Biosecurity Preparedness Analysis for Poultry Large and Small Farms in the United Arab Emirates

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Abstract: Biosecurity implemented on the poultry farms in the United Arab Emirates (UAE), in the form of preparedness against any possible outbreak of disease, is critical for farm survival, safety, and development. Little information on the status of biosecurity readiness for containing any outbreak of poultry disease is available. This study was conducted to evaluate the status of biosecurity on commercial poultry farms in the UAE. Four categories of biosecurity measures/actions: isolation, human and traffic flow, cleaning, and disinfection, and adoption of vaccination protocols were considered. All 37 licensed commercial poultry farms in the country were enrolled in the study’s survey. Cumulative Distribution Functions (CDFs) and Artificial Neural Network statistical (ANN) methods were used for ranking biosecurity on farms, including a breakdown for large and small farms, and to identify areas that require improvements. The ANN is used to correlate preparedness in the focus areas to the poultry farms’ biophysical and business characteristics, such as the number of yearly flock cycles, farm capacity, the total area of the farms, density, and the number of biosecurity workers. This study finds that more stringent implementation of vaccination protocol, isolation, and human and vehicle-flow controls for disinfection are most needed. The study also revealed that poultry farms address biosecurity preparedness differently based on the type of production on large or small farms, and for broilers or layers.

Keywords: poultry farms; biosecurity; assessment; artificial neural network application; preparedness against biosecurity threats

1. Introduction

Globally, many are concerned about the spread of animal diseases that bring negative economic impacts to farms, risks to human health, and threats to food security, especially in light of the 2020 COVID-19 pandemic. This concern may be especially urgent for poultry production in a country such as the United Arab Emirates (UAE), where poultry production is limited. The United States Department of Agriculture (USDA), Foreign Agriculture Services, 2019 [1], found that poultry plays a vital role in securing a protein source in the UAE. Poultry production stocks in the UAE doubled from 12 million birds in 2000 to 24 million birds in 2017 [2], as illustrated in Figure 1. The UAE commercial farms survey, published by the UAE Federal Competitiveness and Statistical Authority [3], showed that
poultry production of both meat and eggs in the country was valued at 1.1 billion UAE Dirhams (about US$295 million) in 2017. The total number of licensed local commercial farms in the UAE is currently 37. Farms are distributed across the two emirates, Abu Dhabi and Dubai, as shown in Figure 2. Therefore, economic losses to a biosecurity incident could have large consequences. Biosecurity in the poultry industry, or preparedness against disease threats for purposes here, is a highly important subject.

Figure 1. Poultry Stock in millions in the United Arab Emirates from 2000 to 2017. Source: Food and Agriculture Organization FAO Stats, 2019 [2].

Figure 2. Poultry farms spatial distribution in the United Arab Emirates, including large and small farms.

Biosecurity in our context refers to the implementation of policies, practices, and necessary measures that enhance preparedness and prevent the introduction and spread of diseases. Contagious poultry diseases with the potential for rapid spread within the country and across national borders cause serious negative impacts on socio-economic and sometimes public health. Poultry production development in the UAE is facing high biosecurity threats represented by several disease outbreaks.
The sector is rapidly growing and little information is known about farms’ biosecurity preparedness. Poultry diseases often cause severe consequences, such as low quality and productivity of meat and eggs, which adversely affect farm sales and returns. The annual report of the USDA, Global Agricultural Information Network report on the UAE poultry sector, and its products indicated that the UAE poultry farms faced challenges in connection to Low Pathogenic Avian Influenza. Moreover, the overall mortality rates were estimated to be around 10%, although some farms reported losses as high as 25% of their total production in the country [1].

The farms in this study were divided into large and small farms. This division was thought helpful, as these two types of poultry production are completely different. Large farms use advanced technology and operate with 50,000 birds’ or more in capacity. Other criteria considered for such classification were bird density, number of employees, and completeness of the marketing and supply chain process. Small farms use a more traditional type of farming that is often mixed with other types of production, such as other livestock or forage production. Production capacity is less than 50,000 birds, and these farmers mostly market their production through other large poultry farms or another marketing entity. The average capacity for the large farms is 461 thousand birds, ranging from 54 thousand to 1.8 million birds. The average capacity of the small farms is 24 thousand birds. Meanwhile, the capacity for the small farms was found to range from 9 thousand to 50 thousand birds.

Maduka et al. (2016) [4] studied biosecurity practices in 80 commercial poultry farms in Nigeria. In their study, they used a biosecurity scoring system for rating farms according to their biosecurity practices. The authors found a tendency of reduction of disease outbreaks with increasing preparedness against biosecurity threats. Furthermore, the study noticed poultry production systems require increased drive for enhanced biosecurity practices, and weak points in the biosecurity could be addressed through information exchange and awareness programs.

The objective of this study is to investigate preparedness through using “Best Biosecurity Practices” to manage against infectious diseases on the country’s poultry farms (e.g., Low Pathogenic Avian Influenza and High Pathogenic Avian Influenza). A recent study on commercial poultry biosecurity in New Zealand [5] indicated that there are limitations in the methods used to assess and quantify both the biosecurity and disease contact risk, as the individual efficacy of all biosecurity measures is presumed equivalent; that is, using 3 of any practices is as effective as 3 of any other. This assumption was made by the authors of this study as well since there is very little research comparing efficacy of different biosecurity measures.

In this research, we also quantify and correlate surveyed farmer responses about biosecurity to farmers’ business and biophysical characteristics (such as farm’s capacity, area, number of workers, density, and distance to nearest other farm). We assess the level of specific biosecurity preparedness measures that poultry farms in the UAE might consider against the spread of contagious poultry diseases. Specifically, the first research objective is to examine and identify the level of biosecurity measures applied by poultry farms in the UAE. The second research objective is to determine the biophysical and business characteristics of the poultry farms that affect different types of biosecurity preparedness (i.e., isolation, human and traffic flow, sanitation and disinfection, and adoption of the vaccination protocol). Finally, we use this information to make recommendations for improving weak spots at the poultry large and small farms in the UAE.

2. Data and Methods

This section includes the data collection and methods applied.

2.1. Data Collection

A team from United Arab Emirates University, College of Food and Agriculture (CFA) and Abu Dhabi Agriculture and Food Safety Authority (ADAFSA) carried out a biosecurity survey during the period 2016–2017. The data obtained from the survey was used to assess, explore, and analyze the importance of biosecurity measures and practices that protect the poultry sector from biosecurity...
threats. The survey solicited the information and data from all of the country’s thirty-seven (37) licensed commercial farms using face-to-face interviews conducted by the research team members. The poultry farms are spread across the Abu Dhabi and Dubai Emirates in the UAE A team of experts visited the farms to conduct on-farm face-to-face interviews with owners or farms’ managers. The written responses in the questionnaire were reported by the experts’ observations as needed.

The questionnaire was divided into four sections; each section included relevant questions about the most critical measures to be used in assessing the biosecurity in this study. The isolation section included 12 questions in connection to perimeter fencing, gate closure, the pavement of the area surrounding the farm, and the presence of buffer zones. Besides, this section also included questions about employees’ awareness regarding avoiding contact with other birds inside and outside the farm. Furthermore, this section included questions about the farm planning for self-quarantine in case of an outbreak of Avian Influenza or any other infectious disease. This section also discussed the process of manure storage and the practices needed for the prevention of vermin and insects. The second section of the questionnaire included 14 questions about human and vehicle traffic flow within and outside the farm. It included questions regarding the movement of vehicles going into and from the farm to facilitate disposal of waste and dead birds. Also, this section included questions regarding the process to secure access to feed delivery trucks inside the farm. The third section included 12 questions about cleaning, sanitation, and disinfection, including the sanitation of vehicles, materials, and other supplies. In addition to other parameters like the efficiency of cleaning and disinfection materials, keeping an adequate downtime between flocks, and the availability of clean water. The last section on biosecurity measures was specific to Avian Influenza vaccination protocol.

Furthermore, the team experts noted it is clear that there is a need to increase disinfection and monitoring of feed distribution vehicles owned by feed companies, as they may serve multiple poultry farms in the area. Such companies visit the farms repetitively, which represents a risk source that increases the diseases spread between the poultry farms.

2.2. Methods: Cumulative Density Functions for Ranking Biosecurity Alternatives

The Cumulative Distribution Function (CDF) of the real-valued observations allows assignment of probability distribution and development, a valuable tool for viewing the relative adoption of poultry biosecurity alternatives. In this simple application, we are determining the cumulative probability that a fraction of available biosecurity practices, from 0–100%, are being used. For example, the CDF can show what fraction of farmers use 6 or more practices, or 50% of 12 available practices, or 8 of 12 practices, or 10 of 12 practices, and so on. Comparing CDFs at various levels of probabilities of performance is useful in ranking the biosecurity control measures. For example, the relevant CDF for ranking alternative A to B is:

$$\int_{-\infty}^{x} F_A(X) dX \leq \int_{-\infty}^{x} F_B(x) dX$$

These functions, when graphed together, provide a clear picture of which practices are being adopted in each biosecurity category and can be compared across large and small farms. Ultimately, this shows where gaps occur in preparedness for poultry farms and identifies such gaps between the large and small farms. Hence, we can identify biosecurity areas that need improvement. Illustrations of the CDFs were developed using the software Simetar©.

2.3. Methods: Artificial Neural Network (ANN)

We next applied an Artificial Neural Network (ANN) to link preparedness to farm and farmer characteristics; ANN is a multilayer perception mathematical optimization approach applied to many practical research problems. The ANN is a preferred model for many predictive data mining applications due to its strength, flexibility, and ease of use for prediction. Considered variables were rescaled using normalization. This research considered the Artificial Neural Network as the appropriate methodological approach to analyze the research data and achieve the research objective,
which addresses and ranks the importance of the biosecurity measures. The dependent variable used in the study was the biosecurity score against the farms’ business and biophysical characteristics.

The Artificial Neural Network (ANN) is considered a prediction method based on simplified mathematical models of the brain. A neural network is a parallel-distributed processor that has a natural propensity for storing experiential knowledge and making it available for use. It resembles the brain in two respects, the learning rules, processes, and weights used to store such learning in an iterative process until the optimized output reached as illustrated in Equations (1) and (2). In this study, data was analyzed using SPSS® software version 26. Artificial Neural Networks are sometimes favored over the other forms of conventional regression analysis such as logistic regression because the dependent variable (biosecurity score) is neither continuous nor a censored range type variable. Samborska et al. (2014) [6] showed that ANN has become an attractive alternative to accepted statistical methods, and provides mean results that fit the pattern of variable and hard-to-foretell phenomena in biological and agricultural systems.

According to Daniel, Graupe, (2013) [7], the ANN model computes output as follows:

\[ y = \sum_{i=0}^{n} [w_i x_i] \]  

where

- \( y \) = Dependent Variables (four dependent variables: Isolation, Traffic Flow, Sanitation, and Specific Biosecurity measure for AI)
- \( w \) = Cases weights
- \( i \) = Independent Variables (poultry farms biophysical characteristics):

  - Total Area (M2)
  - Farm Capacity (Total number of birds)
  - Yearly Flock Cycle (Number of Cycle per Year)
  - Density (Total number of birds/Area)
  - Distance to the closest farm (M)
  - Number of workers involved in the biosecurity measures

The equation can be updated following the weights as:

\[ W_i (t + 1) = W_i (t) + \Delta W_i \]  

Although ANN is a flexible methodological approach and requires minimal demands on model structure and assumptions, it is useful to understand the general network architecture. In this research, the multilayer perceptron (MLP) network process was assumed as the function of predictors’ optimization in this adopted model. A Multilayer Perceptron (MLP) is a class of feedforward Artificial Neural Network (ANN). The MLP consists of four layers of nodes. These nodes are the input layer, two hidden layers, and an output layer. Each node is a neuron that uses a nonlinear activation function. MLP utilizes a supervised learning technique known as the backpropagation, Karayiannis, and Venetsanopoulos (2013) [8]. In this study, each of the farms’ six business and biophysical characteristics are considered the independent or explanatory variables. The model minimizes the prediction error of target variables (each of the four poultry farms biosecurity measures).

The interpretation of the ANN model’s results was explained by Intrator and Intrator (2001) [9], as the authors indicated that one approach to the interpretation of the ANN models is through the study of the effect of each explanatory variable. The authors compared the results of the ANN models to the Logistic regression where odd-ratios calculation required if the dependent variable is binary. Meanwhile, if the model is non-linear, as in this study because the dependent variable is continuous
(biosecurity scores), the results rather show the predictors’ values combing the effect of inputs on all units in the neural network.

The equation used to calculate biosecurity performance for preparedness to achieve the targeted goal (highest possible biosecurity score) is:

\[
\text{Percentage Biosecurity Performance}_i = \frac{E_i}{(B_i - E_i)} \times 100
\]  

(3)

where

\[E_i = \text{Coefficient the independent variable } i\]
\[B_i = \text{Coefficient of the highest independent variable (maximum possible biosecurity score)}\]

3. Results

The results and analyses of this study were divided into three sections to address the two study objectives. The first section summarizes ranking of poultry farm preparedness against biosecurity threats, using the Cumulative Density Functions. The second section, using the Artificial Neural Network Models, correlates implementation of biosecurity measures in the four biosecurity categories (Isolation, traffic flow, cleaning and disinfection, and adoption of vaccination protocols) to the poultry farms’ biophysical and business characteristics in the UAE.

Table 1 summarizes the survey results for small-scale, large-scale, and all poultry farms in the UAE. Large commercial farms adopt many of the available practices. Thirty four of the 39 potential measures that could be adopted were adopted by at least 80% of the large farmers. However, not all measures were adopted by such a large margin of these producers. Less popular measures include dead bird and manure pickup being strictly isolated from other farm traffic, a segregation plan for new birds, having a pre-purchase material testing policy in place, allowing feed companies access to fill silos without entering the clean area of the farm, and allowing feed companies access to the sheds. Small-scale poultry farms were much less prepared, with 25% or less responding that they apply 18 out of the 39 biosecurity (nearly half) measures included in this study. Table 1 also included the results in connection to the response of either the farms adopt and proper protocol to vaccinate against Avian Influenza.
Table 1. Biosecurity Measures Analysis of Poultry Farms by Size in the United Arab Emirates.

| Measure | Survey Items | Small Scale Producer (20 Farms) | Large Scale Producer (17 Farms) | All Farms (37 Farms) |
|---------|--------------|---------------------------------|---------------------------------|----------------------|
|         | % of Yes | % of No | % of Yes | % of No | % of Yes | % of No |
| A-Isolation | | | | | | |
| 1 | Complete perimeter fencing | 100% | 0% | 100% | 0% | 100.0% | 0.0% |
| 2 | Gates that remain closed 1 | 85% | 15% | 100% | 0% | 91.9% | 8.1% |
| 3 | Area surrounding paved and clean 2 | 20% | 80% | 88% | 12% | 51.4% | 48.6% |
| 4 | Buffer zone between flocks and other birds | 85% | 15% | 82% | 18% | 83.8% | 16.2% |
| 5 | Employee awareness about avoiding contact with other birds outside the farm. | 10% | 90% | 88% | 12% | 45.9% | 54.1% |
| 6 | Employees and owners have dedicated clothing and shoes worn in clean areas of the farm. | 5% | 95% | 100% | 0% | 48.6% | 51.4% |
| 7 | All visitors and personnel obliged to wear farm-specific clothing (coveralls, shoes) cleaning, washing, and disinfection of hands before allowed to enter the sheds | 5% | 95% | 100% | 0% | 48.6% | 51.4% |
| 8 | Have a plan in place for self-quarantine in case of disease | 25% | 75% | 88% | 12% | 54.1% | 45.9% |
| 9 | Manure from the farm is neither stored in premises nor spread on neighboring farmland | 100% | 0% | 94% | 6% | 97.3% | 2.7% |
| 10 | The farm remove vermin (rats, mice,) and implements a vermin control program | 100% | 0% | 100% | 0% | 100.0% | 0.0% |
| 11 | Bird and vermin are denied access to the shades by fitting birds and vermin and maintain proof grids that are secured on the air inlets | 100% | 0% | 100% | 0% | 100.0% | 0.0% |
| 12 | Entrance for breeding houses secured, if the farm has a breeding house | 100% | 0% | 100% | 0% | 100.0% | 0.0% |
| B-Human and Vehicles Traffic flow | | | | | | |
| 1 | Dead bird pickup and manure pickup are strictly isolated from other farm traffic | 15% | 85% | 76% | 24% | 43.2% | 56.8% |
| 2 | Visitors are limited to essential people (e.g., government employees) only | 80% | 20% | 100% | 0% | 89.2% | 10.8% |
| 3 | Visitors sign a logbook | 5% | 95% | 100% | 0% | 48.6% | 51.4% |
| 4 | Visitors that have been around birds in the past 24 h are not allowed (such question asked during access at the gate) | 80% | 20% | 100% | 0% | 89.2% | 10.8% |
| 5 | Visitors are required to wear protective clothing | 5% | 95% | 100% | 0% | 48.6% | 51.4% |
| 6 | Signs are posted that prevent inadvertent visitors (visiting the farm without proper authorization) | 5% | 95% | 94% | 6% | 45.9% | 54.1% |
| 7 | Farm site divided into clean and dirty area | 5% | 95% | 100% | 0% | 48.6% | 51.4% |
| 8 | Biosecurity plan for farm that separates clean and dirty functions and establishes traffic flow | 5% | 95% | 100% | 0% | 48.6% | 51.4% |
| 9 | Communication of biosecurity plan to all employees | 10% | 90% | 82% | 18% | 43.2% | 56.8% |
| 10 | Segregation plan for new birds | 100% | 0% | 76% | 24% | 89.2% | 10.8% |
| 11 | Pre-purchase material testing policy for bio-safety and cleanliness | 100% | 0% | 76% | 24% | 89.2% | 10.8% |
| 12 | The Feed Company has access to fill the silos without entering the clean area of the farm | 0% | 100% | 53% | 47% | 24.3% | 75.7% |
| 13 | The Feed Company has no entrance to the sheds and has no possible direct contact with birds | 5% | 95% | 71% | 29% | 35.1% | 64.9% |
| 14 | Silos are well sealed against water, birds, and vermin and are leak-proof | 5% | 95% | 94% | 6% | 45.9% | 54.1% |
Table 1. Cont.

| Measure | Survey Items                                                                 | Small Scale Producer (20 Farms) | Large Scale Producer (17 Farms) | All Farms (37 Farms) |
|---------|-------------------------------------------------------------------------------|---------------------------------|---------------------------------|-----------------------|
|         |                                                                               | % of Yes (% of No)               | % of Yes (% of No)               | % of Yes (% of No)    |
| C-Poultry Farms Sanitation                                                                                           |
| 1       | Vehicle disinfection stations at every entry and exit                         | 100% (0%)                       | 100% (0%)                       | 100.0% (0.0%)        |
| 2       | High pressure spray at vehicle disinfection stations                          | 5% (95%)                        | 100% (0%)                       | 48.6% (51.4%)        |
| 3       | Use of vehicle disinfection bath is strictly followed                         | 10% (90%)                       | 100% (0%)                       | 51.4% (48.6%)        |
| 4       | Is there a policy in place to keep all vehicles out of clean areas on the farm| 5% (95%)                        | 100% (0%)                       | 48.6% (51.4%)        |
| 5       | Is there equipment disinfection policy in place for visitors and on the farm  | 5% (95%)                        | 100% (0%)                       | 48.6% (51.4%)        |
| 6       | Specific disinfection measures applied for material supplies upon arrival. Wood shaving | 100% (0%)                       | 88% (12%)                       | 94.6% (5.4%)         |
| 7       | Complete cleaning and disinfection between flocks                            | 100% (0%)                       | 100% (0%)                       | 100.0% (0.0%)        |
| 8       | The efficiency of cleaning and disinfection is checked by hygiene technicians after each production cycle | 10% (90%)                       | 94% (6%)                        | 48.6% (51.4%)        |
| 9       | At least 2 weeks downtime between flocks                                     | 95% (5%)                        | 100% (0%)                       | 97.3% (2.7%)         |
| 10      | Availability of a clean potable water and feeds all the times                | 100% (0%)                       | 100% (0%)                       | 100.0% (0.0%)        |
| 11      | Medicines are kept in a suitable place and temperature                        | 100% (0%)                       | 100% (0%)                       | 100.0% (0.0%)        |
| 12      | No use of medicines or feeds contain growth promoters                          | 100% (0%)                       | 100% (0%)                       | 100.0% (0.0%)        |
| D-Biosecurity Measures for Avian Influenza                                                                             |
| 1       | Is there a protocol of vaccination for AI in the farm                         | 0% (100.0%)                     | 94.1% (5.9%)                    | 43.2% (56.8%)        |
3.1. Biosecurity Measures Importance Results

Figure 3 below illustrates adoption of biosecurity measures across the four biosecurity categories using Cumulative Density Functions (CDFs). For example, the human and traffic flow CDF (red) indicates that less than 70% of poultry farms (vertical axis) adopt at least 75% of the activities in this biosecurity measure. The remaining 30% adopt 75% or more. About 80–85% of farmers adopt less than 90% of the human and traffic flow activities, and the remaining 10% adopt all of the activities (100% on the horizontal axis). On the lower end, about 40% of the farmers adopt less than 30% of the human and traffic flow measures. Meanwhile, 50% of the poultry farms would adopt 66% or less of the sanitation and disinfection biosecurity measures. There is overall a higher probability that poultry farms in the UAE would apply isolation and sanitation in comparison to the other two biosecurity measures (human and traffic flow measure and adoption of vaccination protocol) as the CDFs of isolation and sanitation appear to the right of the other CDFs at the higher levels of probabilities. Vaccination is a biomodel. More than half of farmers (57%) would not apply proper vaccination against Avian Influenza (AI) disease; the other 43% would vaccinate.

![Figure 3. Cumulative Density Functions (CDFs) for all UAE Poultry Farm Biosecurity Measures.](image-url)

The application of prevention methods can be seen visually in the cumulative distribution functions (CDFs) between various poultry biosecurity alternatives, large poultry farms in Figure 4A, and small poultry farms in Figure 4B. These results are useful to rank poultry biosecurity measures, comparing CDFs for large and small farms. For example, while almost half of the large farms vaccinate, only 6% (one farm) of the smaller farms vaccinate. The CDFs are much flatter for small farms, indicating that adoption is more spread out; that is, most larger farms adopt, while some smaller farms adapt and some do not. For example, 3 farms adopt 20% or fewer of the sanitation measures, while one more adopts 25%, another adopts 30%, and so on; only 1 adopts all of the isolation measures. In both cases, more farmers adopt sanitation and human and traffic flow measures than isolation. Furthermore, the CDF of Avian Influenza biosecurity showed that there is a level of adoption of 54% regarding the proper protocol, leaving 46% for the lack of adoption of such biosecurity measures. Additionally, the CDFs show that almost all small farms do not appropriately apply a protocol to a vaccine against the AI disease. Meanwhile, all but only one large farm apply the proper protocol to vaccinate against AI.
The CDFs comparisons can be useful to examine if there are differences between broiler and layer farms too. As shown in Figure 5A,B, broiler poultry farms perform more sanitation and disinfection biosecurity measures compared to the layers farms (e.g., 50% of the time broilers farms adopt 60% of the sanitation and disinfection measures). Meanwhile, there is only a 0.3 probability that poultry layer farms will fully adopt sanitation and disinfection biosecurity measures. In connection to human
and vehicle traffic flow, poultry layers farms outperform the broilers farms at the 0.5 probability level. Furthermore, all layers farms were found to be applying proper AI vaccination protocol.

3.2. Correlation between Poultry Farms Characteristics and Biosecurity Results

In the previous section, each farm could be given an initial raw biosecurity score based on the percentage of the measures adopted in each biosecurity category. Next, we analyze the correlation between each of the poultry farms' biosecurity scores, isolation, human and traffic flow, cleaning and disinfection, and adoption of vaccination protocols, as well as our stated set of explanatory variables using the Artificial Neural Network approach. As a byproduct of this process, the ANN computes

![Graph A](image1.png)

**Figure 5.** (A) Cumulative Density Functions (CDFS) for the UAE Poultry Farm Biosecurity Measure for Broiler Farms. (B) Cumulative Density Functions (CDFS) for the UAE Poultry Farm Biosecurity Measure for Layers Farms.
importance scores, which are more sophisticated versions of the raw biosecurity scores. Potential explanatory variables are Total Farm Area (in square meters), Farm Capacity (Total number of birds), Yearly Flock Cycle (Number of Cycle per Year), Density (Total number of birds/Area), Distance to the Closest Farm (Meters), and the number of workers involved in the biosecurity measures. Following are the results of this analysis.

3.2.1. Isolation

The ANN coefficients for each potential explanatory variable are shown in Figure 6. Each coefficient represents the sufficiency of the variable’s influence over the biosecurity measure. Higher values are more sufficient (influential) than lower values. These coefficients can point to where government efforts would most likely to lead to increased biosecurity. We found that the most influential factor on isolation was the yearly flock cycles. Helping poultry farms that do not apply enough downtime will heighten the farm’s isolation more than working to help farmers reduce density, for example. The more cycles of production the farm’s implement, the higher the importance of such factor on biosecurity. The yearly flock cycles (score 0.284) are followed in importance by the farm total area factor (score 0.243), which is measured in square meters, and then the farm capacity, measured in the total stock of birds. The number of workers in biosecurity and density had substantially lower sufficiency scores. The lowest impact was from distance to the nearest farm.

![Figure 6. Factors Influence the Isolation Biosecurity Measures.](image)

We can also compute a performance index to reflect the relative difference between the most and least sufficient factors. The lowest sufficiency factor was the distance to the nearest other farms (score of 0.04). The highest sufficiency measure (i.e., least risk influential factor was found to be yearly flock cycles (score of 0.284). This indicates that the difference between the lowest and the highest levels of biosecurity sufficiency is (0.27). Therefore, the biosecurity performance index would be 99% (0.27/0.284)–Equation (3) and Figure 4.

3.2.2. Human and Traffic Flow Control

Human and vehicle traffic control includes allowing only staff who care for the farm’s poultry to come into contact with the birds. Such control includes minimization of the indirect contact of feed and other supply providers’ vehicles. Results show that the most influential factor that contributes to the enhanced human and vehicle traffic-flow control efficiency is the farm capacity, measured in the number of birds held in the facility (0.276), followed by the total area of the farm measured in square
meters (0.276)—Figure 7. These factors were second and third for isolation. The least sufficient factor is the distance to the nearest farm (score of 0.015), as it was for isolation.

The biosecurity performance index in this case was 94%.

3.2.3. Cleaning and Disinfection

Cleaning and disinfection involves the use of physical or chemical processes to reduce, remove, inactivate, or destroy pathogenic microorganisms. Such procedures are crucial in controlling the spread or transfer of microorganisms between animals, between locations, or to people. The potential for disease spread or transfer of microorganisms can occur from the direct or indirect contamination of equipment, facilities, vehicles, people, and the movement of animals or animal products (Clifford, J. (2014).) [10]. The most influential biophysical factor on the adoption of biosecurity practices in this category was yearly flock cycles (0.210), followed by the number of workers involved in the farm’s biosecurity practices (0.202)—Figure 8. Yearly flock cycles was an important factor for isolation, but not for traffic flow measures. The number of farm workers involved in biosecurity had a relatively larger impact for cleaning and disinfection than for isolation of traffic flow.

The biosecurity performance index in this case was 86%.
The least sufficient factor is again distance to the nearest other farms (score of 0.025). The biosecurity performance index is 86%.

3.2.4. Vaccination and Preparedness against Avian Influenza

Routine vaccination for Avian Influenza (AI) has become a common tool for the prevention of biosecurity threats. However, diverse opinions surface worldwide regarding the use of vaccination to control an AI outbreak. Nevertheless, there is general agreement that there is a need to adopt a well-designed protocol of vaccination against such Avian Influenza virus spread. This study found that most of the farms’ biophysical characteristics, including the yearly flock cycle (0.195), numbers of workers involved in biosecurity practices (0.187), birds density (0.187), farm capacity (0.185), and the total area of (0.181) influence the effectiveness of the vaccination process and the implementation of the vaccination protocol—Figure 9. However, results indicate a low influence of the distance to the nearest farm on the vaccination use.

![Figure 9. Factors Influence the Vaccination against Avian Influenza Biosecurity Measures.](image)

The biosecurity performance index is 50%.

In summary, for each type of the four biosecurity categories, there is a set of biophysical characteristics that influence the biosecurity score. We found a high variability between the farms included in the survey when it comes to the adoption of biosecurity measures. Factors found to be the most influential on adoption were flock yearly cycle, density (number of birds per square meter), and number of workers involved in biosecurity. Distance to the nearest other farms was identified as the least influential variable.

3.2.5. Poultry Farms Operational and Biosecurity Cost

Table 2 below shows the average poultry farms’ total annual cost, which was estimated to be about 7.4 million Dirham in total. The cost of the operation data was gathered from both primary sources, such as the Abu Dhabi Agriculture and Food Safety Authority, commercial poultry farms, and the 2017 Commercial Survey (i.e., summarized periodically by the UAE Federal Competitive and Statistical Authority) [3]. Table 2 describes the itemized costs for average poultry farms in the UAE. Feed cost was the highest cost item at 4.66 Dirham per each bird produced at the farms. This figure represents about 89% of the poultry operation’s costs, leaving 11% of the cost directly or indirectly related to biosecurity. The cost of vaccination was estimated to be 415.5 thousand dirhams for the average farm annually. Meanwhile, the cost of cleaning and disinfection is estimated to be 111 thousand dirhams annually (the exchange rate is 1 USD = 3.65 dirhams). This indicates that the cost of biosecurity implementation
is the second-largest item regarding poultry farms in the country, after the cost of feed. In brief, costs of feed and costs of biosecurity implementation were found to be the highest two items of costs at the UAE poultry farms.

**Table 2.** Summary of Typical/Average Poultry Farm Total Annual and Per Capacity Unit (Bird) Operational Cost in UAE Dirhams in 2017.

| Cost Item                                   | Average/Typical Farm Cost in Dirhams | Per Poultry Farm Capacity Unit (Bird) Cost in Dirhams |
|---------------------------------------------|--------------------------------------|-------------------------------------------------------|
| Farm Capacity (Birds)                       | 1,417,632                            | 1,417,632                                             |
| Feed                                        | 6,524,545                            | 4.660                                                 |
| Electricity                                 | 66,972                               | 0.050                                                 |
| Water                                       | 52,610                               | 0.040                                                 |
| Labor Involved in Biosecurity               | 73,860                               | 0.050                                                 |
| Vaccination Costs                           | 415,511                              | 0.300                                                 |
| Avian Influenza Vaccination                 | 166,505                              | 0.120                                                 |
| All Other Vaccination                       | 249,006                              | 0.180                                                 |
| Cleaning and Disinfection                   | 111,050                              | 0.080                                                 |
| Pest Control                                | 19,336                               | 0.010                                                 |
| Waste Management                            | 96,214                               | 0.070                                                 |
| **Total Operational Cost**                  | **7,360,098**                        | **5.260**                                             |

4. Discussion

4.1. Biosecurity Measures Importance Ranking

In this study, we noticed that answers by the respondents and the research team experts’ remarks indicated a notable lack of awareness for the poultry farms about the importance and the benefits of proper vaccination processes and the lack of adopting a specific proper protocol on such vaccination implementation. This implies the strategies and action plans have to consider how factors such as the number of yearly cycles, number of workers involved in biosecurity implementation, bird density at the farm, farm total capacity, and total farm area influence the level of the farm’s preparedness against disease.

In this research, the biosecurity measures were grouped into four categories against contagious diseases, which differs from previous studies on poultry farm biosecurity. This research used the Artificial Neural Network (ANN) optimization model to score and rank the importance of the studied biosecurity measures. Survey input factors were entered into the ANN-based model. Aggregation of biosecurity practices into groups was helpful to identify gaps, and then to propose proper-targeted measures for enhancement. This research analysis indicated that for the intensive farm production system in the country, it is highly essential to increase targeting cleaning and disinfection. We found that in isolation, farms showed an 83% probability of performance (10 out of each 12 isolation measures are likely to be adopted by all farms). The model’s results showed a 71% probability of performance (10 out of 14 measures are expected to be successfully implemented) on human and traffic flow. Only 50% (6 out every 12 measures) were adopted in the cleaning and disinfection biosecurity category. This analysis would be helpful to the policymakers on identifying specific types of farms to address relevant specific areas of biosecurity (i.e., isolation, traffic flow, cleaning and disinfection, and adoption of vaccination protocols). Furthermore, the findings’ of this research would support and enhance the overall biosecurity preparedness against infection and the spread of birds’ diseases.

4.2. Correlation between Poultry Farm Characteristics and Biosecurity Preparedness

This research studied the correlation between the biosecurity measures for each focus area’s level of preparedness against the farms’ biophysical and business characteristics. These selected
characteristics were; farm area in square meters, number of birds on the farm, number of yearly flock cycles, density, measured in a number of birds, per area, distance to the closest farm, and number of workers involved in the biosecurity work. Results for each type of biosecurity examined here are presented below.

4.2.1. Isolation

Confinement of animals within a controlled environment is essential to prevent risk and to keep high biosecurity standards. In general, isolation aims to minimize any potential source of contamination from the farm, so isolation applies to control entering and exiting the farm. Negro-Calduch et al. (2013) [11] incorporated a mixed method including direct observations, questionnaire survey to group discussion for 160 participants, and interviews with 463 poultry supply chain stakeholders. The collected data required for assessing biosecurity grouped practices and measures of small-scale broiler producers in central Egypt that could help to understand the reasons pertinent to disease transmission within and between poultry farms. The results showed that several necessary biosecurity measures were rarely implemented. For example, the number of production cycles per year on most farms seemed high, which means that there was not enough proper downtime between cycles. Therefore, if the market price were attractive, farmers would start a new production cycle regardless of the need for downtime. In addition, the authors found that control measures had been ineffective due to limited cooperation between the private and public sectors, and a lack of compensation for incurred losses. The authors mentioned best practices for improving biosecurity, such as vaccinators, and all other workers should practice personal cleaning, changing clothes, and disinfecting between farm visits. Vehicles have to be clean and disinfected before entering the farm.

4.2.2. Human and Traffic Flow

To prevent disease spread and ensure a proper level of biosecurity, it is important to control human and vehicle traffic-flow within the farm and within and outside the farm’s premises. Traffic flow control refers to biosecurity measures such as fencing, human, and vehicle control within and into the farm. The measure includes preventing visitors’ direct contact with the birds, controlling movements of material, supplies, equipment, finished final products, and limiting such movements to only necessary ones. Sematimba et al. (2013) [12] analyzed the biosecurity measures structure qualitatively in Dutch poultry farming to determine the practices and risks related to introducing the viruses and contagious disease into the poultry farms. The results showed that the riskiest forms of contact are between birds during thinning and restocking the flock processes. In addition, the contact between humans and birds when accessing poultry houses was found to be a high source of risk. The authors noticed that the contacts and traffic flow between different poultry farms located near each other were high. The overall risk posed by humans, equipment, and premises-only contact was considered a medium for both broiler and layer farms. Finally, the authors recommended that an improvement in biosecurity measures, therefore, would be beneficial for controlling the spread of avian influenza. Considering the studies that modeled biosecurity assessment, Van Steenwinkel et al. (2011) [13] offered an assessment of biosecurity practices, movements, and densities of poultry sites across Belgium to describe on-farm biosecurity levels. The required data were collected by a questionnaire-based survey from 342 poultry farms and sites (37 professional poultry farms, 19 hatcheries, and 286 hobby poultry sites). The analysis of collected data used a combination of a linear scoring system, a Categorical Principal Component Analysis (CATPCA), and a Two-Step Cluster Analysis (TSCA) on grouped biosecurity measures. The results obtained showed that most professional poultry farms and hatcheries have reasonable on-farm biosecurity levels and practices. However, the movements were high in and out of the farm. In contrast, on the hobby poultry sites, the level of biosecurity was lower due to poor control of the external environment and inadequate infrastructures. Finally, the authors indicated that there are still many biosecurity measures not well implemented and that there are still areas for improvement. Authors
advise that workers must avoid contact with other poultry farms or other sources. Also, producers should control movement within and outside the farm and limit the visit for only necessary people.

4.2.3. Cleaning and Disinfection

Preventing the introduction of a disease agent into a farm can stop the spread of disease agents, depending on how a farm is adopting and applying proper cleaning and sanitation practices. One of these practices related to this biosecurity measure is the availability of vehicle disinfection points at every entry and exit and performing such practice properly. Sanitation of equipment, housing cleaning, and wearing protective clothing for poultry workers’ practices contribute to the prevention of the spread of the disease agents. Workers sustaining personal hygiene lead to the destruction of the disease agents. Relevant published studies were useful to this study to decide on the relevant business and biophysical and characteristics for this study. The authors noticed that very few previous studies (Negro-Calduch [11], and Steenwinkel, et al. [13]) grouped the biosecurity measures to identify biosecurity measures gaps and areas of strengths or weaknesses and qualify such strengths or weaknesses. Other studies Scott et al. [14], Millman et al. [15], and Sematimba et al. [12] did not consider such grouping of biosecurity measures to analyze specific areas importance (e.g., cleaning and disinfection against isolation) nor studied the correlation between biosecurity and the poultry farms’ business, biophysical characteristics.

4.2.4. Vaccination and Preparedness against Avian Influenza

Rimi et al. (2018) [16] published a research article aimed at understanding the biosecurity conditions and farmers’ perception of avian influenza biosecurity on Bangladeshi small commercial chicken farms between 2011–2012. The authors completed interviews with 16 poultry farms and analyzed the data using an inductive approach. The results of this study considered the farms’ demographics and chicken sheds’ description, as well as the biosecurity measures such as farms segregation, cleaning and disinfection, and the farmers’ perception of Avian Influenza and biosecurity. The authors found that none of the farms was completely segregated from people, other farms, vendors, and households. The authors recommended that farmers could be motivated to protect their investment and explore the feasibility and effectiveness of low-cost biosecurity measures. Alhaji and Odetokun (2011) [17] considered the assessment of biosecurity measures against Highly Pathogenic Avian Influenza (HPAI) risks on small-scale commercial farms and free-range poultry flocks in Northcentral Nigeria. The study objective was to assess the biosecurity measures on small-scale commercial poultry farms and the free-range bird flocks owned by households in northcentral Nigeria. The study data was collected using a questionnaire to farms and flock owners. The results showed that among 165 small-scale commercial poultry farms, 95% sold poultry and poultry products directly at the farm (involving extensive movements of people in and out of the farm premises). 70% stored litter was found to be in areas prone to contamination, 56% only cleaned equipment without disinfection, 47% of farm workers did not have protective clothing, and 65% of the purchased drugs and vaccines were over-the-counter. Meanwhile, 33% did not have access to veterinary services. The authors suggest control of livestock and poultry movements within and outside the country, and that farmers avoid close contact between poultry and humans. In addition, authorities should control and provide well-organized poultry marketing for the live birds to minimize the risk of disease spread at the live birds market. On the farms, producers should pay attention to the sources of water, feed, and avoid poor handling of litter.

5. Conclusions

Contagious poultry diseases have the potential to have a devastating effect on poultry production in the United Arab Emirates (UAE). We investigated the use of 39 biosecurity measures arranged into four groups: isolation, sanitation and disinfection, personal vehicle and traffic flow, and vaccination against specific contiguous diseases. We did not have the information necessary to compute impacts
or efficacy of methods, so we counted the number of available recommended practices that each farmer applied on their operation. More methods are presumed to mean more protection, with all methods having equal importance. Results revealed that poultry farms showed an 83% probability of performance. We found that at least 80% of larger farms adopted most of the available practices, and that less than 25% almost half of available practices. The ANN model revealed that yearly flocks’ cycles, farm capacity, the total area of the farm’s density, and the number of workers involved in the biosecurity would be the most influential factors on adoption of biosecurity measures in the four areas we examined. Furthermore, the a performance index, which reflects the relative size of the gap between the factor with the lowest influence and the highest influence was 99% for isolation, 94% for human and vehicle flow, and 86% for cleaning and disinfection. We recommend further development of an effective vaccination protocol at the poultry farms in the UAE. We also analyzed how the farms’ characteristics influence biosecurity effectiveness.

The development of vaccination protocols and the implementation of vaccination effectiveness is essential. However, because our survey showed that a portion of large farms and small farms do not apply the proper protocol of vaccination against Avian Influenza, this implies high uncertainty by the respondent in the adoption of this measure. Based on this research, we recommend support for the small poultry farms to increase their awareness about the importance of vaccination against Avian Influenza disease. Finally, in conclusion, these research results show the importance of ranking the biosecurity system in the four areas of isolation: traffic flow control, cleaning and disinfection, and vaccination biosecurity measures. More specifically, the results indicated that for the intensive farm production system, it is highly important to focus on cleaning, disinfection, and vaccination. Therefore, to enhance business intensification and increase biosecurity efficiency simultaneously, isolation and traffic flow reduction are more necessary than other biosecurity measures. Furthermore, we recommend the development of an awareness program among poultry farms on biosecurity elements’ importance, which also addresses the importance of efficient vaccination protocol development.

In summary, large farms are doing well in all measures except vaccination. Small farms need to boost all biosecurity measures. The best way to boost adoption is to apply proper vaccination protocol against Avian Influenza (AI) diseases, followed by control of human and vehicle traffic flow, and apply effective isolation (e.g., control the distance between small farms and the nearest other poultry operations).

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