One Health 16 (2023) 100574

Contents lists available at ScienceDirect

One Health

journal homepage: www.elsevier.com/locate/onehlt

An assessment of the highly pathogenic avian influenza resurgence at human-poultry-environment interface in North-central Nigeria: Sociocultural determinants and One Health implications

Nma Bida Alhaji [a,b,*], Abdulrahman Musa Adeiza [a], Enid Abutu Godwin [a], Aliyu Evuti Haruna [a,c], Mohammed Baba Aliyu [c], Ismail Ayoade Odetokun [d]

[a] Africa Centre of Excellence for Mycotoxin and Food Safety, Federal University of Technology, Minna, Nigeria
[b] Department of Veterinary Public Health and Preventive Medicine, University of Abuja, Federal Capital Territory, Nigeria
[c] Niger State Ministry of Livestock and Fisheries, Minna, Nigeria
[d] Department of Veterinary Public Health and Preventive Medicine, University of Ilorin, Ilorin, Nigeria

ARTICLE INFO

Keywords:
Biosecurity and biosafety
Conceptual one health model
HPAI H5N1
Ppoultry
Resurgence
Socio-culture
Nigeria

ABSTRACT

Highly pathogenic avian influenza H5N1 resurgence has occurred in Nigerian domestic bird flocks with public health concern. This study assessed poultry farmers' knowledge, perceptions, and biosecurity and biosafety practices regarding H5N1 resurgence, explore risk pathways for viral dissemination and associated socio-cultural and economic drivers in poultry flocks in Nigeria. A cross-sectional survey was carried out in randomly selected two poultry production systems, commercial intensive poultry production system and the backyard traditional free-range poultry production system. A One Health framework model was conceptualized to assess inter-links of biophysical, environmental, and sociocultural activities that interface to drive resurgence for better interventions. Descriptive and analytical statistical analyses were performed at 95% confidence level. Of the 422 recruited poultry farmers, 98.6% ($n = 416$) participated. Majorities of smallholder commercial farmers (93.5%) and backyard poultry keepers (97.7%) engaged in intensive and extensive management, respectively. Identified significant zoonotic risk pathways for H5N1 virus spread were through consumption of undercooked poultry meat and products, and contacts with infected birds and contaminated fomites. Separation of sick birds from apparently healthy ones, frequent cleaning and disinfection of equipment and premises, movement control of birds to nearby water bodies, use of personal protective equipment, and movement control of persons and vehicles into the flock settlements were significantly practiced biosecurity measures. Presence of nearby water bodies (ponds) close to flock settlements ($p < 0.001$), frequent contact of wild and domestic birds ($p < 0.001$), cultural practice of bird exchange between flocks ($p < 0.001$), and wild waterfowls' seasonal migrations ($p < 0.001$) significantly influenced resurgence. Understanding determinants interactions in the 'Conceptual One Health framework model' is required for better intercontinental intervention against HPAI H5N1. Reform of socio-cultural and economic activities using One Health approach will not only assure food safety and food security, but also guarantee public and environmental health.

1. Introduction

Poultry provides a high source of animal protein through eggs and meat worldwide, and accounts for 24% of total meat production in sub-Saharan Africa [1]. In Nigeria, 33% of the available total animal protein source emanates from poultry production [1,2]. Poultry is an important contributor to nutrition, income, and food security in the rural communities of developing nations [3]. In many of these communities, birds are reared on small-scale level of free-range or village farms, where birds freely roam and interact with wild waterfowls and contaminated aquatic environment, thereby introducing and facilitating the transmission of avian influenza viruses in poultry settings. In low- and middle- income countries (LMICs), different bird species are often taken to the live bird markets (LBMs) for sales, slaughters or transported by the vendors to other flocks, facilitating avian influenza distribution, persistence, and the potential of novel viruses' emergence [4].

* Corresponding author at: Africa Centre of Excellence for Mycotoxin and Food Safety, Federal University of Technology, Minna, Nigeria.
E-mail address: nmabida62@gmail.com (N.B. Alhaji).

https://doi.org/10.1016/j.onehlt.2023.100574
Received 2 February 2023; Received in revised form 20 May 2023; Accepted 26 May 2023
Available online 1 June 2023

Avian influenza is an infectious and contagious transboundary disease caused by virus belonging to the genus *Alphainfluenzavirus* and family Orthomyxoviridae. Poultry that are highly susceptible to the virus include chicken (*Galliformes*), domestic and wild ducks, as well as geese, swans (*Anseriformes*), and other water birds (*Charadriiformes*) [5]. The first occurrence of the highly pathogenic avian influenza (HPAI) subtype H5N1 in Nigeria was 2006, but was successfully controlled [6,7]. However, the disease re-emerged in 2015 and 2017, as well as in 2018, and spread extensively across the country [8]. It disseminated from Nigeria to the neighbouring countries in the West African subregion between 2015 and 2016 [8–10]. In Nigeria, the transmission and severity of the HPAI H5N1 resurgence in 2015 to 2017 were due to the decline in surveillance and poor biosecurity measures towards the disease in poultry farms [7,11]. The resurgence of HPAI H5N1 virus in the poultry industry has been reported in many African countries, the Middle East, Europe, and Asia [8,12].

In addition to the impact of H5N1 resurgence in domestic birds in Nigeria, there have been detections of H5N1 virus in humans, poultry farms, and LBMs in 2017 and 2018, likely due to the re-emergence [13]. Nevertheless, the zoonotic potential of HPAI H5N1 in Nigeria has been further established with the detection of human cases in two states in Nigeria [14]. This is not surprising with the increasing number of human contacts with smallholder poultry farms and free-range backyard flocks, and poor biosecurity practices. Records of the World Health Organization (WHO) in April 2021 show 862 human H5N1 cases from 17 different countries that include Nigeria [13,15].

The One Health is an integrated, unifying approach that aims to sustainably balance and optimize health of the people, animals and ecosystems [16]. The resurgence of HPAI in Nigeria should be seen as a threat to the achievement of One Health concept because of the viral global scale spread at the poultry-human-environment interface. The mitigation will require multidiscipline and multisectoral collaborations for proper disease surveillance and implementation of policies across human, animal, and the shared environmental domains. In Nigeria, a One Health concept is particularly important because of the high prevalence of zoonotic diseases and their interfaces among humans, animals, and the environment.

Although biophysical determinants of biological hosts (birds), pathogens (avian influenza viruses), biotic and abiotic environments have significant influences on the HPAI H5N1 emergence and re-emergence, health status driven by social determinants such as the economic, cultural, and social variables of cultural practices, gender, tribe, occupation, education, and income, also have influence on infectious diseases outcomes [17–20]. However, there is dearth of research evidence on the implementation of One Health approach intervention against HPAI H5N1 emergence and re-emergence in sub-Saharan Africa. This gap can inhibit the ability to evaluate control and prevention of the virus progress in developing countries. Also, science-based information on socio-cultural and economic factors that drive poultry flocks' exposure to the risk of avian influenza resurgence in Nigeria is not readily available. Understanding the influence of disease epidemiology, husbandry management practices, social and demographic characteristics of farmers, as well as the environment that provides avenues for HPAI interfaces with hosts becomes imperative. The availability of this information will facilitate surveillance and intervention standard operating procedure development against resurgence of the avian influenza in LMICs.

We assessed poultry farmers' knowledge, perceptions, and biosecurity and biosafety measure practices towards HPAI H5N1 resurgence and explore zoonotic risk pathways in two poultry production systems in Nigeria. Our Null hypothesis was that farmers' socio-demographics, and cultural and economic activities cannot drive HPAI H5N1 resurgence in the flocks. The outcomes of this research would demonstrate where the risks lie, identify possible critical points for intervention using conceptual modeling, and also provide background information for policy-makers on preventive preparedness at human-poultry-environment interface in the developing economies.

2. Methods

2.1. Study area

The survey was conducted in smallholder poultry farms and backyard free-range flocks in Niger and Nassarawa States, as well as the Federal Capital Territory Abuja, all located in the North-central geopolitical zone of Nigeria. The region was purposively selected based on epidemiological observation and interactions with some key stakeholders in veterinary practice, poultry farmers' groups, and research experts' opinions. It has a substantial presence of smallholder commercial poultry farms and backyard traditional scavenging flocks of birds, and has experienced HPAI H5N1 resurgence. It has variable agro-ecological zones and logistics challenges such as security issues (https://en.wikipedia.org/wiki/North_Central_(Nigeria).

2.2. Study design and target populations

A cross-sectional study was conducted between January and December 2019, and from November 2020 to October 2021 on two poultry production systems, commercial intensive poultry production system and the backyard traditional free-range poultry production system, in Northcentral Nigeria. In view of the importance poultry industry in the study area, lists of smallholder commercial poultry farms and backyard traditional poultry settlements were collected from the government animal health authorities, identified, and used as target populations.

The farms were selected using the following inclusion criteria: must be smallholder commercial poultry farms with birds' populations ranging between 1000 and 10,000 on intensive management, and established backyard traditional poultry flocks on free-range (scavenging) with populations ranging from 10 to 200 on selected for the survey. We targeted 211 farms for either of the production systems.

2.3. Sample size and sampling method

The simple random sampling method was used to compute the estimated sample size [21]. The formula used was, $n = Z^2 p (1 - p)/d^2$, where n = required sample size; Z = Multiplier from normal distribution at 95% Confidence interval (1.96); p = the participants' expected responses; and d = the desired absolute precision. We hypothesized the percentage frequency of outcome responses in the population to be 50% at 95% confidence level, the margin of error (d) to be 5%. The sample size for the poultry establishments was 384. A contingency of 10% was added to take care of non-response because the desired effect for a cross-sectional study at a single-level sampling is not >1%. The sample size was then adjusted to 422, stratified as 211 smallholder commercial poultry farms and 211 backyard traditional poultry flocks.

2.4. Designing, pretesting, and administering of questionnaire

A structured questionnaire was designed and contained mostly close-ended questions to improve the precision of responses and minimize variation. The designed questions were on themes that included farmers' socio-demographic characteristics of age, gender, occupation, and formal education; Knowledge variables on bird flu epidemiology; risk perceptions on the disease; biosecurity and biosafety practices; and sociocultural and economic activities, among others. Though designed in English, it was translated verbally to the *Hausa* language to the farm/flock holders or managers who do not possess adequate or without formal education. The collected data were carried out through the interviewer-administered procedure on flock owners.

Prior to the study, we pre-tested the questionnaire on three smallholder commercial poultry farms and three established backyard flocks in Niger State and observed variations were corrected. Furthermore, before the commencement of exercise, participants' informed consents were verbally obtained and assured of the confidentiality of all responses.

2.5. Conceptual One Health framework model

A conceptual One Health framework model was postulated and adopted in the research. The model was used to assess interactions of the various biophysical factors, environment exigencies, and the sociocultural and economic activities that could drive the resurgence of HPAI H5N1 and its zoonotic impact in poultry flocks, and the likelihood of intervention points. It was developed to illustrate the interfaces of the biophysical-environmental-sociocultural/economic domains that converged to drive the occurrence of avian influenza in the flocks (Fig. 1). It contained valuable links with points for interventions against the interfacing variables in the model. Consequently, breaking the links will allow prevention and control of zoonotic transboundary diseases, such as the HPAI H5N1.

2.6. Defined variables from the questionnaire

The hypothesized covariates were assessed. All variables in each of the questionnaire themes constituted the explanatory (independent) variables. However, farmers' categorical positive or negative (Yes or No) responses were the dependent (outcome) variables. We assessed the association of independent and dependent variables using a designed unique scoring system. A score was assigned to each respondent to show the stringency of the respondent's levels of knowledge, perceptions, and practices themes. Responses to the explanatory variables (i.e., the dependent variables) were measured using a scoring system that ranged from one to 10 points, and then converted to 100%. Average cut-off score was 50%, and the range was categorized into 'inadequate' ($\leq$50%) and 'adequate' ($\geq$50%) to maintain their categorical format [20].

2.7. Statistical analysis

The obtained data was entered into Microsoft Excel (Microsoft Corporation, Redmond, WA, USA) spreadsheets and STATA 14.1 (Stata Corporation, College Station, Texas, USA) was used for statistical analysis. Both descriptive and analytical statistical analyses were conducted, with the former presented in frequencies and proportions. However, univariate, bivariate, and multivariate analyses were used in the analytic statistics. Bivariate analysis was used also to assess the significant relationship between the two poultry producers' responses to the theme variables.

To assess associations, we first examined the independent and dependent variables using Chi-square ($\chi 2$) test for univariate analysis. Only variables with biological plausibility and a value of $p \leq 0.05$ at this analysis were further selected for logistic regression modeling. To eliminate the predictors that were potential confounders and effect modifiers, a likelihood backward stepwise elimination procedure was conducted using multivariable logistic regression model. At each step, all the socio-demographic, and socio-cultural and economic predictor variables with the highest p-value were removed, and only those with p values$\leq$0.05 were kept remaining in the model. Statistically significant variables in both analyses were those with $p \leq 0.05$. The p-values of less or equal to 0.05 were statistically considered significant in all the analyses.

3. Results

3.1. Participants' demographic and flocks' characteristics

Of the 422 recruited poultry farms/owners, 98.6% ($n = 416$) of them:

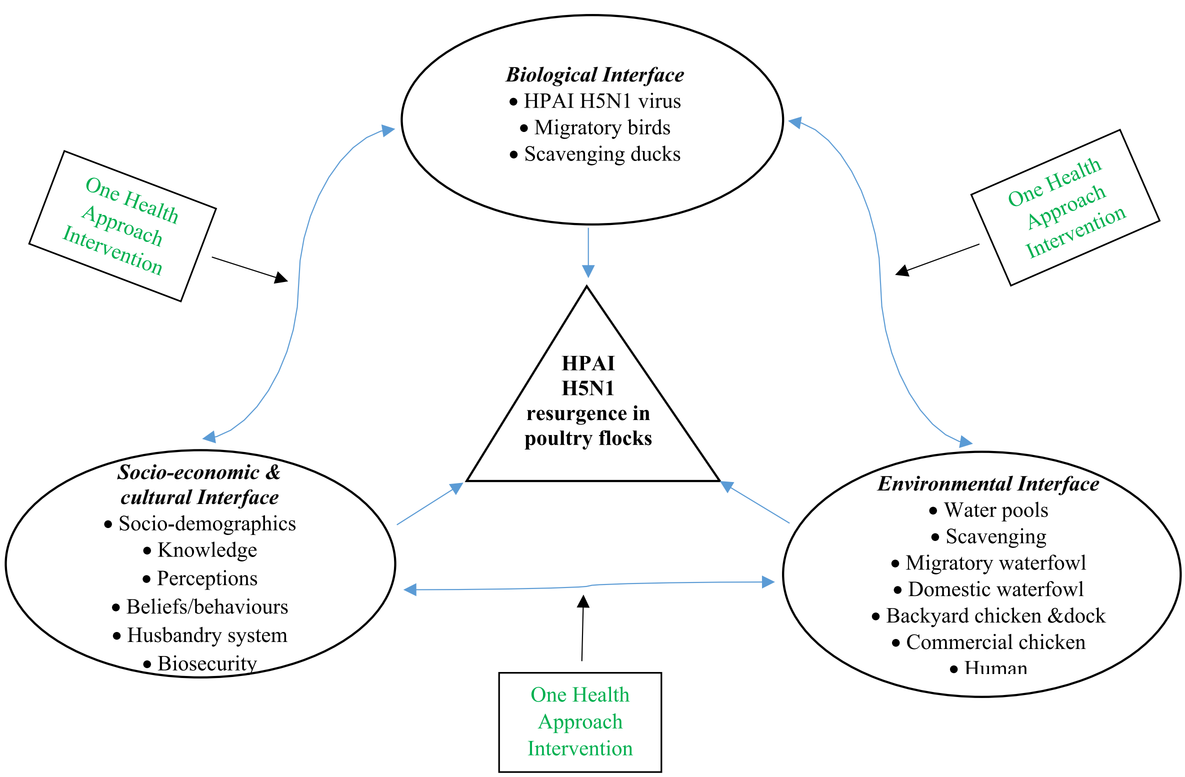

Fig. 1. A Conceptual One Health framework model for HPAI H5N1 resurgence at human-bird-environment interface in Nigerian poultry flocks and the intervention points. The concept provides a framework for building capacity around zoonotic HPAI and mitigation using a One Health approach putting into consideration socio-cultural and economic activities.

47.4% ($n = 197$) smallholder commercial poultry farmers and 52.6% ($n = 219$) backyard traditional poultry keepers participated. However, 6 (1.4%) of them dropped out. The majority of farmers (26.3%, $n = 110$) were found to be in the age group 48–57 years. Males had the highest participation (52.2%, $n = 217$), and 76.7% ($n = 319$) of the participants were married. Majority (31.2%, $n = 130$) of the farmers had no formal education, while 29.1% ($n = 121$), 9.0% ($n = 79$), and 20.7% ($n = 86$) of them possessed primary, secondary, and tertiary formal education, respectively.

On the type of birds kept, 94% of the smallholder commercial farmers reared chickens only, 4.7% kept ducks and turkeys, and 1.3% kept geese. Also, 46% of the backyard traditional poultry keepers kept only chickens, 41% reared chickens and ducks, 9% kept chickens and geese, 2.8% kept only ducks, and 1.2% flocked turkeys only. Furthermore, the majority of the smallholder commercial farmers (93.5%) engaged in the intensive management system, while 6.5% of them were on the semi-intensive management system. Also, 97.7% of the backyard poultry keepers engaged on the extensive management system (scavenging) and only 2.3% were on the semi-intensive management system. Furthermore, only 16.1% of the smallholder commercial farmers had their poultry houses closed to the water bodies; while 94.8% of the backyard poultry keepers are surrounded by water bodies.

3.2. Knowledge about HPAI H5N1 epidemiology during resurgence

More than two-thirds of the smallholder commercial farmers (89.7%) and less than one-quarter of the backyard traditional poultry keepers (17.2%) significantly ($p < 0.05$) indicated that the outbreaks of HPAI H5N1 have previously occurred in Nigeria. Also, the majority of commercial farmers (72.6%) and very few of the backyard keepers (15.1%) significantly reported that avian influenza resurgence has occurred in Nigerian poultry flocks. HPAI H5N1 has been reported by 44.0% of the commercial farmers and 12.3% of poultry keepers to significantly affect wild birds. Only 42.6% of the commercial farmers and 13.2% of the backyard keepers significantly mentioned bird flu can affect humans. Additionally, about half of the commercial farmers (49.7%) and less than a quarter of the backyard farmers (7.8%) significantly reported that avian influenza can be disseminated from birds to humans (zoonosis). However, only 8.6% of the commercial farmers and 7.2% of the backyard keepers significantly reported to know about humans that contracted bird flu in Nigeria. Less than half of the commercial farmers (46.2%) and one-quarter of backyard keepers (13.7%) significantly mentioned that resurgence of HPAI H5N1 in poultry flocks has been associated with high morbidity, while 21.3% of the commercial farmers and 3.2% of the backyard keepers significantly mentioned that the resurgence of avian influenza in bird flocks has been associated with high deaths in bird flocks (Table 1).

3.3. Zoonotic risk pathways for HPAI H5N1 virus transmission during resurgence and spread

The majority of smallholder commercial farmers (65.5%) and backyard traditional poultry keepers (82.6%) perceived significant ($p < 0.5$) consumption of undercooked poultry meat and products to have low risk of zoonosis, while only about one-third (36.5%) and less than a quarter (18.3%) of these groups of participants, respectively indicated contacts with infected birds and contaminated fomites during handling to be of significantly high zoonotic risk. Furthermore, co-habiting with poultry in the same environment was significantly perceived by 42.1% of the smallholder commercial farmers and 15.1% of the backyard flock keepers to be of high zoonotic risk. Also, less than one-third of the (30.5%) of the smallholder commercial farmers and backyard flock keepers (21.5%) significantly perceived a contaminated environment with aerosols of poultry faeces and wastewater to have high risk of zoonosis during the HPAI H5N1 resurgence in poultry flocks (Table 2).

Table 1
Knowledge about HPAI H5N1 resurgence in poultry production systems in Nigeria.

Variable	Farmers	Correctly answered n (%)	Incorrectly answered n (%)	P-value
Bird flu outbreaks have previously occurred in Nigerian poultry flocks	Commercial	177 (89.7)	20 (10.3)	<0.001
	Backyard	37 (17.2)	182 (82.8)	
Bird flu resurgence has occurred in Nigerian poultry flocks	Commercial	143 (72.6)	54 (27.4)	<0.001
	Backyard	33 (15.1)	186 (84.9)	
Bird flu can affect wild birds	Commercial	67 (44.0)	130 (66.0)	0.001
	Backyard	27 (12.3)	192 (87.7)	
Bird flu can affect in humans	Commercial	84 (42.6)	113 (57.4)	<0.001
	Backyard	29 (13.2)	190 (86.8)	
Knew about humans that contract bird flu in Nigeria	Commercial	17 (8.6)	180 (91.4)	0.008
	Backyard	6 (7.2)	213 (92.3)	
Bird flu can be transmitted from birds to humans (zoonosis)	Commercial	98 (49.7)	99 (50.3)	<0.001
	Backyard	17 (7.8)	202 (92.2)	
Bird flu can be transmitted from environment to birds	Commercial	14 (7.1)	183 (92.9)	0.116
	Backyard	8 (3.7)	211 (96.3)	
Bird flu resurgence has been associated with high morbidity in poultry flocks	Commercial	91 (46.2)	106 (53.8)	<0.001
	Backyard	30 (13.7)	189 (86.3)	
Bird flu resurgence has been associated with high mortality in poultry flocks	Commercial	42 (21.3)	155 (78.7)	<0.001
	Backyard	7 (3.2)	212 (92.8)	

Statistically significant at $p < 0.05$.

Table 2
Zoonotic pathways for HPAI H5N1 transmission during resurgence in poultry production systems in Nigeria.

Pathway	Farmers	Low risk n (%)	High risk n (%)	P-value
Consumption of undercooked poultry meat and products	Commercial	129 (65.5)	68 (34.7)	0.001
	Backyard	181 (82.6)	38 (17.4)	
Contacts with infected birds and contaminated fomites during handling	Commercial	125 (63.5)	72 (36.5)	0.001
	Backyard	170 (81.7)	49 (18.3)	
Co-habiting with poultry in the same environment	Commercial	114 (57.9)	83 (42.1)	<0.001
	Backyard	186 (84.9)	33 (15.1)	
Contaminated environment with aerosols of poultry faeces and wastewater	Commercial	137 (69.5)	60 (30.5)	0.030
	Backyard	172 (78.5)	47 (21.5)	

Statistically significant at $p < 0.05$.

3.4. Biosecurity and biosafety measures practice against HPAI H5N1 resurgence at poultry flock settlements

Stratified by the husbandry management systems, more than two-thirds of the smallholder commercial poultry farms (92.9%) and about one-third of the backyard traditional poultry flocks (33.8%) significantly practiced separation of sick birds apparently healthy ones in the flock as biosecurity measure against the resurgence of HPAI H5N1 of poultry flocks. More than two-thirds of the commercial poultry farmers (86.8%) and about one-quarter of the backyard keepers (25.6%) significantly clean the equipment and premises frequently as a measure against the disease. On regular disinfection of equipment and premises, the majority of the commercial poultry farmers (53.3%) and few of the backyard flock keepers (12.2%) significantly practiced biosecurity and biosafety measures against bird flu resurgence in the flocks. Also, 94.9% of the commercial poultry farmers and 21.9% of the backyard flock keepers significantly practiced movement control of birds to nearby water bodies as a biosecurity measure. The majority of the smallholder commercial poultry farmers (97.0%) and very few of the backyard flock keepers (7.3%) significantly practiced the burial of dead birds in deep ditches far from the flock site as a biosecurity measure.

Furthermore, more than half of the smallholder commercial poultry farmers (55.3%) and very few backyards traditional poultry keepers (4.2%) significantly used personal protective equipment as biosecurity/biosafety protections against avian influenza resurgence in the birds. Also, 95.9% of commercial poultry farmers and 46.6% of backyard flock keepers significantly practiced the non-introduction of new birds into the flock as a biosecurity measure against bird flu resurgence in flocks. Nevertheless, only 45.7% of the commercial poultry farmers and 2.7% of the backyard flock keepers significantly practiced movement control of persons and vehicles into the flock settlements as biosecurity measures against bird flu resurgence (Table 3).

Table 3
Biosecurity and biosafety measures practice against HPAI H5N1 resurgence in poultry production systems in Nigeria.

Variable	Farmers	Correct practice n (%)	Incorrect practice n (%)	P-value
Separation of sick birds from apparently healthy ones in the flock	Commercial	183 (92.9)	14 (7.1)	<0.001
	Backyard	74 (33.8)	145 (66.2)	
Frequent cleaning of equipment and premises	Commercial	171 (86.8)	26 (13.2)	<0.001
	Backyard	56 (25.6)	163 (74.4)	
Regular disinfection of equipment and premises	Commercial	105 (53.3)	92 (46.7)	<0.001
	Backyard	18 (12.2)	201 (87.8)	
Movement control of birds to nearby water bodies	Commercial	187 (94.9)	10 (5.1)	<0.001
	Backyard	48 (21.9)	171 (78.1)	
Separate keeping of birds according species	Commercial	190 (96.4)	7 (3.6)	<0.001
	Backyard	43 (19.6)	176 (80.4)	
Burial of dead birds in deep ditches far from the flock site	Commercial	191 (97.0)	6 (3.0)	<0.001
	Backyard	16 (7.3)	203 (92.7)	
Use personal protective equipment (PPE)	Commercial	109 (55.3)	88 (44.7)	<0.001
	Backyard	19 (4.2)	200 (96.8)	
Non-introduction of new birds into flock	Commercial	189 (95.9)	8 (4.1)	<0.001
	Backyard	102 (46.6)	117 (53.4)	
Movement control of persons and vehicles	Commercial	90 (45.7)	107 (54.3)	<0.001
	Backyard	6 (2.7)	213 (97.3)	

Statistically significant at $p < 0.05$.

3.5. Sociodemographic characteristics associated with their risk perceptions, and biosecurity and biosafety measures practices against HPAI H5N1 resurgence in bird flocks

At univariate analysis, all the hypothesized poultry flock owners' sociodemographic variables were significantly associated with their perceptions of risks and practices of biosecurity measures and biosafety towards HPAI H5N1 resurgence in bird flocks. However, with the multivariable logistic regression models, only those in age groups 38–47, 48–57, and 58–67 years were significantly more likely [(OR: 3.16; 95% CI: 1.60, 6.25), (OR: 2.08; 95% CI: 1.09, 3.95), and (OR: 2.36; 95% CI: 1.18, 4.74), respectively] to have correct risk perceptions and practice of biosecurity measures towards avian influenza resurgence than those in the 18–27 years' age group. Also, male poultry flock owners were significantly two times more likely (OR: 1.48; 95% CI: 1.01, 2.18) to possess correct risk perceptions and practice of biosecurity measures towards HPAI H5N1 resurgence than females.

Backyard poultry flock keepers significantly, were less likely (OR: 0.40; 95% CI: 0.27, 0.59) to possess correct risk perceptions and practice biosecurity measures towards avian influenza resurgence in flocks than the commercial poultry farmers. Poultry flock owners with formal tertiary education significantly, were also less likely [(OR: 0.41; 95% CI: 0.24, 0.73) to have risk perceptions and practice biosecurity measures on avian influenza resurgence in bird flocks than the participants without formal education (Table 4).

3.6. Social, cultural and economic drivers of HPAI H5N1 resurgence and spread in poultry flocks

The results at univariate analysis presented all the hypothesized social, cultural, and economic predictor variables to significantly ($p <$

Table 4
Farmers' sociodemographic characteristics associated with their perceptions, and biosecurity and biosafety practices towards HPAI H5N1 resurgence and spread in poultry flocks in Nigeria.

Characteristics	Correctly answered n (%)	Incorrectly answered n (%)	Odds ratio	95% CI	P-value
Age					
18–27	37 (62.7)	23 (38.3)	1.00		
28–37	59 (71.1)	24 (28.9)	0.65	0.32, 1.32	0.244
38–47	30 (33.7)	59 (66.3)	3.16	1.60, 6.25	0.001
48–57	48 (43.6)	62 (56.4)	2.08	1.09, 3.95	0.020
58–67	30 (40.5)	44 (59.5)	2.36	1.18, 4.74	0.010
Gender					
Female	113 (56.8)	86 (43.2)	1.00		
Male	102 (47.0)	115 (53.9)	1.48	1.01, 2.18	0.040
Marital status					
Single	47 (48.4)	50 (51.6)	1.00		
Married	194 (60.8)	125 (39.2)	0.61	0.38, 0.96	0.030
Occupation					
Backyard flock keeper	97 (44.3)	122 (55.7)	1.00		
Commercial farmer	131 (67.5)	66 (33.5)	0.40	0.27, 0.59	0.001
Formal education					
None	60 (46.2)	70 (53.8)	1.00		
Primary	37 (30.6)	84 (69.4)	1.35	0.82, 2.23	0.245
Secondary	44 (55.7)	35 (44.3)	0.68	0.39, 1.20	0.185
Tertiary	58 (67.4)	28 (32.6)	0.41	0.24, 0.73	0.002

Statistically significant at $p < 0.05$; CI – Confidence interval.

0.05) influenced HPAI H5N1 resurgence and spread in poultry flocks. However, the multivariable logistic regressions showed that the availability of nearby water bodies (ponds) close to flock settlements was significantly six times likely (OR: 5.48, 95% CI: 3.58, 8.38) to drive avian influenza resurgence in flocks. Similarly, the presence of wild water birds nearby flock settlements was significantly 23 times likely (OR: 23.26; 95% CI: 13.68, 39.53) to drive the resurgence of avian influenza in poultry. Keeping different bird species in a flock, and frequent contact of wild and domestic birds were eight and ten times significantly eight times likely [(OR: 8.42; 95% CI: 5.37, 13.21) and (OR: 9.51; 95% CI: 5.93, 15.25), respectively] to influenced resurgence of avian influenza in poultry flocks. Noteworthy, the cultural practice of bird exchange between flocks, and poor biosecurity practice at the poultry settlements were significantly more likely [(OR: 7.33; 95% CI: 4.53, 11.85) and (OR: 35.20; 95% CI: 19.94, 62.14), respectively] to influenced avian influenza resurgence in poultry flocks. Furthermore, the incorporation of birds bought at live bird markets into flocks, and wild waterfowls' seasonal migrations were significantly more likely [(OR: 89.41; 95% CI: 39.51, 202.4) and (OR: 1.25; 95% CI: 0.77, 2.04), respectively] to influenced HPAI H5N1 resurgence in poultry flocks in Nigeria (Table 5).

Table 5
Social, cultural, and economic factors that drive resurgence and spread of HPAI H5N1 in poultry flocks in Nigeria.

Factors	Correctly answered n (%)	Incorrectly answered n (%)	Odds ratio	95% CI	P-value
Nearby water bodies (ponds)					
Commercial farmer	123 (62.4)	74 (37.6)	1.00		
Backyard keeper	51 (23.3)	168 (76.7)	5.48	3.58, 8.38	<0.001
Presence of wild water birds nearby the flock settlement					
Commercial farmer	146 (74.1)	51 (25.9)	1.00		
Backyard keeper	24 (11.0)	195 (89.0)	23.26	13.68, 39.53	<0.001
Keeping different birds species in a flock					
Commercial farmer	130 (66.0)	67 (34.0)	1.00		
Backyard keeper	41 (18.7)	178 (81.3)	8.42	5.37, 13.21	<0.001
Frequent contacts of wild and domestic birds					
Commercial farmer	122 (61.9)	75 (38.1)	1.00		
Backyard keeper	32 (14.6)	187 (85.4)	9.51	5.93, 15.25	<0.001
Cultural practice of bird exchange between flocks					
Commercial farmer	104 (52.8)	93 (87.8)	1.00		
Backyard keeper	29 (13.2)	190 (86.8)	7.33	4.53, 11.85	<0.001
Incorporation of birds bought at live bird markets into flocks					
Commercial farmer	190 (47.2)	7 (52.8)	1.00		
Backyard keeper	51 (23.3)	168 (76.7)	89.41	39.51, 202.4	<0.001
Poor biosecurity practice at the poultry settlements					
Commercial farmer	177 (89.8)	20 (10.2)	1.00		
Backyard keeper	44 (20.1)	175 (79.9)	35.20	19.94, 62.14	<0.001
Wild waterfowls seasonal migrations					
Commercial farmer	41 (20.8)	156 (79.2)	1.00		
Backyard keeper	38 (17.4)	181 (82.6)	1.25	0.77, 2.04	0.372

Statistically significant at $p < 0.05$; CI – Confidence interval.

4. Discussion

To the best of our knowledge, this study is the first to investigate resurgence of HPAI H5N1 in relation to social, cultural, and economic factors and demonstrates their dynamic influence on the disease across Nigeria. These findings could help inform better strategies for effective target intervention towards prevention of its transmission. Generally, this study found that the majority of smallholder commercial farmers rear chickens only, and few of them keep ducks and turkeys or geese. Mixed keeping of poultry species in an environment has been reported to provide favorable forum for cross-transmission of avian influenza virus among birds [22–25]. Ducks were observed to be commonly reared by the traditional poultry keepers in Nigeria. Birds from the Orders *Anseriformes* (ducks, geese, swans) have been reported to be the natural reservoir of the HPAI H5N1 virus [26]. The majority of backyard poultry holders were found to engage in the extensive management system. Scavenging system of domestic birds, especially ducks, have been reported to facilitate the emergence and re-emergence of avian influenza subtypes that are also zoonotic [27]. Of noteworthy was the presence of water bodies close to almost all the backyard poultry settlements, which could serve as feeding and breeding sites for wild waterfowls. Wild waterfowls have contributed to the emergence and spread of the HPAI viruses on a global scale [28].

We observed disparities in the knowledge variables among the two groups of poultry farmers, with the smallholder commercial farmers significantly being more knowledgeable about avian influenza than the backyards traditional poultry keepers. Both have indicated that bird flu outbreak has previously occurred in Nigeria and its resurgence has occurred in the country's poultry flocks. This is likely due to low levels of formal education, low economic importance of backyard poultry worldwide, and the impression that backyard poultry poses few risks associated with infectious diseases [8,29,30]. They also mentioned that the disease is zoonotic and few of them indicated knowing humans that have contracted it during the resurgence in Nigeria. Its resurgence in poultry flocks has been reported with high morbidity and mortality. To promote farmers' knowledge and preventive practices on HPAI, formal education is very important [31].

Our study found consumption of undercooked poultry meat and products, contact with infected birds and contaminated fomites during handling, co-habiting with poultry in the same environment, and contaminated environment with aerosols of poultry faeces and wastewater to have significant high zoonotic risk during the HPAI H5N1 resurgence. Contact points between humans and birds provide optimal platform for the spread and evolution of zoonotic pathogens, especially the avian influenza viruses [32,33]. Direct exposure of poultry workers to infected poultry has been reported as the prime risk factor in the dissemination of zoonotic avian influenza viruses [34–36]. Furthermore, a report has shown that susceptible birds can pick up HPAI virus through direct contact with nasal secretion, saliva, blood or faeces, of infected birds or when in contact with fomites surfaces contaminated with the materials [37]. Improving farmers' knowledge on viral spread and use of adequate preventive measures are the needed public health strategies that would reduce the effects of avian influenza in poultry farms.

We found sick birds' separation from apparently healthy ones, frequent cleaning and disinfection of equipment and premises, birds' movement control to nearby water bodies, burial of dead birds in deep ditches far from the flock site, use of personal protective equipment, non-introduction of new birds into flocks, and movement control of persons and vehicles into the flock settlements as practice biosecurity measures. However, these measures were adequately practiced in some commercial poultry farms but inadequate to non-existence in backyard flocks as indicated in the response rates. Previous studies have reported certainty of backyard traditional bird flocks lacking practice of biosecurity measures, thus having more chances of contacting wild birds due to scavenging disposition that exposes them to constant avian influenza virus strains challenge, a great role in the dissemination of the viruses [22,38]. This traditional farmers' behaviour could be likely due to the impression that their birds do not play any significant role in avian influenza virus transmission [29]. With an increase in demand for poultry products in Nigeria, surveillance and research become imperative to identify gaps and achieve optimum mitigations against the disease in poultry and its public health risk.

On the influence of farmers' socio-demographics, this study found those in high age groups (38–47 years and above) and males to significantly possess correct risk perceptions and practice biosecurity measures towards H5N1 resurgence in poultry flocks. This portrays older farmers perceiving higher vulnerability to the disease and higher efficacy to practice measures against it. Meanwhile, we found the majority of backyard poultry keepers with less likelihood of correctly perceiving risks and practicing biosecurity measures towards the bird flu resurgence and spread in poultry flocks. It is, therefore, important to structure surveillance protocols to target scavenging free-range poultry flocks in developing countries. Furthermore, farmers with tertiary education were found with less likelihood of perceiving risks and practicing biosecurity measures towards bird flu resurgence in flocks compared with those without formal education. This indicates that better-educated farmers, especially the backyard poultry keepers may not perceive higher risks and practice adequate measures against H5N1 of the management nature. This is in contrast to findings of previous studies that reported advanced educated poultry farmers and traders to be more likely to perceive high risks and practice better biosecurity measures against avian influenza [31,39].

Contrary to our hypotheses, this study observed the availability of nearby water bodies (ponds) close to flock settlements, wild water birds' presence close to the flock settlements, keeping different bird species in flocks, and frequent contact of wild and domestic birds to be significantly associated with HPAI H5N1 resurgence in Nigerian poultry flocks. Noteworthy, cultural practice of bird exchange between flocks, poor biosecurity practice at the poultry settlements, incorporation of birds bought at live bird markets into flocks, and wild waterfowls' seasonal migrations were found to significantly drive the resurgence of the disease in poultry flocks in Nigeria. Wild water birds harboring this virus have been reported to undergo intercontinental annual migratory movements and shedding it along wintering and breeding grounds within the flyways [40]. Also, the warm tropical climate of Nigeria with abundant wetlands, rivers, and lakes makes the country a favorable habitat for the migratory wild waterfowls to stopover for feeding and resting during transboundary flights and consequently mix and infect scavenging local birds with the avian influenza virus and as well contaminate the environment [41].

The resurgence of the bird flu in Nigeria has previously been reported to be influenced by migratory wild waterfowls' voyage during long distances seasonal migrations from Eurasia since the country is located along the major flyways, such as the Atlantic-America, East-Africa-Asia, and the Black Sea-Mediterranean flyways [41,42]. Furthermore, report has indicated that migratory wild waterfowls have contributed to the spread of the HPAI viruses globally [28].

We observed HPAI H5N1 to be a true One Health concern given its potential to emerge due to influencing activities in poultry, human and environmental domains (Fig. 1). The resurgence and potential for transmission within and between flocks in developing countries pose a challenge that requires special interventions because of the dynamic interfacing biological, environmental, and salient socio-cultural and economic factors. Actions to prevent the resurgence and spread of the disease can be achieved through application of the One Health conceptual framework. In the middle of the model is a triangle showing the interfacing links of these factors that influence the virus resurgence and spread. The three major circles are the factors associated with the resurgence, interlinking one another and meeting at the centre. The study observed that H5N1 resurgence and dissemination in poultry flocks in Nigeria and other countries are associated with these interfacing three domains of influencing factors. Environmental contamination occurs when wild aquatic birds, believed to be the natural reservoir hosts, excrete high levels of avian influenza viruses into the environment which supports indirect contact by environmental transmission, especially in birds maintained outdoors. Poultry farmers' socio-cultural and economic behaviours are considered to be the most complex determinants, as previously reported for other infectious and contagious transboundary health events [17,19,20]. Since the principles of disease control and prevention are intervention efforts meant to stop its occurrence or transmission from one source to another, the efforts can be instituted along the interfacing links between the domains in the model through collaborative multi-disciplinary and multi-sectorial One Health approach implementation. Attack on the links would interrupt the transmission cycle and protect susceptible birds and humans thereby mitigating economic losses faced by farmers and public health risks.

We found some limitations to this study. Firstly, we could not assess the impact of causal relationships due to cross-sectional design of the research, but it does show associations. Secondly, the study was limited by non-adjustment for states clustered in the design of random sampling. The use of central tendency could, however, be valuable enough to mitigate likely confidence intervals imperfections. Finally, although we did not use sero-positivity as a measure of previous challenge of the birds by the avian influenza virus, high proportions of the interviewer-administered questionnaire responses were considered credible enough to provide significant outcomes for all the predictors.

5. Conclusion

The resurgence highlights the highly contagious and zoonotic nature of the avian influenza H5N1 virus. There is also challenging knowledge, perceptions, and biosecurity gaps among farmers of the two poultry production systems. Given these concerns, it is necessary to strengthen farmers' education, culture of biosafety and biosecurity in the farming systems, and promote surveillance programs for influenza A viruses and other zoonotic pathogens in Nigeria. Understanding the interactions between the determinants in the postulated 'One Health conceptual framework model' will enable better intervention. Socio-cultural and economic activities significantly influenced H5N1 resurgence in flocks. Behavioral transformation of these activities through the One Health perspective will not only ensure public and environmental health, but also assure food security and food safety.

Ethical approval

Not Applicable.

Funding

No funding.

CRediT authorship contribution statement

Nma Bida Alhaji: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. **Abdulrahman Musa Adeiza:** Conceptualization, Investigation, Methodology, Supervision, Validation, Writing – original draft, Writing – review & editing. **Enid Abutu Godwin:** Investigation, Methodology, Validation, Writing – original draft, Writing – review & editing. **Aliyu Evuti Haruna:** Investigation, Methodology, Validation. **Mohammed Baba Aliyu:** Investigation, Methodology, Validation. **Ismail Ayoade Odetokun:** Supervision, Validation, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no competing interests.

Data availability

The data of farms visited are available on request from the corresponding author.

Acknowledgement

The authors thank all the Animal Health Technologists for providing links of contact with the poultry farmers in the semi-urban areas and particularly those at the rural areas. Also, the authors appreciate participation of all the respondents.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.onehlt.2023.100574.

References

[1] FAOSTAT, Biosecurity for Highly Pathogenic Avian Influenza: Issues and Options, FAO, Rome, 2021 [cited 2022 April 20]. Available from: https://www.fao.org/faostat/en/#data/QCL.
[2] FAO, Small Scale Poultry Production: A Technical Guide, Food and Agriculture Organization of the United Nations, Rome, 2004.
[3] A. Mottet, G. Tempo, Global poultry production: current state and future outlook and challenges, World Poult. Sci. J. 73 (2017) 245–256.
[4] A. Suttie, E.A. Karlsson, Y.M. Deng, A.C. Hurt, A.R. Greenhill, I.G. Barr, P. Dussart, P.F. Horwood, Avian influenza in the greater Mekong subregion, infect, Genet. Evol. 74 (2019), 103920.
[5] I. Iglesias, A.M. Perez, A. De la Torre, M.J. Munoz, M. Martinez, J.M. Sanchez-Vizcaino, Identifying areas for infectious animal disease surveillance in the absence of population data: highly pathogenic avian influenza in wild bird populations of Europe, Prev. Vet. Med. 96 (1–2) (2010) 1–8.
[6] A. Fusaro, T. Joannis, I. Monne, A. Salviato, B. Yakubu, C. Meseko, T. Oladokun, S. Fassina, I. Capua, G. Cattoli, Introduction into Nigeria of a distinct genotype of avian influenza virus (H5N1), Emerg. Infect. Dis. 15 (3) (2009) 445–447.
[7] A.T. Oladokun, C.A. Meseko, E. Ighodalo, B. John, P.S. Ekong, Effect of intervention on the control of highly pathogenic avian influenza in Nigeria, Pan African Med. J. 13 (2012) 14.
[8] FAO, Food and Agriculture Organization of the United Nations (FAO), Global AIV with Zoonotic Potential: situation update, FAO, 2021 [cited 2022 April 20]. Available from: http://www.fao.org/ag/againfo/programmes/en/empres/Global_AIV_Zoonotic_Update/situation_.
[9] I. Monne, C. Meseko, T. Joannis, I. Shittu, M. Ahmed, L. Tassoni, G. Cattoli, Highly pathogenic avian influenza a (H5N1) virus in poultry, Nigeria, Emerg. Infect. Dis. 21 (7) (2015) 1275–1277.
[10] L. Tassoni, A. Fusaro, A. Milani, P. Limey, J. Awuni, V. Sedor, C. Dogbey, O. A. Commey, C. Meseko, T. Joannis, G.L. Minoungou, L. Ouattara, A.B. Haido, D. CisseAman, E. Couacy-Hymann, G. Dauphin, G. Cattoli, I. Monne, Genetically different highly pathogenic Avian Influenza A(H5n1) viruses in West Africa, 2015, Emerg. Infect. Dis. 22 (12) (2016) 2132–2136.
[11] I. Shittu, C. Meseko, D. Gado, K. Olawuyi, C. Chinyere, E. Anefu, P. Solomon, P. A. Okewole, D. Shamaki, T. Joannis, Highly pathogenic avian influenza (H5N1) in Nigeria in 2015: evidence of widespread circulation of WA2 clade 2.3.2.1c, Arch. Virol. 62 (3) (2017) 841–847.
[12] WOAH, World Organisation for Animal Health (WOAH). Highly Pathogenic Avian Influenza (HPAI) Report No. 21: January 15 to Feb 04, 2021, 2021 [cited 2022 April 20]. Available from: https://www.oie.int/app/uploads/2021/03/hpai—asof0402202.
[13] WOAH, World Organization for Animal Health (WOAH), OIE Situation Report for Highly Pathogenic Avian Influenza, WOAH, 2018 [cited 2022 April 20]. Available from: https://www.woah.org/fileadmin/Home/eng/Animal_Health_in_the_World/docs/pdf/OIEAI_situation_report/OIE_SituationReport_AI_August2018.pdf.
[14] NCDC, Nigeria Centre for Diseases Control (NCDC), Avian Influenza Situation Report. Epi Week 12, 22–28 Mar, NCDC, 2021 [cited 2022 Jun 23]. Available from: www.ncdc.gov.ng [cited 2022 Jun 23]. Available from:.
[15] WHO, World Health Organization (WHO), Cumulative number of confirmed human cases for avian influenza A (H5N1) reported to WHO, 2003–2021, 15 April 2021. In Emergency Situational Updates, World Health Organization (WHO), Geneva, 2021.
[16] One Health High-Level Expert Panel (OHHLEP), W.B. Adisasmito, S. Almuhairi, C. B. Behravesh, P. Bilivogui, S.A. Bukachi, N. Casas, N.C. Becerra, D.F. Charron, A. Chaudhary, J.R.C. Zanella, A.A. Cunningham, O. Dar, N. Debnath, B. Dungu, E. Farag, G.F. Gao, D.T.S. Hayman, M. Khaitsa, M.P.G. Koopmans, C. Machalaba, J. S. Mackenzie, W. Markotter, T.C. Mettenleiter, S. Morand, V. Smolenskiy, L. Zhou, One health: a new definition for a sustainable and healthy future, PLoS Pathog. 18 (6) (2022), e1010537.
[17] R. Bell, S. Taylor, M. Marmot, Global health governance: commission on social determinants of health and the imperative for change, J. Law, Med. Ethics 38 (2010) 470–485.
[18] WHO, in: O. Solar, A.A. Irwin (Eds.), A Conceptual Framework for Action on the Social Determinants of Health Discussion Paper 2 (Policy and Practice), The World Health Organization Press, Geneva, 2010.
[19] N.B. Alhaji, J. Kabir, Influence of Pastoralists' sociocultural activities on tsetse–trypanosome–cattle reservoir Interface: the risk of human African trypanosomiasis in north-Central Nigeria, Zoonoses Public Health 63 (4) (2015) 271–280.
[20] N.B. Alhaji, O.O. Babalobi, Qualitative and quantitative impacts assessment of contagious bovine pleuropneumonia in Fulani pastoral herds of north-Central Nigeria: the associated socio-cultural factors, Prev. Vet. Med. 128 (2016) 124–134.
[21] M. Thrusfield, Veterinary Epidemiology, 3rd ed, Blackwell Science Ltd, A Blackwell Publishing company, 9600 Garsington Road, Oxford OX4 2DQ, UK, 2009, pp. 228–238.
[22] N.B. Alhaji, I.A. Odetokun, Assessment of biosecurity measures against highly pathogenic avian influenza risks in small-scale commercial farms and free-range poultry flocks in the northcentral Nigeria, Transbound. Emerg. Dis. 58 (2011) 157–161.
[23] L. Loth, M. Gilbert, J. Wu, C. Czarnecki, M. Hidayat, X. Xiao, Identifying risk factors of highly pathogenic avian influenza (H5N1 subtype) in Indonesia, Prev. Vet. Med. 102 (1) (2011) 50–58.
[24] R. Metras, K.B. Stevens, P. Abdu, I. Okike, T. Randolph, D. Grace, D.U. Pfeiffer, S. Costard, 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 (1) (2013) 87–96.
[25] O.B. Akanbi, P.S. Ekong, C.I. Odita, V.O. Taiwo, The effect of highly pathogenic avian influenza (HPAI) H5N1 outbreaks on mixed species poultry farms in Nigeria, J. World Poult. Res. 6 (3) (2016) 147–152.
[26] S. Sonnberg, R.J. Webby, R.G. Webster, Natural history of highly pathogenic avian influenza H5N1, Virus Res. 178 (1) (2013) 63–77.
[27] A.T.M. Badruzzaman, M.M. Rahman, M. Hasan, M.K. Hossain, A. Husna, F.M. A. Hossain, M. Giasuddin, M.J. Uddin, M.R. Islam, J. Alam, S.-K. Eo, F.O. Fasina, H. M. Ashour, Semi-scavenging poultry as carriers of avian influenza genes, Life 12 (2022) 320.
[28] A. Blagodatski, K. Trutneva, O. Glazova, O. Mityaeva, L. Shevkova, E. Kegeles, N. Onyanov, K. Fede, A. Maznina, E. Khavina, S.J. Yeo, H. Park, P. Volchkov, Avian influenza in wild birds and poultry: dissemination pathways, monitoring methods, and virus ecology, Pathogens 10 (2021) 630.
[29] V. Bavinck, A. Bouma, M. van Boven, M.E. Bos, E. Stassen, J.A. Stegeman, The role of backyard poultry flocks in the epidemic of highly pathogenic avian influenza virus (H7N7) in the Netherlands in 2003, Prev. Vet. Med. 88 (4) (2009) 247–254.
[30] I.A. Odetokun, N.B. Alhaji, T.O. Isola, A.A. Erena, B. Mohammed, Risk perceptions and preventive preparedness towards avian influenza (H5N1) at live bird markets in north-Central Nigeria: public health implications, Savannah Vet. J. 1 (1) (2018) 31–40.
[31] P.C. Kuo, J.H. Huang, M.D. Liu, Avian influenza risk perception and preventive behavior among traditional market workers and shoppers in Taiwan: practical implications for prevention, PLoS One 6 (9) (2011), e24157.
[32] N.B. Alhaji, I.A. Odetokun, Biosecurity measures against highly pathogenic avian influenza (HPAI) in free range flocks and commercial poultry in developing countries: A review, in: K.M. Taylor, B.O. Connor (Eds.), Avian Influenza: Molecular Evolution, Outbreaks and Prevention/Control, NOVA Publishers, USA, 2013, pp. 23–48.
[33] X. Zhou, Y. Li, Y. Wang, J. Edwards, F. Guo, A.C.A. Clements, The role of live poultry movement and live poultry market biosecurity in the epidemiology of influenza A (H7N9): A cross sectional observational study in four eastern China Province, J. Inf. Secur. 71 (4) (2015) 470–479.
[34] C.B. Bridges, W. Lim, J. Hu-Primmer, L. Sims, K. Fukuda, K.H. Mak, T. Rowe, W. W. Thompson, L. Conn, X. Lu, N.J. Cox, J.M. Katz, Risk of influenza a (H5N1) infection among poultry workers, Hong Kong, 1997–1998, J. Infect. Dis. 185 (2002) 1005–1010.
[35] D. Areechokchai, C. Jiraphongsa, Y. Laosiritaworn, W. Hanshaoworakul, M. O'Reilly, Centers for Disease Control and Prevention (CDC), Investigation of avian influenza (H5N1) outbreak in humans—Thailand, 2004, MMWR morbid, Mortal. Weekly Rep. 55 (Suppl. 1) (2006) 3–6.
[36] A. Thorson, M. Petzold, N.T. Chuc, K. Ekdahl, Is exposure to sick or dead poultry associated with flulike illness? A population-based study from a rural area in Vietnam with outbreaks of highly pathogenic avian influenza, Archiv, Intern. Med. 166 (2006) 119–123.
[37] CDC, Transmission of avian influenza H5N1 in birds. Centers for Disease Control and Prevention, Atlanta [cited 2022 April 20]. Available from: https://www.cdc.gov/flu/avianflu/avian-in-birds.htm, 2015, 2015.
[38] N.A. Rimi, M.Z. Hassan, S. Chowdhury, M. Rahman, R. Sultana, P.K. Biswas, N. C. Debnath, S.S. Islam, A.G. Ross, A decade of avian influenza in Bangladesh: where are we now? Trop. Med. Infect. Dis. 4 (3) (2019) 119.
[39] B. Cui, Q. Liao, W.W.T. Lam, Z.P. Liu, R. Fielding, Avian influenza a/H7N9 risk perception, information trust and adoption of protective behaviours among poultry farmers in Jiangsu Province, China, BMC Public Health 17 (2017) 463–475.
[40] D.J. Prosser, J. Chen, C.A. Ahlstrom, A.B. Reeves, R.L. Poulson, J.D. Sullivan, D. McAuley, C.R. Callahan, P.C. McGowan, J. Bahl, D.E. Stallknecht, A.M. Ramey,

Maintenance and dissemination of avian-origin influenza a virus within the northern Atlantic flyway of North America, PLoS Pathog. 18 (6) (2022), e1010605.

[41] M.F. Ducatez, C.M. Olinger, A.A. Owoade, S. De Landtsheer, W. Ammerlaan, H.G. M. Niesters, A.D.M.E. Osterhaus, R.A.M. Fouchier, C.P. Muller, Avian flu: multiple introductions of H5N1 in Nigeria, Nature 442 (2006) 37.

[42] R.A. Fouchier, V.J. Munster, Epidemiology of low pathogenic avian influenza viruses in wild birds, Scient. Techn. Rev. 28 (2009) 49–58.