1) in the Americas Region*, 2025. PAHO/WHO, Washington, D.C.
- Peacock, T.P., Moncla, L., Dudas, G., VanInsberghe, D., Sukhova, K., Lloyd-Smith, J.O., Worobey, M., Lowen, A.C., Nelson, M.I., 2024. The global H5N1 influenza panzootic

- in mammals. *Nature* 637 (8045), 304–313. <https://doi.org/10.1038/s41586-024-08054-z>.
- Peiris, J.S.M., De Jong, M.D., Guan, Y., 2007. Avian influenza virus (H5N1): a threat to human health. *Clin. Microbiol. Rev.* 20, 243–267. <https://doi.org/10.1128/cmr.00037-06>.
- Planchand, S., Vergne, T., Guérin, J., Rautureau, S., Gerbier, G., Lambert, S., 2025. Surveillance Strategy in Duck Flocks Vaccinated against Highly Pathogenic Avian Influenza Virus. *Emerg. Infect. Dis.* 31 (1), 115–122. <https://doi.org/10.3201/eid3101.241140>.
- Plaza, P.I., Gamarra-Toledo, V., Euguí, J.R., Rosciano, N., Lambertucci, S.A., 2024. Pacific and Atlantic sea lion mortality caused by highly pathogenic Avian Influenza A(H5N1) in South America. *Travel Med Infect. Dis.* 59, 102712. <https://doi.org/10.1016/j.tmaid.2024.102712>.
- Qi, W., Su, S., Xiao, C., Zhou, P., Li, H., Ke, C., Gray, G.C., Zhang, G., Liao, M., 2014. Antibodies against H10N8 avian influenza virus among animal workers in Guangdong Province before November 30, 2013, when the first human H10N8 case was recognized. *BMC Med* 12. <https://doi.org/10.1186/s12916-014-0205-3>.
- Rajabali, N., Lim, T., Sokolowski, C., Prevost, J.D., Lee, E.Z., 2015. Avian Influenza a (H5N1) Infection with Respiratory Failure and Meningoencephalitis in a Canadian Traveller. *Can. J. Infect. Dis. Med Microbiol* 26, 221–223. <https://doi.org/10.1155/2015/961080>.
- Shi, C., Shi, P., Yang, X., Bao, J., Qian, Y., Shen, Y., 2020. Person-to-Person Transmission of Avian Influenza A (H7N9) Among Family Members in Eastern China, 2016. *Disaster Med Public Health Prep.* 15, 164–169. <https://doi.org/10.1017/dmp.2020.6>.
- Shi, J., Deng, G., Kong, H., Gu, C., Ma, S., Yin, X., Zeng, X., Cui, P., Chen, Y., Yang, H., Wan, X., Wang, X., Liu, L., Chen, P., Jiang, Y., Liu, J., Guan, Y., Suzuki, Y., Li, M., Qu, Z., 2017. H7N9 virulent mutants detected in chickens in China pose an increased threat to humans. *Cell Res* 27, 1409–1421. <https://doi.org/10.1038/cr.2017.129>.
- Sjurseth, S.K., Gjerset, B., Bragstad, K., Hungnes, O., Wisløff, H., Er, C., Valheim, M., Løtvedt, S.M., David, B., Hanssen, S.A., Hauge, S.H., Hofshagen, M., 2017. Human to animal transmission of influenza A(H1N1)pdm09 in a turkey breeder flock in Norway. *Infect. Ecol. Epidemiol.* 7, 1416249. <https://doi.org/10.1080/2008686.2017.1416249>.
- Smith, G., Dunipace, S., 2011. How backyard poultry flocks influence the effort required to curtail avian influenza epidemics in commercial poultry flocks. *Epidemics* 3, 71–75. <https://doi.org/10.1016/j.epidem.2011.01.003>.
- Sulaiman, L., Shittu, I., Fusaro, A., Inuwa, Bitrus, Zecchin, B., Gado, D., Schivo, Alessia, Bianco, A., Laleye, A., Gobbo, F., Vakuru, Columba, Joannis, T., Monne, I., Meseke, C., 2021. Live Bird Markets in Nigeria: A Potential Reservoir for H9N2 Avian Influenza Viruses. *Viruses* 13, 1445. <https://doi.org/10.3390/v13081445>.
- Sutton, T., 2018. The Pandemic Threat of Emerging H5 and H7 Avian Influenza Viruses. *Viruses* 10, 461. <https://doi.org/10.3390/v10090461>.
- The Global Consortium For H5N8 And Related Influenza Viruses, 2016. Role for migratory wild birds in the global spread of avian influenza H5N8. *Science* 354 (6309), 213–217. <https://doi.org/10.1126/science.aaf8852>.
- Thomas, M., Bouma, A., Ekker, H., Fonken, A., Stegeman, J., Nielen, M., 2005. Risk factors for the introduction of high pathogenicity Avian Influenza virus into poultry farms during the epidemic in the Netherlands in 2003. *Prev. Vet. Med* 69, 1–11. <https://doi.org/10.1016/j.prevetmed.2004.12.001>.
- Thompson, P.N., Sinclair, M., Ganzevoort, B., 2008. Risk factors for seropositivity to H5 avian influenza virus in ostrich farms in the Western Cape Province, South Africa. *Prev. Vet. Med* 86, 139–152. <https://doi.org/10.1016/j.prevetmed.2008.03.011>.
- Tombari, W., Paul, M., Bettaieb, J., Larbi, I., Nsiri, J., Elbehi, I., Gribaa, L., Ghram, A., 2013. Risk Factors and Characteristics of Low Pathogenic Avian Influenza Virus Isolated from Commercial Poultry in Tunisia. *PLoS ONE* 8, e53524. <https://doi.org/10.1371/journal.pone.0053524>.
- Tseng, Is, Pan, B.-Y., Feng, Y.-C., Fang, C.-T., 2024. Re-evaluating efficacy of vaccines against highly pathogenic avian influenza virus in poultry: a systematic review and meta-analysis. *One Health*, 100714. <https://doi.org/10.1016/j.onehlt.2024.100714>.
- Van Leeuw, V., Depoort, P., Mauroy, Axel, Beck, O., Claeys, H., Regge, N.D., De Waele, Valérie, Winter, P.D., Heymans, J., Hooyberghs, Jozef, Houdart, Philippe, Houtsaege, Cyrelle, Linden, A., Mori, M., Nauwynck, H., Parys, A., Romero, J.R., Rettigner, C., Rouffaer, Lieze, Stassijns, Jorgen, 2025. Susceptibility of mammals to highly pathogenic avian influenza: a qualitative risk assessment from the Belgian perspective. *Zoonoses Public Health* 72 (2), 150–165. <https://doi.org/10.1111/zph.13194>.
- Van Reeth, K., De Vleswer, A., Kyriakis, C.S., 2017. Influenza in birds, pigs and humans: how strong is the species barrier? *J. Hel Vet. Med Soc.* 58, 208.
- Animal and Plant Health Inspection Service, 2024. USDA Builds on Actions to Protect Livestock and Public Health from H5N1 Avian Influenza. (<https://www.aphis.usda.gov/news/agency-announcements/usda-builds-actions-protect-livestock-public-health-h5n1-avian-influenza>) (Accessed 13 March 2025).
- Veritas Health Innovation, 2024. Covidence systematic review software. (www.covidence.org) (Accessed 13 March 2025).
- Wang, X., Fang, S., Lu, X., Xu, C., Cowling, B.J., Tang, X., Peng, B., Wu, W., He, J., Tang, Y., Xie, X., Mei, S., Kong, D., Zhang, R., Ma, H., Cheng, J., 2014a. Seroprevalence to avian influenza A(H7N9) virus among poultry workers and the general population in Southern China: a longitudinal study. *Clin. Infect. Dis.* 59, e76–e83. <https://doi.org/10.1093/cid/ciu399>.
- Wang, Y., Li, P., Wu, Y., Sun, X., Yu, K., Yu, C., Qin, A., 2014b. The risk factors for avian influenza on poultry farms: a meta-analysis. *Prev. Vet. Med* 117, 1–6. <https://doi.org/10.1016/j.prevetmed.2014.06.008>.
- Wegner, G.I., Murray, K.A., Springmann, M., Muller, A., Sokolow, S.H., Saylor, K., Morens, D.M., 2022. Averting wildlife-borne infectious disease epidemics requires a focus on socio-ecological drivers and a redesign of the global food system. *EClinicalMedicine* 47, 101386. <https://doi.org/10.1016/j.eclinm.2022.101386>.
- Wells, S.P., Kromm, M., VanBeusekom, E.T., Sorley, E.J., Sundaram, M.E., VanderWaal, K., Bowers, J., Papinaho, P.A., Osterholm, M.T., Bender, J., 2017. Epidemiologic investigation of highly pathogenic H5N2 avian influenza among upper midwest U.S. Turkey Farms, 2015. *Avian Dis.* 61, 198. <https://doi.org/10.1637/11543-112816-reg.1>.
- Wille, M., Barr, I.G., 2022. Resurgence of avian influenza virus. *Science* 376, 459–460. <https://doi.org/10.1126/science.abo1232>.
- Willyard, C., 2019. Flu on the farm. *Nature* 573, S62–S63. <https://doi.org/10.1038/d41586-019-02757-4>.
- Woo, J., Park, B.K., 2008. Seroprevalence of low pathogenic avian influenza (H9N2) and associated risk factors in the Gyeonggi-do of Korea during 2005–2006. *J. Vet. Sci.* 9, 161. <https://doi.org/10.4142/jvs.2008.9.2.161>.
- World Health Organization, 2022. Influenza A (H5) - United Kingdom of Great Britain and Northern Ireland. ([https://www.who.int/emergencies/disease-outbreak-news/item/influenza-a-\(h5\)—united-kingdom-of-great-britain-and-northern-ireland](https://www.who.int/emergencies/disease-outbreak-news/item/influenza-a-(h5)—united-kingdom-of-great-britain-and-northern-ireland)) (Accessed 13 March).
- Wu, D., Zou, S., Bai, T., Li, J., Zhao, X., Yang, L., Liu, H., Li, X., Yang, X., Xin, L., Xu, S., Zou, X., Li, X., Wang, A., Guo, J., Sun, B., Huang, W., Zhang, Y., Li, X., Gao, R., 2015. Poultry farms as a source of avian influenza A (H7N9) virus reassortment and human infection. *Sci. Rep.* 5 (1). <https://doi.org/10.1038/srep07630>.
- Yamaji, R., Saad, M.D., Davis, C.T., Swayne, D.E., Wang, D., Wong, F.Y.K., McCauley, J. W., Peiris, J.S.M., Webby, R.J., Fouchier, R.A.M., Kawaoka, Y., Zhang, W., 2020. Pandemic potential of highly pathogenic avian influenza clade 2.3.4.4 A(H5) viruses. *Rev. Med Virol.* 30. <https://doi.org/10.1002/rmv.2099>.
- Yang, F., Wang, J., Jiang, L., Jin, J., Shao, L., Zhang, Y., Zhang, J., Weng, X., Chen, S., Zhang, W., 2013. A fatal case caused by novel H7N9 avian influenza A virus in China. *Emerg. Microbes Infect.* 2, 1–2. <https://doi.org/10.1038/emmi.2013.22>.
- Yoo, D., Lee, K., Chun, B., Lee, H., Park, H., Kim, J., 2021. Preventive effect of on-farm biosecurity practices against highly pathogenic avian influenza (HPAI) H5N6 infection on commercial layer farms in the Republic of Korea during the 2016–17 epidemic: a case-control study. *Prev. Vet. Med* 199, 105556. <https://doi.org/10.1016/j.prevetmed.2021.105556>.
- Zhang, J., Geng, X., Ma, Y., Ruan, S., Xu, S., Liu, L., Xu, H., Yang, G., Wang, C., Liu, C., Han, X., Yu, Q., Cheng, H., Li, Z., 2010. Fatal avian influenza (H5N1) infection in human, China. *Emerg. Infect. Dis.* 16, 1799–1801. <https://doi.org/10.3201/eid1611.090212>.