ORIGINAL ARTICLE

Factors influencing chicken farmers' decisions to implement prevention and control measures to reduce avian influenza virus spread under endemic conditions

Short running title

Farmers' perceptions to control avian influenza

Suman Das Gupta[1], Guillaume Fournié[2], Md. Ahasanul Hoque[3], Joerg Henning[1]

[1]School of Veterinary Science, University of Queensland, Queensland, Australia [2]Veterinary Epidemiology, Economics and Public Health Group, Department of Pathobiology and Population Sciences, Royal Veterinary College, University of London, United Kingdom [3]Department of Medicine and Surgery, Faculty of Veterinary Medicine, Chattogram (previously Chittagong) Veterinary and Animal Sciences University, Bangladesh

Summary

The ongoing circulation of Highly Pathogenic Avian Influenza (HPAI) H5N1 poses a threat to both poultry and public health. Adapting the constructs of the Health Belief Model (HBM) framework, we investigated perceptions of backyard, commercial broiler and layer chicken farmers to implement HPAI prevention and control measures in Bangladesh. Two cross-sectional studies were conducted in 2016 and 2017 on 144 backyard, 106 broiler and 113 layer chicken farms. Using Structural Equation Modelling, we modelled the direct and indirect effects on farmers' perceptions on taking HPAI prevention and control actions. Our results indicate that farmers of different chicken production systems have different decision-making processes. While perceived barriers to the implementation of prevention and control measures (e.g. wearing protective equipment when handling chickens) prevented both broiler and backyard farmers to adopt interventions, perceived benefits of measures (e.g. maintaining high biosecurity will reduce the risk of birds becoming sick) strongly influenced commercial farmers', but not backyard farmers' decisions. Information provided on HPAI through media, meetings or via information campaigns played an important role in farmers' decision making in all production systems. Outcomes of this research can be used to tailor advice on HPAI control and prevention to different poultry farming groups by accounting for specific factors influencing their decision-making, instead of using one-size-fit-all communication approach.

KEYWORDS

Chicken, prevention, control, Highly Pathogenic Avian Influenza

1 | INTRODUCTION

Highly Pathogenic Avian Influenza (HPAI) H5N1 was first reported in 1959 on a small poultry farm in Scotland, UK (Capua & Alexander, 2007). Since then, several localised outbreaks occurred in different countries across the world. However, in 1996, HPAI H5N1 emerged in southern China, and subsequently spread across Asia, Europe and Africa, resulting in high mortalities of birds, and requiring the culling of many infected and unaffected flocks (Alexander, 2000; OIE, 2019a). Moreover, the zoonotic potential of the virus raises public health concerns (Fournie, Hog, Barnett, Pfeiffer, & Mangtani, 2017). Although the combined efforts from national and international communities resulted in the elimination of HPAI H5N1 in a number of countries, the virus remains endemic in Bangladesh, China, Egypt, India, Indonesia and Vietnam (FAO, 2011, 2013; OIE, 2019b).

A long-term approach was recommended by FAO/OIE in 2008 to eliminate HPAI H5N1 virus circulation in these endemically infected countries. It includes disease monitoring and surveillance, stamping out, the application of country-adjusted preventive measures (e.g. vaccination) and improved biosecurity measures (FAO, 2011; OIE,2019c). Disease monitoring and surveillance are essential for the early detection of HPAI H5N1 in order to trigger a rapid response to reduce the viral load in poultry and in the environment (FAO, 2011, 2013; OIE, 2019c). Stamping out of HPAI H5N1 infected flocks has only been partly successful in endemically infected countries, as moving or selling poultry by farmers before culling takes place, and the absence or inadequate compensation mechanisms are major constraints to control and prevention programs (FAO, 2011, 2013; OIE, 2019c; USDA, 2017). All endemically infected countries except India are currently using vaccination against HPAI with a focus on commercial poultry, but several factors, including poor vaccine-induced immune response due to antigenic mismatch or inappropriate cold chains, limit the effectiveness of vaccination programs (FAO, 2011; Kandeil et al., 2018; Kapczynski et al., 2015). Thus, improved biosecurity is the first line of defence in HPAI prevention as it establishes a barrier for the introduction of HPAI virus into farms (Conan, Goutard, Sorn, & Vong, 2012). Improved biosecurity measures include restricting the movement of visitors and vehicles to farms, cleaning and disinfecting of farms and farm equipment and wearing of protective gear while handling of poultry. However, the compliance with recommended biosecurity measures is often poor in HPAI endemically infected countries (Conan et al., 2012; FAO, 2011, 2013; Rimi et al., 2017). Hence, there is a need to understand the factors that influence farmers' decision to implement HPAI preventive or control measures on their farms. Yet, the diversity of husbandry practices, scale of production and livelihood strategies of farmers in HPAI-endemic countries may mean that factors influencing their decisions vary greatly between poultry production systems (Cui, Liao, Lam, Liu, & Fielding, 2017; Cui & Liu, 2016; Jemberu, Mourits, & Hogeveen, 2015).

Qualitative and semi-quantitative methods can be used to provide insights into farmers' perceptions and the factors influencing their attitudes towards biosecurity measures (Cui & Liu, 2016; Cui, Wang, Ke, & Tian, 2019; Oliveira, Anneberg, Voss, Sørensen, & Thomsen, 2018). For example, Knowledge, Attitudes and Practices (KAP) approaches have been used to describe knowledge, attitudes and practices of farmers towards HPAI (Ismail & Ahmed, 2010; Sarker, Sumon, Khan, & Islam, 2016; Xiang et al., 2010; Zhou et al., 2019), but these type of studies do not fully consider the integrated nature of farmers' perceptions and its influence on farmers' behaviours. This limits the applicability of KAP study results in health education or promotion programs (Caldwell, Caldwell, & Quiggin, 1989; Cleland, 1973; Green, 2001; Ratcliffe, 1976; Smith, 1993).

A number of psychological or behavioural frameworks (e.g. Theory of Planned Behaviour, Protection Motivation Theory, Social Cognitive Theory, Theory of Belief Functions or Dempster–Shafer Theory) have been developed to analyse individuals' perceptions or beliefs that influence their decision making (Ajzen, 1991; Ajzen, 2011; Bandura, 2001; Rogers, 1975; Shafer, 1992). The Health Belief Model (HBM) framework is a social cognition model that is frequently used in health education and promotion programs. Compared to other frameworks (for instance, the Theory of Planned Behaviour or Protection Motivation Theory), the HBM provides more flexibility as it is provides less constraints as to how different variables predict behaviours (Nejad, Wertheim, & Greenwood, 2005). Furthermore, the use of *cues to action* as a component in HBM, allows researchers to assess a wide range of experiences of humans that might influence their behaviours (Becker, Maiman, Kirscht, Haefner, & Drachman, 1977; Sheeran & Abraham, 2005). Also, in contrast to qualitative approaches like ethnography or grounded theory, which are more exploratory and therefore limit the generalization of results to other populations, the use of HBM is a method of choice for researchers in health sciences as it allows the quantification and analysis of the phenomes observed (Bryant & Charmaz, 2007; Hussein, Hirst, Salyers, & Osuji, 2014; Goodson & Vassar, 2011; Khan, 2018; Milliken, 2010). Thus, in a HBM framework, behaviours and actions of individuals are explored, while their perceptions and attitudes towards potential negative or positive outcomes associated with these behaviours and actions are considered. Hence, the HBM was selected as the most appropriate framework for our research to explore the perceptions of individuals to implement health-protecting actions to reduce the burden of a disease, while considering their perceptions on the susceptibility to the disease, the consequences of the disease, the benefits of implementing actions, and the barriers and constraints that might hinder the implementation of these actions (Champion & Skinner, 2008). In addition, as sources of information that may influence individuals' perceptions (*cues to action*) can be considered in a HBM framework (Glanz & Bishop, 2010; Glanz, Rimer, & Viswanath, 2008; Rosenstock, 1974), the HBM was selected as the most appropriate methodology for our investigations.

Adapting the constructs of the HBM framework, the objectives of our research were: 1) to describe biosecurity measures implemented by poultry farmers operating under different production systems in Bangladesh to prevent HPAI infection in their flocks, and 2) to identify factors influencing the ability of farmers to implement biosecurity measures.

2 | MATERIALS AND METHODS

2.1 | Theoretical framework

In the HBM framework, multiple aspects of an individual's perceptions of a given topic are assessed and used to describe the individual's decision-making (Glanz, Marcus Lewis, & Rimer, 1997; Glanz et al., 2008). We aimed to identify factors that influence backyard and commercial chicken farmers' perceptions to implement HPAI preventive and control measures and six HBM components or constructs were developed (Becker, 1974a; Champion & Skinner, 2008; Rosenstock, 1974):

i. *Perceived susceptibility*: Perceptions of the risk of chickens or humans to become infected with HPAI virus. Separate questions for HPAI susceptibility in chickens and in humans were included in the questionnaire.

ii. *Perceived severity*: Perceptions of the consequences associated with HPAI infection in chickens and humans. Separate questions for HPAI severity in chickens and in humans were included in the questionnaire.

iii. *Perceived benefits*: Perceptions of the positive impacts of HPAI preventive and control measures on chickens and humans. Separate questions for benefits of HPAI preventive and control measures in chickens and in humans were used in the questionnaire.

iv. *Perceived barriers*: Perceptions of the constraints that prevent farmers to implement HPAI preventive and control measures.

v. *Cues to action*: Engagement of farmers with different sources of information on HPAI preventive and control measures.

vi. *Self-efficacy*: Perceptions of farmers on their ability to implement HPAI preventive and control measures.

As the flexibility of the HBM allows adapting the original model (Becker, 1974b; Rosenstock, 1974) to predict a variety of behaviours in various research contexts (Becker, Drachman, & Kirscht, 1974; Champion & Skinner, 2008; Davies, Fielding, Noble, & Okpo, 2019; Dulli, Eichleay, Rademacher, Sortijas, & Nsengiyumva, 2016; Tshuma et al., 2017), we conceptualised the constructs of the HBM in a modified framework to explore the drivers that influence chicken farmers' decision-making processes to implement HPAI prevention and control measures, an outcome conceptualised as *self-efficacy*. We hypothesized that *perceived susceptibility, perceived severity, perceived benefits* and *perceived barriers* had a direct influence on the perceived ability of farmers to implement HPAI preventive and control measures (i.e. *self-efficacy*), and that *cues to action* had a mediating role on the impact of the four perceptive constructs on *self-efficacy*, and a direct influence on *self-efficacy* (Figure 1**)**.

2.2 | Study design

Two cross-sectional studies were conducted in the Chittagong and Cox's Bazaar districts of Bangladesh to explore farmers' perceptions and attitudes towards HPAI prevention and control.

The study design, sample size calculation and selection process of farms/farmers of these cross-sectional studies were described in detail in Gupta, Fournié, Hoque, and Henning (2019).

Briefly, the selection of eight sub-districts (upazillas) in the Chittagong district was based on 1) the density of backyard poultry farms, 2) density of backyard chickens, 3) location with of the upazilla within the district, 4) environmental characteristics, and 5) distance to Chittagong City, where most live bird markets are located. The same upazillas were used for the selection of commercial farms. Two upazillas in the Cox's Bazaar district were elected, because they were the main suppliers of poultry for live bird markets in Chittagong City (Moyen, 2019). Four villages were randomly selected from each of the 8 selected upazillas in the Chittagong district, and 5 villages were selected from each of the 2 selected upazillas in Cox's Bazaar district for the selection of backyard farms (Gupta et al., 2019). Simple random sampling was used to select broiler or layer farms within each upazilla and backyard farms in the selected villages (Gupta et al., 2019). Sample size calculations were based on a two stage sampling approach to estimate 1) the number of farms, and 2) the number of birds per farm to be sampled (see details in Gupta et al., 2019).

A total of 144 backyard chicken farmers were interviewed from February to April 2016, while 106 commercial broiler and 113 layer chicken farmers were interviewed from February to April 2017. Backyard chicken farmers usually raise Deshi (meaning 'indigenous' in Bengali language) chickens under scavenging or free ranging condition (Barua & Yoshimura, 1997; Das et al., 2008; FAO, 2008), whereas commercial farmers raise chickens of mainly exotic strains under confined or intensive systems with provision of supplementary feed (FAO, 2008; Huque, Saleque, & Khatun, 2011).

2.3 | Questionnaire

Two questionnaires were designed, one for backyard chicken farmers, and one for commercial broiler and layer chicken farmers. The questionnaires were developed in English and then translated into Bengali language (and back translated it into English to cross-check the wording of the statements used). Each of the HBM constructs were measured in the questionnaire by a set of 6-12 questions and all answers were recorded on a 6-Point Likert scale (‘Strongly disagree’, ‘Disagree’, ‘Neither agree nor disagree’, ‘Don’t know’, ‘Agree’, ‘Strongly agree’). The questionnaires were pilot-tested with 6 backyard chicken, 5 broiler and 5 layer farmers who were not part of the finally interviewed cohort and resulted in minor modifications of 5 questions in the backyard and 3 questions in the commercial chicken farmer questionnaires. The interviews were conducted by one female and one male field veterinarians who were trained in interviewing techniques. Each interview lasted about 25 minutes.

2.4 | Data analyses

Frequencies of farmers’ responses to each question were calculated in STATA 14.1 (Stata Corporation, College Station, Texas, USA). Frequencies of responses provided by farmers were initially summarized for the original 6-Point Likert scale. However, in the subsequent analysis, the categories ‘Don’t know’ and ‘Neither agree nor disagree’ were combined in a category ‘Uncertain’. Positive item question (e.g. ‘I could dispose dead birds/litter/waste properly’), were coded as follows: ‘Strongly disagree’=1, ‘Disagree’=2, ‘Uncertain’=3, ‘Agree’=4, ‘Strongly agree’=5. Negative item question (e.g. ‘Uncooked poultry meat doesn’t pose risk for getting avian influenza’), were coded as follows: ‘Strongly disagree’=5, ‘Disagree’=4, ‘Uncertain’=3, ‘Agree’=2, ‘Strongly agree’=1. We then used Structural Equation Modelling (SEM) to identify factors influencing farmers’ perceived ability to implement HPAI preventive or control measures. SEM is a statistical approach used in behavioural sciences (Hox & Bechger, 1998) to explore the theoretical or underlying constructs that cannot be directly observed and therefore are named latent variables. The SEM includes two parts: a measurement part, in which latent variables were related to observed variables, and 2) a structural part, in which relationships between latent variables were explored (Beaubien, 2000).

The 6 HBM constructs in our study represented the latent variables in the SEM models. Separate conceptual models for backyard, commercial broiler and layer farmers (Supplementary Figures S1-S3) were initially developed to visualize the observed variables informing each HBM construct, and the hypothesized causal relationships between the HBM constructs. Following the two-step approach developed by Anderson and Gerbing (1988, 1992), we used one-factor Confirmatory Factor Analysis (CFA) in the measurement part of the SEM, to identify for each HBM construct the minimum set of observed variables that best represented this construct. Then, in the structural part of the model, we considered *perceived susceptibility*, *perceived severity*, *perceived benefits*, *perceived barriers* and *cues to action* as independent variables influencing *self-efficacy*, the main dependent and outcome variable in the model. We also considered *cues to action* as intervening variable that could mediate the effect of the constructs measuring perceptions on *self-efficacy*. The results of the measurement part of the model were displayed using a path diagram. Results were shown as direct effects of *perceived susceptibility*, *perceived severity*, *perceived benefits, perceived barriers* and *cues to action* on *self-efficacy,* as indirect effects of the four perceived constructs via *cues to action* on *self-efficacy*, and as total effects. The association between two independent latent constructs was measured by the standardized covariance (ϕ), which can be interpreted as correlation between these latent constructs (Cudeck, 1989). The effects were measured by standardized regression coefficients (β). Bootstrapping was used to test the significance (p-values) of the effects. A p-value of ≤ 0.05 was used as cut-off to test the significance of the variables in the CFA and to test the effects in the SEM. Finally, to assess how well the data fitted the final models, we used the Hu and Bentler's Two-Index Presentation Strategy (Hu & Bentler, 1999).

Separate models were developed for backyard, commercial broiler and commercial layer chicken farmers. The SEM analysis was performed using AMOS software version 25.0 (IBM® SPSS® Amos™ 25, IBM Corp., 2017. U.S.A).

3 | RESULTS

3.1 | Study populations

The demographics of interviewed farmers (gender, marital status, religion, educational qualification, age and experiences in chicken farming) are presented in Table 1. Most (>91%) of the backyard chicken farmers were women and married; in contrast, almost all of the commercial chicken farmers were male (>98%), of which more than two-thirds were married. Commercial layer farmers had a higher level of education than backyard and commercial broiler chicken farmers. There was no major difference in the mean age of farmers across production systems, but backyard chicken farmers were more experienced in raising chickens than commercial farmers.

Summary statistics (percentage, number of responses) of original responses on a 6-Point Likert provided by backyard, commercial broiler and layer chicken farmers are shown in Supplementary Tables S1-S3. Due to the low frequency of responses to 'Don't know' and 'Neither agree nor disagree', these responses were combined in a category 'Uncertain'. Summary statistics (percentage, number of responses) of responses on a 5-Point Likert Scale associated with Health Belief Model constructs in the final SEM are summarized in Tables 2-4.

3.2 | Backyard chicken farmers

Backyard chicken farmers (Table 2) were confident about their ability to implement HPAI preventive and control measures, with more than 96% of farmers agreeing or strongly agreeing that they were able to conduct actions that would reduce the chance of HPAI virus spread from their properties (e.g. informing livestock officers if backyard farmers suspected HPAI outbreaks in their flocks). However, backyard chicken farmers were often concerned about constraints to implement these measures on their farms. For example, about a third of backyard farmers indicated that washing of hands after handling chickens was not practicable. Backyard farmers were strongly influenced by social pressures. For example, almost 30% of them would not apply hygienic measures if their neighbours did not use them. However, almost 90% of backyard farmers were open to learn more about HPAI and biosecurity if they were provided with information through the media or via other sources.

The final SEM for backyard chicken farmers (Figure 2) highlighted that the perceived ability (i.e. *self-efficacy*) of farmers to implement HPAI preventive and control measures on their farms was strongly reduced by *perceived barriers* (β=-0.52, $p<0.001$). However, information provided on HPAI (i.e. *cues to action*) marginally reduced this negative impact of *perceived barriers* (β=-0.13, $p=0.072$), and had a direct positive impact on the perceived ability (i.e. *self-efficacy*) of farmers implementing HPAI prevention and control measures (β=0.26, $p=0.002$). Surprisingly, the risk and consequences associated with HPAI infection in chickens and people, and the advantages of implementing preventive actions were not found to significantly influence backyard chicken farmers to implement HPAI prevention and control measures.

3.3 | Broiler chicken farmers

All (100%) commercial broiler chicken farmers (Table 3**)** either agreed or strongly agreed that they were able to implement actions that would reduce the chances of HPAI virus spread, such as the proper disposal of dead birds or litter.

Broiler farmers also strongly acknowledged the risk of chickens to become infected by HPAI virus if biosecurity is not properly maintained. For example, 95% of broiler farmers believed that chickens have an increased risk of becoming sick if the farm and farm equipment are not regularly cleaned and disinfected. However, they were somewhat concerned about constraints to implement these measures on their farms, for example, about 8% of farmers indicating that wearing protective gear was not conducive for work with chickens. On the other hand, broiler farmers were also aware of the advantages of adopting HPAI prevention and control measures, for example, more than 85% farmers agreeing or strongly agreeing that fewer chickens and farmers will become sick if good biosecurity is maintained on farms. Social pressures were reported to have a lesser impact than for backyard farmers, with only a small number of broiler farmers (10%) agreeing or strongly agreeing that they would not use HPAI virus vaccine because neighbouring farmers did not do so. Commercial broiler farmers also showed a strong interest in being informed about HPAI, with almost all farmers (99%) strongly agreeing or agreeing to be interested in receiving information about HPAI.

The final SEM for broiler farmers (Figure 3) highlighted that the perceived ability (i.e. *self-efficacy*) to implement HPAI preventive or control measures was strongly reduced by *perceived barriers* to implement these measures (β=-0.41, $p<0.001$), but strongly increased by *perceived benefits* (β=0.44, $p<0.001$) and *perceived susceptibility* (β=0.16, p=0.046). Information provided on HPAI (i.e. *cues to action*) also had a direct marginal impact on the implementation of measures (β=0.12, p=0.067), but did not have a significant mediating effect at $p<0.05$. Consequences associated with HPAI infection did not influence broiler farmers' decision to implement HPAI preventive or control measures. Furthermore, the constructs of *perceived susceptibility*, *perceived benefits* and *perceived susceptibility* correlated significantly with each other: ϕ=0.60 ($p<0.001$) for *perceived susceptibility* and *perceived benefits*, ϕ=-0.38 ($p<0.001$) *for perceived susceptibility* and *perceived barriers* and ϕ=-0.37 ($p=0.002$) for *perceived benefits* and *perceived barriers*.

3.4 | Layer farmers

Similarly to backyard and broiler farmers, almost all commercial layer farmers (>98%) agreed or strongly agreed that they were able to implement recommended actions to avoid HPAI infection and spread (e.g. wearing protective equipment even if neighbouring poultry farmers do not) (Table 4). Most striking was that although layer farmers were aware of the obstacles to implement HPAI preventive measures, much fewer (compared to backyard and broiler farmers) highlighted that these obstacles negatively influenced their decision-making. They were also less likely to be influenced by social pressures. For instance, only 9% would not use HPAI virus vaccine if their neighbouring farmers did not use it.

Layer farmers were strongly convinced about the advantages of maintaining good biosecurity on their farms, with more than 80% farmers agreeing or strongly agreeing that good maintenance of biosecurity measures would results in less HPAI cases in chickens and humans. Once again, almost 98% of layer farmers were interested in receiving additional information about HPAI and biosecurity measures.

In the final SEM for layer farmers (Figure 4), the perceived ability (*i.e. self-efficacy*) of farmers to implement HPAI preventive and control measures on their farms was strongly increased by the *perceived benefits* ($\beta=0.68$, $p<0.001$) and, to a lesser extent, by the information provided on HPAI (i.e. *cues to action*) ($\beta=0.15$, $p=0.065$). Interestingly, *perceived barriers* did not seem to influence the implementation of HPAI preventive measures. *Cues to action* had no significant mediating effect on preventive measures. Likewise, consequences associated with

HPAI infection and risk of chickens and humans to become infected did not influence layer farmers' decisions to implement HPAI preventive or control measures. In addition, there was a significant association between the *perceived benefits* and *perceived barriers* (ϕ= -0.59, p<0.001).

4 | DISCUSSIONS

To our knowledge, this is the first study that conceptualised the HBM framework to explore the perceptions of farmers across different chicken production systems (backyard, commercial broiler and layer farmers) on the implementation of HPAI prevention and control measures. Our research provided new insights about factors influencing poultry farmers' decision-making processes in regards to improved biosecurity and could be used to guide the design of more effective preventive behaviour-change interventions (Glanz et al., 2008).

Farmers showed different perceptions on HPAI prevention and control depending on the type of poultry production, reflecting different contexts, needs, and experiences. This is consistent with findings by Jemberu et al. (2015), who identified that farmers' perception on Foot and Mouth Disease (FMD) control measures differed by cattle production systems, such as crop-livestock, pastoral and market-oriented systems. In particular, the HBM constructs in our study (*perceived severity*, *perceived susceptibility*, *perceived barriers*, *perceived benefits* and *cues to action*) had a different impact on the perceived ability of farmers' to implement HPAI preventive and control measures (*self-efficacy*). For example, *perceived barriers* prevented broiler and backyard farmers to implement HPAI preventive actions, but did not influence commercial layer farmers' decision-making. One possible explanation for this finding is that commercial layer farmers raise flocks over longer periods, manage larger flock sizes, with comparatively larger capital investment, which might make them more conscious of the need to plan preventive and control measures in the long term, enabling them to overcome *perceived barriers*.

Nevertheless, *perceived barriers* were the most influential construct affecting poultry farmers' behaviours. A meta-analysis of the effectiveness of HBM variables in predicting human actions conducted by Carpenter (2010) and a critical review carried by Janz and Becker (1984) of 46 HBM-related studies highlighted that *perceived barriers* were the HBM construct with the strongest influence on individuals' health-related behaviours. Similary, focussing on preventive medical interventions, Tanner-Smith and Brown (2010) indentified that conducting a pap smear, which was considered by women as embarassing and time consuming, was a signficant *perceived barrier* for the involvement of these women in cervical cancer prevention programs. Jemberu et al. (2015) also found that the cost of vaccination was a strong *perceived barrier* impacting on farmers' intentions to vaccinate their animals against FMD. Likewise, a study conducted on backyard poultry farmers in Bangladesh exploring farmers' perceptions and practices related to zoonotic transmission of avian influenza found that limited ressourcces was one of the main barriers to change behaviour (Sultana et al., 2012). Backyard poultry farmers were not intrested to accept recommended practices to prevent avian influenza transmission, if these practices required addtional time and funds (Sultana et al., 2012). Thus, to overcome *perceived barriers* for HPAI prevention and control, carefully tailored educational program need to be developed for each chicken production system in Bangladesh.

Our study further highlighted that *perceived benefits* of preventive and control measures only influenced broiler and layer farmers' decisions, most likely as the potential financial losses due to HPAI outbreaks are more substantial for commercial farmers compared to backyard farmers, with backyard poultry raising being usually conducted only for supplementary income (Henning, Pym, Hla, Kyaw, & Meers, 2007). This is supported by research conducted in China and Kenya, which highlighted that farmers with larger flock sizes were more aware of the advantages of improved biosecurity (Cui, Liu, Ke, & Tian, 2019; Tiongco, Narrod, Scott, Kobayashi, & Omiti, 2012). Hence, results of production-specific (backyard, broiler or layer) economic analyses on the benefits of implementing HPAI prevention and control measures should be included in educational training and extension programs for chicken farmers working in these three different production systems.

Perceived susceptibility of HPAI infection only influenced broiler farmers to implement HPAI preventive measures, but it did not influence backyard and layer farmers. A possible reason for this finding might be that as the production cycle for backyard and layer chickens is longer, farmers might believe that birds develop immunity over time, making them less susceptible to HPAI virus infection.

Surprisingly, the *perceived severity* of HPAI infection in chickens and people did not influence backyard, broiler and layer farmers' perceived ability to implement HPAI prevention and control measures. Poultry farmers might have developed lesser concerns about the impact of HPAI, as there are fewer official and media reports on HPAI outbreaks and human infections in endemically infected countries like Bangladesh (DLS, 2019; WHO, 2019), or because farmers reduced potential economic consequences by conducting rapid sales of their chickens when an HPAI outbreak is experienced (Høg et al., 2018).

Usually little attention has been paid in animal health research to farmers' willingness to seek information (Valeeva, van Asseldonk, & Backus, 2011). We identified that the availability of information on HPAI played an important role in the farmers' decision-making processes to implement HPAI prevention and control measures for all three chicken production systems. Similarly, Toma, Stott, Heffernan, Ringrose, and Gunn (2013) found that the provision of biosecurity information had a positive impact on farmers' biosecurity behaviour, while Cui, Wang, Ke, and Tian (2019) also observed that information on avian influenza disseminated through TV, web news and chats and via conversations among chicken farmers influenced the implementation of HPAI preventive measures. In fact, information obatined through social interactions are paramount for farmers' decision making processes. A study conducted with Bangladeshi backyard poultry farmers highlighted that information from neighbours and family members strongly influenced their awareness and risk perception on avian influenza (Sultana et al., 2012). The role of mass media as an important medium to convey information on avian influenza to backyard and commercial poultry farmers in Bangaldesh has been highlighted previously (Sarker et al., 2016), but unfortunately, farmers with different levels of intensification are often provided with similar advice on disease management. In our study, farmers of different chicken production systems had different perceptions on HPAI prevention and control, highlighting that information and extension messages need to be adjusted to the respective audiences. A study conducted in the UK by Heffernan, Nielsen, Thomson, and Gunn (2008) found that bio-security behaviours by cattle and sheep farmers did not improve despite the provision of information through multiple sources (e.g. TV, radio, newspapers, Government agencies, private actors like feed representatives etc.), and the authors speculated that the way information was commuicated might have been viewed negatively by some farmers. The researchers highlighted the importance of reframing biosecurity messages by paying attention to farmers' perceptions and to the way in which information is delivered to farmers.

Similarly, the means of communication do also influence the uptake of information by farmers. For example, although government agencies in Bangladesh disseminated messages on avian influenza control through radio and television channels, rural women who are predominantly responsible for rearing backyard poultry in Bangladesh, had limited access to these information channels (Shanta et al., 2017). In addition, almost one third of backyard poultry farmers in this study had no formal education and were not able to read the printed materials provided to them (Shanta et al., 2017).

Thus, to communicate advice succesfully, appropriate comunciation methods need to be considered that account for the cultural environment, education level and experience of farmers (Henning, Hla, & Meers, 2014). Furthermore, behavior change communication through education programs need to be interactive and innovative and could include tools like documentaries, drama, social marketing campaigns and puppet plays (Jones, Waters, Holland, Bevins, & Iverson, 2010). Thus, the importance how farmers involved in different chicken management systems perceive benefits and barriers of HPAI prevention and control as well as different means of communication for commercial and backyard farmers need to be considered for the establishment of an effective and successful education campaign to reduce the risk and spread of HPAI.

Our study had some limitations. Firstly, we explored farmers' perceived ability to implement HPAI prevention and control measures, but if these measures were actually implemented by farmers was beyond the scope of our study. However, we are confident that farmers would implement the outlined, HPAI prevention and control measures as a number of recent research studies highlighted that poultry farmers' perceptions on the ability to implement actions against avian influenza (*self-efficacy*) resulted in the change of behaviors of these farmers (Cui et al., 2017; Cui, Wang, Ke, & Tian, 2019). Secondly, we hypothesized and analyzed causal relationships between perceptions and the implementation of HPAI preventive and control measures, but validating these causal relationships was not possible in our cross-sectional study design. Thirdly, the framework used in this research paid more attention to the subjective state of an individual rather than other contextual factors, such as social acceptability, habitual factors, environmental factors, interpersonal influences (e.g. dealers of feed, chick or medicines), which would need to be explored through more qualitative approaches. Finally, as the development of the constructs was based on a number of statements, it might be argued that some farmers were likely to provide the 'correct' answer, regardless of what their actual intentions might have been. However, statements or questions were carefully drafted and in discussion with farmers further refined during the pilot testing of the questionnaire. Farmers did not receive any benefits or support for providing the 'correct' answers and the broad distribution of answers provided highlighted that farmers did not just supply the answers that was expected from them. Thus, we are confident that in general truthful answers were provided by farmers.Overall, the results of our research are practical and applied as they can assist policy makers to tailor specific education programs to different types of poultry farmers and will thereby support the establishment of a more effective strategy to control and prevent HPAI virus spread.

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ETHICS STATEMENT

The authors confirm that the ethical policies of the journal, as noted on the journal's author guidelines page, have been adhered to and the appropriate ethical review committee approval has been received. Human Ethics approval for the research was obtained from Behavioural &

Social Sciences Ethical Review Committee at the University of Queensland (Approval number: 2015001703).

CONFLICT OF INTEREST

None

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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TABLE 1 Demographic information of chicken farmers interviewed in cross-sectional studies in the Chittagong and Cox's Bazaar districts of Bangladesh to explore their ability to implement Highly Pathogenic Avian Influenza control and prevention measures.

	Backyard chicken farmer	**Commercial broiler chicken farmer**	**Commercial layer chicken farmer**
	% (n)	**% (n)**	**% (n)**
Gender			
Male	6.3 (9)	98.1 (104)	99.1 (112)
Female	93.7 (135)	1.9 (2)	0.9 (1)
Marital status			
Single	2.1 (3)	31.1 (33)	31.0 (35)
Married	91.7 (132)	68.9 (73)	69.0 (78)
Divorced	0.7 (1)	-	-
Widowed	5.5 (8)	-	-
Religion			
Muslim	90.3 (130)	94.3 (100)	89.4 (101)
Hindu	6.9 (10)	5.7 (6)	9.7 (11)
Buddhist	2.8 (4)	-	0.9 (1)
Education			
Illiterate	12.5 (18)	1.9 (2)	3.5 (4)
Primary	56.2 (81)	22.6 (24)	15.9 (18)
Secondary	25.7 (37)	39.6 (42)	38.1 (43)
Higher Secondary	4.9 (7)	17.0 (18)	16.8 (19)
Tertiary	0.7 (1)	18.9 (20)	25.7 (29)
Mean (Minimum, Maximum)			
Age (in years)	38.2 (17, 70)	36.6 (15, 70)	35.0 (6, 58)
Experience in chicken farming (in years)	20.4 (2, 52)	8.5 (<1†, 23)	9.2 (<1‡, 27)

†represents 15 days, ‡ represents 90 days

TABLE 2 Summary statistics (percentage, number of responses) of observed variables associated with constructs retained in the final Health Belief Model for backyard chicken farmers in Bangladesh. The constructs describe the perceptions of backyard chicken farmers on the ability to implement Highly Pathogenic Avian Influenza control and prevention measures.

Constructs retained in the final model	Observed independent variable (Abbreviation used for observed independent variable in models and in figures)	Farmer's response % (n)				
		Strongly disagree	Disagree	Uncertain	Agree	Strongly agree
Self-efficacy	I would clean poultry house/equipment regularly **(SEff2)**	0.0 (0)	1.4 (2)	0.0 (0)	41.7 (60)	56.9 (82)
	I would be able to identify signs of the disease, if my chickens were infected with avian influenza/bird flu **(SEff3)**	0.7 (1)	0.7 (1)	0.7 (1)	46.5 (67)	51.4 (74)
	I would inform the local livestock related personnel, when I suspect that my chickens have avian influenza/bird flu **(SEff4)**	1.4 (2)	1.4 (2)	0.7 (1)	49.3 (71)	47.2 (68)
	I could wash my hands with soap before and after handling poultry, even if my neighbours are not **(SEff7)**	1.4 (2)	0.0 (0)	1.4 (2)	46.5 (67)	50.7 (73)
Perceived barriers	Regular cleaning of poultry house/equipment is time consuming and not practical for me, because my family/I have to do many other things **(PBar3)**	40.3 (58)	35.4 (51)	0.0 (0)	21.5 (31)	2.8 (4)
	Washing hands before and after handling poultry is not practical for me, because my family/I have to do many other things **(PBar4)**	38.9 (56)	28.5 (41)	0.0 (0)	28.5 (41)	4.2 (6)
	I can't cover my mouth and nose with cloths during handling chickens, because they are not conducive for work **(PBar5)**	37.5 (54)	25.0 (36)	4.2 (6)	29.9 (43)	3.5 (5)
	I don't cover my mouth and nose with cloths during handling chickens, because my neighbour do not **(PBar6)**	37.5 (54)	32.6 (47)	0.0 (0)	25.7 (37)	4.2 (6)
Cues to action	If I find a program on TV about avian influenza/bird flu and other aspects of poultry rearing, then I would watch it **(Cue2)**	1.4 (2)	2.8 (4)	0.0 (0)	38.2 (55)	57.6 (83)
	If I find a program on the radio about avian influenza/bird flu and other aspects of poultry rearing, then I would listen to it **(Cue3)**	1.4 (2)	2.8 (4)	0.0 (0)	38.9 (56)	56.9 (82)
	If I get invited to a meeting or campaign, etc. about avian influenza/bird flu and other aspects of poultry rearing, then I would attend it **(Cue4)**	2.1 (3)	6.9 (10)	0.0 (0)	41.0 (59)	50.0 (72)

TABLE 3 Summary statistics (percentage, number of responses) of observed variables associated with constructs retained in the final Health Belief Model for commercial broiler chicken farmers in Bangladesh. The constructs describe the perceptions of commercial broiler chicken farmers on the ability to implement Highly Pathogenic Avian Influenza control and prevention measures.

Constructs retained in the final model	Observed independent variable (Abbreviation used for observed independent variable in models and in figures)	Farmer's response % (n)				
		Strongly disagree	Disagree	Uncertain	Agree	Strongly agree
Self-efficacy	I could dispose dead birds/litter/waste properly **(SEff5)**	0.0 (0)	0.0 (0)	0.0 (0)	23.6 (25)	76.4 (81)
	I could clean & disinfect poultry house/equipment regularly **(SEff6)**	0.0 (0)	0.0 (0)	0.0 (0)	25.5 (27)	74.5 (79)
	I could wear protective gear, even if my neighbouring poultry farmers are not **(SEff7)**	0.0 (0)	0.0 (0)	0.0 (0)	31.1 (33)	68.9 (73)
Perceived susceptibility	My chickens have an increased risk of getting avian influenza/bird flu: when I don't regularly clean and disinfect my farm and farm equipment **(PSus3)**	0.0 (0)	4.7 (5)	0.0 (0)	31.1 (33)	64.2 (68)
	My chickens have an increased risk of getting avian influenza/bird flu: when I don't control wild birds/backyard poultry from entering into my poultry shed/house **(PSus4)**	0.0 (0)	5.7 (6)	1.9 (2)	28.3 (30)	64.2 (68)
	My chickens have an increased risk of getting avian influenza/bird flu: when my workers don't wash their hands/feet/change clothes before entering poultry shed/house **(PSus5)**	0.0 (0)	5.7 (6)	0.9 (1)	27.4 (29)	66.0 (70)
	My chickens have an increased risk of getting avian influenza/bird flu: when I don't clean and disinfect vehicles, egg trays, cages, de-beaking machine, vaccination gun, etc. before entering into my farm **(PSus6)**	0.0 (0)	4.7 (5)	0.0 (0)	33.0 (35)	62.3 (66)
Perceived benefits	If I maintain biosecurity (proper prevention & control measures) in my poultry farm, then my chickens will : not get sick from avian influenza and the possibility of disease outbreaks in my locality will reduce **(PBen2)**	0.0 (0)	7.6 (8)	0.0 (0)	24.5 (26)	67.9 (72)
	If I maintain biosecurity(proper prevention & control measures) in my poultry farm, then my chickens will : not get sick from avian influenza as well as my family members and I will not get sick from avian influenza **(PBen3)**	0.0 (0)	8.5 (9)	5.7 (6)	28.3 (30)	57.6 (61)
Perceived barriers	My neighbouring farmer doesn't use avian influenza vaccine, so I don't use avian influenza vaccine **(PBar8)**	67.0 (71)	22.6 (24)	0.0 (0)	8.5 (9)	1.9 (2)
	I can't wear protective gear, because they are not conducive for work **(PBar9)**	68.9 (73)	23.6 (25)	0.0 (0)	6.6 (7)	0.9 (1)
	I don't wear protective gear because my neighbouring poultry farmers do not **(PBar10)**	72.6 (77)	18.9 (20)	0.0 (0)	6.6 (7)	1.9 (2)
Cues to action	If I find a program on TV about avian influenza, then I would watch it **(Cue3)**	0.0 (0)	0.9 (1)	0.0 (0)	15.1 (16)	84.0 (89)
	If I find a program on the radio about avian influenza, then I would listen to it **(Cue4)**	0.0 (0)	0.9 (1)	0.0 (0)	14.2 (15)	84.9 (90)
	If I find information about avian influenza in leaflet/brochure/billboard, etc., then I would read it **(Cue5)**	0.0 (0)	0.0 (0)	0.9 (1)	16.0 (17)	83.0 (88)

TABLE 4 Summary statistics (percentage, number of responses) of observed variables associated with constructs retained in the final Health Belief Model for commercial layer chicken farmers in Bangladesh. The constructs describe the perceptions commercial layer chicken farmers on the ability to implement Highly Pathogenic Avian Influenza control and prevention measures.

Constructs retained in the final model	Observed independent variable (Abbreviation used for observed independent variable in models and in figures)	Farmer's response % (n)				
		Strongly disagree	Disagree	Uncertain	Agree	Strongly agree
Self-efficacy	I could wear protective gear, even if my neighbouring poultry farmers are not **(SEff7)**	0.9 (1)	0.0 (0)	0.0 (0)	35.4 (40)	63.7 (72)
	I could wash my hands with soap before and after handling chickens even if my neighbouring poultry farmers are not **(SEff8)**	0.9 (1)	0.9 (1)	0.0 (0)	33.6 (38)	64.6 (73)
Perceived benefits	If I maintain biosecurity (proper prevention & control measures) in my poultry farm, then my chickens will not get sick from avian influenza, and I will not lose income **(PBen1)**	0.0 (0)	6.2 (7)	1.8 (2)	28.3 (32)	63.7 (72)
	If I maintain biosecurity(proper prevention & control measures) in my poultry farm, then my chickens will not get sick from avian influenza and the possibility of disease outbreaks in my locality will reduce **(PBen2)**	0.9 (1)	8.0 (9)	2.7 (3)	24.8 (28)	63.7 (72)
	If I maintain biosecurity(proper prevention & control measures) in my poultry farm, then my chickens will : not get sick from avian influenza as well as my family members and I will not get sick from avian influenza **(PBen3)**	0.9 (1)	15.0 (17)	3.5 (4)	23.0 (26)	57.5 (65)
	If my chickens receive avian influenza vaccine, then they will not get sick and die and I will not lose income **(PBen4)**	0.9 (1)	7.1 (8)	0.9 (1)	24.8 (28)	66.4 (75)
Perceived barriers	Washing hands all the time is not practical for me, because I have to do many other things **(PBar7)**	62.0 (70)	25.7 (29)	0.0 (0)	12.4 (14)	0.0 (0)
	My neighbouring farmer doesn't use avian influenza vaccine, so I don't use avian influenza vaccine **(PBar8)**	62.8 (71)	28.3 (32)	0.0 (0)	8.9 (10)	0.0 (0)
	I don't wear protective gear because my neighbouring poultry farmers do not **(PBar10)**	65.5 (74)	28.3 (32)	0.0 (0)	5.3 (6)	0.9 (1)
Cues to action	If I find a program on TV about avian influenza, then I would watch it **(Cue3)**	0.0 (0)	0.9 (1)	0.0 (0)	23.9 (27)	75.2 (85)
	If I find a program on the radio about avian influenza, then I would listen to it **(Cue4)**	0.0 (0)	1.8 (2)	0.0 (0)	23.0 (26)	75.2 (85)
	If I get invited to a meeting or campaign, etc. about avian influenza, then I would attend it **(Cue6)**	0.0 (0)	1.8 (2)	0.9 (1)	23.9 (27)	73.5 (83)

FIGURE LEGENDS

FIGURE 1 Hypothesised relationships between latent constructs (shown as ovals) that influence chicken farmers' ability to implement Highly Pathogenic Avian Influenza control and prevention measures in Bangladesh. The red arrows represent the direct effects of *perceived susceptibility, perceived severity, perceived benefits, perceived barriers* on the outcome *self-efficacy.* The orange arrows represent the mediation effect of *cues to action* between *perceived susceptibility, perceived severity, perceived benefits, perceived barriers* and the outcome *self-efficacy*.

FIGURE 2 Final Structural Equation Model for the ability of backyard chicken farmers to implement Highly Pathogenic Avian Influenza control and prevention measures in Bangladesh. The rectangles represent observed variables and the ovals represent latent constructs. The circles labelled 'd' and 'e' represent errors associated with the measurements of the observed variables, and circles labelled 'z' represent residuals of the dependent latent constructs. Single-headed red arrows represent the direct effects and the single-headed orange arrow represents the mediation effects. The total effect for *Perceived barrier*s→*Cues to action*→*Self-efficacy* was β=-0.66 (p=0.001).

FIGURE 3 Final Structural Equation Model for the ability of commercial broiler chicken farmers to implement Highly Pathogenic Avian Influenza control and prevention measures in Bangladesh. The rectangles represent observed variables and the ovals represent latent constructs. The circles labelled 'd' and 'e' represent errors associated with the measurements of the observed variables, and circles labelled 'z' represent residuals of the dependent latent constructs. Single-headed red arrows represent the direct effects, single-headed orange arrows represents the mediation effects and double-headed green arrows represent the standardised covariance (correlation) between independent latent constructs. The total effect for *Perceived barriers→Cues to action→Self-efficacy* was β= -0.43 (p=0.006), and the total effect for *Perceived benefits→Cues to action→Self-efficacy* was β= 0.48 (p=0.001).

FIGURE 4 Final Structural Equation Model for the ability of commercial layer chicken farmers to implement Highly Pathogenic Avian Influenza control and prevention measures in Bangladesh. The rectangles represent observed variables and the ovals represent latent constructs. The circles labelled 'd' and 'e' represent errors associated with the measurements of the observed variables and circles labelled 'z' represent residuals of the dependent latent constructs. Single-headed red arrows represent the direct effects, single-headed orange arrows represents the mediation effects and double-headed green arrows represent the standardised covariance (correlation) between independent latent constructs. The total effect for *Perceived benefit*s→*Cues to action→Self-efficacy* was β= 0.72 (p=0.009).

SUPPORTING INFORMATION

SUPPLEMENTARY TABLE S1 Summary statistics (percentage, number of responses) of original responses (on a 6-Point Likert scale) summarizing perceptions of backyard chicken farmers on the ability to implement Highly Pathogenic Avian Influenza control and prevention measures in Bangladesh.

SUPPLEMENTARY TABLE S2 Summary statistics (percentage, number of responses) of original responses (on a 6-Point Likert scale) summarizing perceptions of commercial broiler chicken farmers on the ability to implement Highly Pathogenic Avian Influenza control and prevention measures in Bangladesh.

SUPPLEMENTARY TABLE S3 Summary statistics (percentage, number of responses) of original responses (on a 6-Point Likert scale) summarizing perceptions of commercial layer chicken farmers on the ability to implement Highly Pathogenic Avian Influenza control and prevention measures in Bangladesh.

SUPPLEMENTARY FIGURE S1 Conceptualization of a Structural Equation Model using the Health Belief Model framework to explore the ability of backyard chicken farmers to implement Highly Pathogenic Avian Influenza control and prevention measures in Bangladesh. The rectangles represent observed variables and the ovals represent latent constructs. The circles labelled ‘d’ and ‘e’ represent errors associated with the measurements of the observed variables, and circles labelled ‘z’ represent residuals of the dependent latent constructs. Single-headed red arrows represent the direct effects, single-headed orange arrows represents the mediation effects and double-headed green arrows represent the standardised covariance (correlation) between independent latent constructs.

SUPPLEMENTARY FIGURE S2 Conceptualization of a Structural Equation Model using the Health Belief Model framework to explore the ability of commercial broiler chicken farmers to implement Highly Pathogenic Avian Influenza control and prevention measures in Bangladesh. The rectangles represent observed variables and the ovals represent latent constructs. The circles labelled ‘d’ and ‘e’ represent errors associated with the measurements of the observed variables, and circles labelled ‘z’ represent residuals of the dependent latent constructs. Single-headed red arrows represent the direct effects, single-headed orange arrows represents the mediation effects and double-headed green arrows represent the standardised covariance (correlation) between independent latent constructs.

SUPPLEMENTARY FIGURE S3 Conceptualization of a Structural Equation Model using the Health Belief Model framework to explore the ability of commercial layer chicken farmers to implement Highly Pathogenic Avian Influenza control and prevention measures in Bangladesh. The rectangles represent observed variables and the ovals represent latent constructs. The circles labelled ‘d’ and ‘e’ represent errors associated with the measurements of the observed variables, and circles labelled ‘z’ represent residuals of the dependent latent constructs. Single-headed red arrows represent the direct effects, single-headed orange arrows represents the mediation effects and double-headed green arrows represent the standardised covariance (correlation) between independent latent constructs.