THE PROGRESS: A Journal of Multidisciplinary Studies
Vol.6, No.2 (June, 2025), Pp.30-40
ISSN (Online): 2958-292X, ISSN (Print): 2958-2911
DOI: https://doi.org/10.71016/tp/4estzr71

Review Article https://hnpublisher.com

Poultry Flock Profiling and Interpretations: A Critical Review of Current Strategies and Future Prospects

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ABSTRACT

Aim of the Study: The main focus of this study is on the flock profiling in poultry industry as it plays essential role in the maintenance of the poultry flock. Poultry sector largely depends upon efficient flock profiling and bird health immunization.

Methodology: Since this is a review article, its main objective is to conduct a thorough analysis of all relevant material on flock profiling and the methods opted in this regard in the poultry industry.

Findings: Flock profiling and immunization protocols are being opted by poultry industry which involve gathering, examination, and interpretation of information obtained after data collecting about the performance, health, and environmental circumstances of poultry, particularly chickens and turkeys. Flock profiling is used in poultry management as it helps in examination, interpretation of data regarding the health, analysis, environmental conditions of poultry. This review focuses on prerequisites of improving the current standards for monitoring and reporting poultry diseases in chickens. The utilization of technological advancements such as smart sensors, AI-powered monitoring systems, and infrared technologies is transforming flock profiles and improving farm management through real-time health and welfare assessments. Regular data collection also helps with risk assessment and its mitigation, which leads to more productive flocks. This is due to use of sensors like genetic testing and biochemical profiling in conjunction.

Conclusion: This study looks at the primary aspects of flock profiling, such as data collection techniques, health monitoring, environmental factors, and the role of technology in improving the welfare and performance of chickens. The findings demonstrate that how flock profiling can save costs, increase productivity, and promote ecologically friendly methods of raising chickens.

Keywords: Flock Profiling, Biosensors, Vaccinations, Immunity and Biochemical Profiling.

Article History

Received:
March 05, 2025

Revised:
May 23, 2025

Accepted:
May 25, 2025

Online:
May 29, 2025

1. INTRODUCTION

The Poultry industry is among the world's largest and fastest expanding agro-based sectors. Therefore, in order to optimize production in this sector it is important to develop a strategic approach for assessing large flocks of poultry birds especially chicken to meet requirements regarding their health and welfare management. For this purpose, flock profiling is done which entails weighing a sample of the flock at regular intervals and utilizing the date to create a growth chart. Data on the health, performance, and habitat of a group of birds are gathered, analyzed, and interpreted. In contemporary chicken farming, this technique is employed to boost output, enhance animal welfare, and lessen disease outbreaks. Data-driven insights can help farmers make well-informed decisions that enhance sustainability, lower costs, and improve flock performance (Wolfert, Ge, Verdouw, & Bogaardt, 2017). Your flock's growth rate and feed efficiency may both be checked by a new growth curve which can be compared to the average or earlier flocks in the same facilities to see whether any improvements are being achieved. A drop in growth rate could suggest an impending sickness or a shift in feeding or care techniques.

1.1 Flock Profiling in Case of Layers

A full flock's relative success can be measured using a number of metrics. The most commonly used layer bird's performance metric is total eggs per hen housed (TE/HH). Hatching eggs per hen housed (HE/HH) can also be employed to keep in mind the fact that the egg sorting criteria for cull (or disqualified) eggs may change between operations. The hatchery's LOF fertility data represents field performance of bird. Chicks per hen housed (Chicks/HH) is an effective metric for demonstrating combined flock performance of females and males. In order to optimize laying bird's genetic potential, it is important to respond to early warning signs from your flock. Then, make certain that the birds have always have access to food and clean drinking water. An abrupt change in water and feed intake is one of the early warning indicators; it is crucial to periodically collect data and analyze it on the day of collection.

1.2 Flock Profiling in Case of Broilers

Broiler chicken behavior has been widely examined in terms of stocking density and environmental variables. The most important input in chicken production is feed, which has a major impact on the production cycle's financial sustainability. Past and present studies have been conducted to increase the feeding efficiency of broiler chickens in areas such as ingredient selection and feed processing technologies, as well as the impact produced by feed particle sizes on flock performance and gut development. In many contexts, flock movement patterns of broiler chickens have been observed using computational image analysis techniques (Neethirajan, 2017). It can be a useful technique to gauge the degree of animal welfare in order to enhance flock management by supporting forecasts for subsequent decision-making (Zhuang & Zhang, 2019).Be advised that the quality of the data has an equal bearing on how the results are interpreted. Start by deciding which information is most crucial for flock management and how frequently you want to gather this parameter. Additionally, confirm that the information you gather is trustworthy.

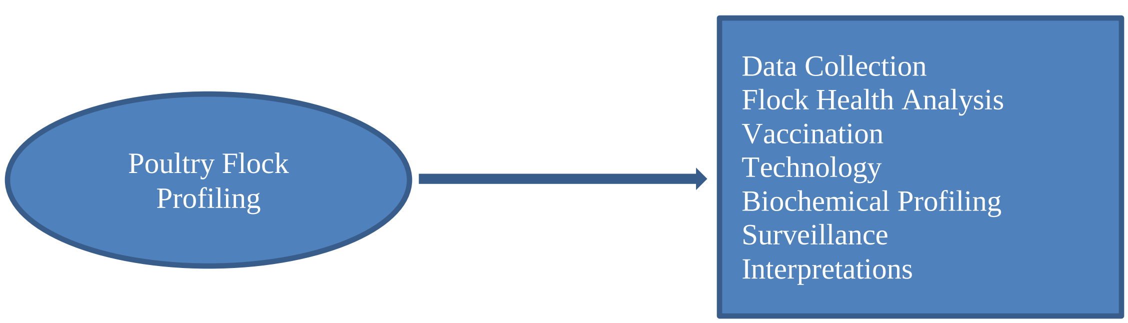

Figure 1: *Key Aspects of flock profiling*

2. TECHNOLOGICAL INNOVATIONS FOR FLOCK PROFILING:

In recent years, a variety of technological advancements, sophisticated data processing, and modeling tools have surfaced that have the ability to evaluate, regulate, and enhance the welfare of chickens. Current technological advancements and mathematical modeling create new opportunities for automated real-time animal health and welfare monitoring. Although their actual application is still being determined, new technical advancements that may be tailored to commercial poultry are starting to emerge. Infrared technologies to assess birds' thermoregulatory characteristics and metabolic changes, which may be suggestive of welfare, health, and management issues; sensors for farm environmental monitoring, movement, or physiological parameters; and imaging technologies like optical flow to identify gait issues and feather pecking. All of these technologies have the potential to be used commercially to enhance flock management and the wellbeing of birds, which would increase the system's resource efficiency and, ultimately, its long-term sustainability (Ben Sassi, Averós, & Estevez, 2016).

Some innovations have already been put into use in commercial settings, while others are still in the development stage. SY-Track, an improved algorithm has been used to ensure accurate chicken flock detection, tracking, and calculation of activity indices a lightweight method for tracking and detecting chickens, is suggested. It combines enhanced StrongSort with YOLOv7-tiny. The Efficient Long-range Aggregation Network (ELAN-A) module is replaced with the Efficient Long-range Spatial Aggregation Network (ELAN-SA) module, and a novel convolution known as Spatial Separable and Ghost Convolution (SAGConv) is proposed in conjunction with the YOLOv7-tiny detection model. To improve model convergence, SCYLLA-IOU (SIOU) is also employed. These improvements compress and converge the model to produce a lightweight effect, resulting in lower GFLOPs and YOLOv7-tiny parameters. The Kalman filter algorithm is optimized, and the StrongSort is used to track chicken flocks. On three distinct films, the optimized model shows outstanding accuracy and a notable increase in frame rate when compared to the pre-optimized StrongSort. SY-Track computes the Unrest Index to represent the degree of chicken activity. Three tracking films and independent detection photos with a variety of chicken breeds and shooting angles make up the dataset.

Indeed, many of the technologies discussed here might be incorporated into farm management procedures to improve farm productivity and poultry welfare while streamlining decision-making throughout the growing season.

When comparing barns or flocks, the data must be gathered similarly. All global breed standards are available online and in excel files upon request, making it simple to compare collected data to those of other or past flocks and breed standards. Do remember that farm management, disease, rearing time, and chicken diets can significantly affect flock performance, and that traits can depart from the standards.

2.1. Common Tools for Flock Profiling

2.1.1. Softwares for Farm Management: AgriWebb, FarmWizard, and PoultryManager are examples of tools that are intended to manage data, track flock performance, and offer real-time insights on a range of indicators.

2.1.2. IoT Gadgets and Smart Sensors: The Internet of Things (IoT) technology allows smart sensors to collect environmental data (temperature, humidity, CO2 levels) as well as avian behavior.

2.1.3. Laboratory Examinations: Early detection and control of diseases are made possible by routine testing using biological sensing technologies, done whether by fecal collection or blood tests (Du & Zhou, 2018).

2.1.4. Behavior Analysis: Pecking, hostility, and other changes in social behavior are frequently signs of environmental stressors, hunger, or overcrowding.

2.2 *Key Benefits of Flock Profiling*

2.2.1 **Increasing Productivity:** Farmers can improve the performance of their flocks by carefully monitoring important indicators such as feed conversion, egg production, and weight gain.

2.2.2 **Managing Disease:** Early detection of disease outbreaks results in quicker interventions, potentially decreasing losses.

2.2.3 **Minimizing Expenditures:** Flock profiling can save operating costs by lowering mortality rates, increasing feed efficiency, and preserving ideal environmental conditions.

2.2.4 **Bird Well-being:** Understanding flock health and behavior promotes optimal care and prevents stress-related illnesses.

2.2.5 **Sustainability:** By improving efficiency, flock profiling contributes to sustainable farming practices, reducing waste and enhancing the overall environmental footprint.

2.3 *Flock Health Monitoring*

It is an important system, used in the poultry industry worldwide to minimize the production cost, detect clinical and subclinical diseases and acquire data to make comparisons among the farms and identify the future research area drop in water and feed intake can have several causes, think off stress due to vaccination, environmental stress (heat stress), a different flavor or texture of the feed, antinutritional factors or mechanical system failures. This system was introduced in 1982 in by collaboration with the poultry sector of Mississippi. With the passage of time, this system has gained several innovations in terms of regular heath checks of live birds, performing necropsy examinations of morbid birds, and it is extremely important in predicting a disease or an infection especially newly emerging disease outbreaks in birds. This system of early disease diagnosis by regular health checks of birds is very helpful in initiating a rapid response to the disease for its timely control thus preventing further spread (Shriner et al., 2016). Investing in feed monitoring can be challenging and costly, for example when having no automated measuring system, you can only make a rough estimate from the feed left in the silos. However, monitoring of water intake via a water meter system is cheap and provides objective data. This data can be very well used as a first warning to indicate possible issues if monitoring and interpretation is done on a regular basis. Moreover, presumptive diagnosis can be made on the basis of clinical signs and symptoms and postmortem lesions in birds suffering from any bacterial or viral diseases. In case of bacterial diseases transmission mapping of bacterial species by use of phenotyping and genotyping tools following their isolation from samples of infected organs collected from outbreak areas in poultry farms provide information about ongoing infection in those areas such as in case of E. coli and Enterococcus outbreaks (Course, Boerlin, Slavic, Vaillancourt, & Guerin, 2021). Moreover, biochemical profiling can be done with automated analytical profile index systems that make profile indexes for bacterial identification along with phenotyping which depends upon colony morphology, physiological conditions and serological testing for various bacterial species. Molecular testing of genomic DNA, plasmid and RNA for identification and discrimination of various isolates of bacterial and viral species is being done using techniques such as PCR (Polymerase Chain Reaction) which reveal prevalence and transmission of isolates by identifying the presence or absence of specific genes or set of genes responsible for an outbreak in that area (Hauck, Carrisosa, McCrea, Dormitorio, & Macklin, 2019).

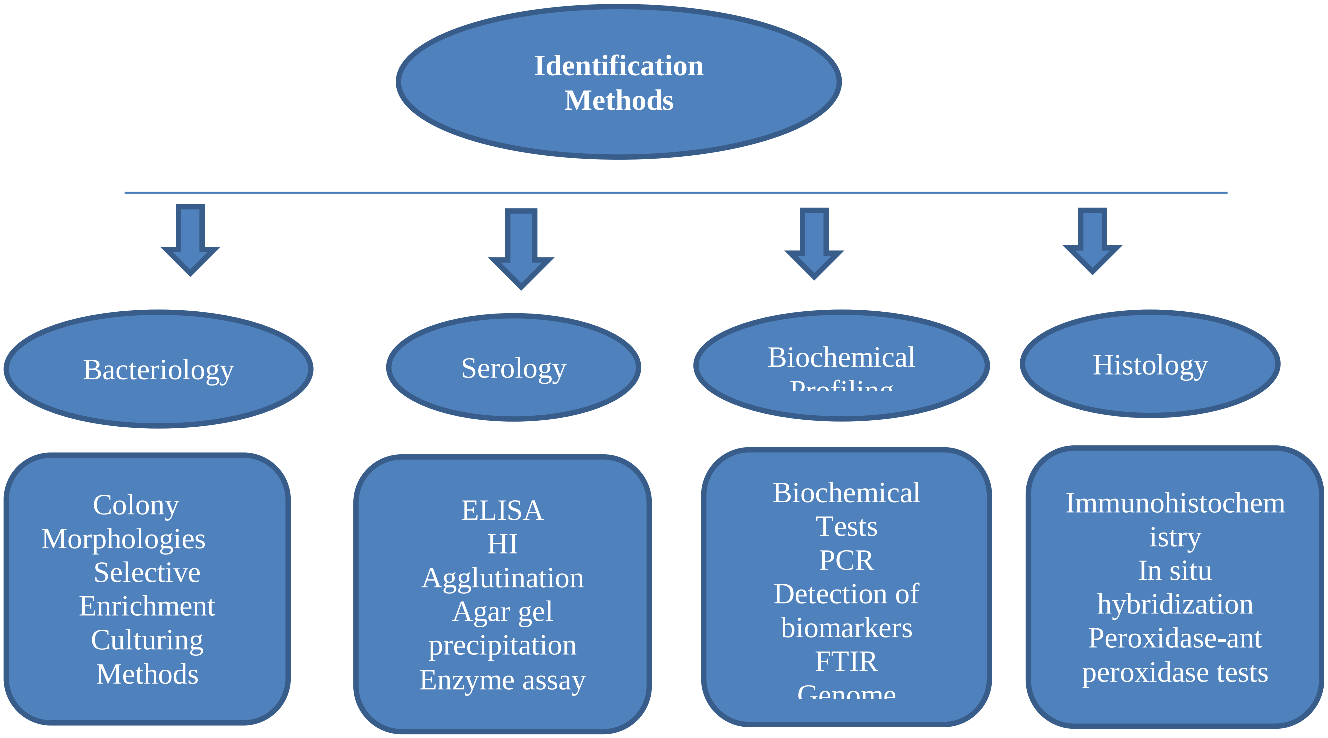

Figure 1: *Identification methods commonly used for identification of diseases in poultry diagnostic laboratories*

3. BIOSENSORS FOR DISEASE DIAGNOSIS

Innovations in the field of poultry industry are being introduced that ensure efficacy of data collection and interpretations. This data usually comprises of data about bird health its performance, environment, and outbreak of a disease. Use of innovative technology to minimize the chance of uncertainty with the help of devices called biosensors in forming a diagnosis against and infection. These devices detect a biological element and encode it in the form of a signal that is transmitted and recognized. Biosensors consist of multiple segments; a bioreceptor which recognizes biological analyte which can be an enzyme, protein, antibody, cell, or any other molecule, a transducer which converts the recognized element into a signal and transmits it to the electronics which converts and amplifies the signal in the form a readable display. Such as in case of Avian Influenza virus detection these biosensors detect viruses by use of recognition elements such as aptamers glycan, which are responsible for detection of influenza virus subtypes and the differentiation between highly pathogenic and low pathogenic avian influenza viruses (Gopinath et al., 2014). Some of these biosensors are tested by use of biological samples collected from the bird suffering from diseases such as Avian Influenza virus. Impedance biosensors using aptamers for recognition in tracheal swabs obtained from infected chicken showed different results when compared to RT-PCR (Karash et al., 2016).

Rapid disease diagnosis can be done with the use of biosensors and rapid detection assays by help of efficient profiling systems in poultry housing. These require frequent and careful manual sampling and it is usually evident after an outbreak where clinical signs are evident in birds thus it is time saving technology which helps in efficient diagnosis of pathogen and save the time expenditure in different lab methods needed for diagnosis as real time detection is an ultimate goal of today's researchers.

3.1. Wearable Sensors

As the name implies, these are the devices use to tract the overall birds' performance and have been widely used in agriculture sector for precision livestock farming. These are used for monitoring of physiological activities, detecting stress and healthy and diseased conditions in animals. In poultry sector, these find their role in tracking bird's health by attaching these to a number of proportioned flock due to their large number of birds only proportioned flocks are fitted to these and the data obtained from those flocks is used to determine overall health status of farm (Neethirajan, 2017). Mostly these wearable sensors focus on changes in physiological conditions of birds infected with H5N1 HPAI such as fever and provide information by active surveillance to producers about infection before death. These provide data in near real time and earlier detection of infection saves from major losses by on time biosecurity measures after infection, culling of infected birds and prophylactic treatment protocols.

4. TECHNOLOGY FOR REAL TIME ANALYSIS

It is possible for collecting data about bird's activity by surveillance methods used in poultry houses in real time. Real time analysis can be made in action after collection of data by use of machine technology as machine learning tools make it possible to analyze a large collection of data obtained. Algorithms in machine learning can be used to detect disease and behavior activities from the surveillance data (Morota, Ventura, Silva, Koyama, & Fernando, 2018). Moreover, vocalization techniques, robotic surveillance and image analysis can also be used for real time data analysis in disease diagnosis approach in poultry farms.

4.1. Vocalization Techniques

Vocalization analysis is being done in poultry birds to detect weight and age of broiler chicken (Fontana et al., 2017)and in layers it is used to detect production and incidence of pecking in birds. By use of Fisher's discriminate analysis broiler vocalization recorded of infected birds from Clostridium perfringens was compared to healthy bird's vocalization by selecting five features. These five features differentiated healthy birds from infected birds and by their use a neural network was applied to detect the infected birds among healthy birds (Fontana, Tullo, Butterworth, & Guarino, 2015). Moreover it is possible to detect IBV (Infectious Bronchitis Virus) infected chickens recording manually and labeling collected recordings and training a computer algorithm is possible by vocalization analysis (Rizwan et al., 2016) .

4.2. Image Analysis

These techniques are used to collect data in real time by minimal invasiveness using image analysis and optical flow and infrared analysis strategies. These are focused on health, welfare and production status of birds in poultry industry. In image analysis diagnosis of infection is being made by detecting several changes in behavioral patterns of birds such as movement, activity of infected birds different from healthy birds by image analysis (Colles et al., 2016). Moreover change in brightness is measured in optical flow as in case of infection with Campylobacter infection despite being subclinical is detected by optical flow patterns due to changes in chicken movement (Sassi, Averós, & Estevez, 2016) . Infrared thermal imaging technology to detect changes in temperature if bird due to infection or change in diet or environment is used to diagnose in real time the cause and infection by detecting superficial body temperature of birds (Garcia & Caldara, 2014).

5. VACCINATION

Frequent outbreaks in poultry occur due to increased ratio of dense farming practices. An outbreak's mortality and morbidity can result in large financial losses, which can then have a negative effect on the world's food supply chain. Several etiological agents have been isolated from farmed animals, including bacteria such as acute coliform bacillary and chronic tuberculosis, ecto- and endo-parasites, and fungal agents, as well as at least eleven virus species that can be transmitted horizontally, vertically, or both. The most common bacterial cause of infections in poultry farms is Escherichia coli, sometimes known as colibacillosis (Jørgensen et al., 2019) . Recent investigations have concluded that it is frequently a major pathogen, despite its classification as the secondary pathogen in coinfections with other bacteria like Mycoplasma, Gallibacterium, or infectious bronchitis virus, or to certain risk factors including stress and substandard housing (Barbieri et al., 2015).

In chicken husbandry, it is not uncommon for farmed birds to become infected with more than one virus. It has been shown that previous avian respiratory virus infections put birds at risk for developing a secondary bacterial infection (Sid, Benachour, & Rautenschlein, 2015).

Vaccinating chicken farms to control virus outbreaks will reduce the possibility of zoonotic infection, prevent the spread of new infections into wild populations, and prevent the introduction of a wildlife reservoir. One of the primary methods for managing and avoiding viral infection in poultry is mass vaccination. In addition to reducing selection pressure on field virus strains, the creation of broadly protective vaccines against avian viral illnesses will streamline vaccination schedules for commercial farms, resulting in total savings in husbandry expenses as viral outbreaks are a major cause of economic losses (Brown Jordan, Gongora, Hartley, & Oura, 2018). Understanding the methods for enhancing the vaccines' ability to protect against various viral strains is crucial given the rise in newly and re-emerging viral infections in birds. Mass immunization, surveillance, and the physical separation or proactive culling of diseased birds are all ways to stop the spread of disease. Mass vaccination is still one of the key disease prevention strategies advised by authorities worldwide, and it aims to limit interspecies transmission in addition to avoiding financial losses (Roth & Sandbulte, 2021).

5.1. Types of Vaccines:

Different vaccine platforms for various poultry diseases are opted including;

5.1.1. Inactivated Vaccines: These are viral vaccines having lower immunogenicity and are prepared by inactivating cultured viral particles for the purpose of removing infectivity by physical and chemical means such as by ultraviolet gamma radiations and formalin etc. Due to their low immunogenicity they are used in combination with adjuvants such as oil, aluminum hydroxide formulations with booster doses in order to provide long term immunity to birds. These are generally safer to use as compared to other types of vaccines.

5.1.2. Live Attenuated Vaccines: These vaccines are prepared by weakening of the organism responsible for triggering the immune system to produce its consequent antibodies. The organism is weakened so that it may not produce disease for which it is responsible after its administration inside the body. However, host bird might be contracting the mild illness just as a general reaction to vaccine. Attenuated live vaccines are produced in vitro in labs mostly through a procedure of reverse genetics which induces both humoral and cellular immune response in the body (Jorge & Dellagostin, 2017).

5.1.3. Subunit Vaccines: These recombinant vaccines are prepared by fractioning the virus particles usually proteins that are combined with chemical formulations to enhance their protective response in body along with adjuvants. Other than using the whole organism only their proteins are used to induce immunity. These are generally of lower efficacy and are used in a high dose. Mostly these vaccines are administered in booster doses to enhance their efficacy (Dungu & Donadeu, 2021).

5.1.4. Recombinant Vector Vaccines: These vaccines are prepared by using Recombinant DNA technology. Currently, two major viruses are used as vectors to produce recombinant vector vaccines. These include, Fowl pox virus and Turkey Herpes virus with the use of both these virus vectors many vaccines against major diseases such as Avian influenza, Gumboro and Newcastle disease are prepared so far (Hein et al., 2021).

5.1.5. Nucleic Acid Based Vaccines: These vaccines are basically DNA and m RNA based prepared to encode genes in the host cell to produce specific multivalent antigenic immune response by inducing cell mediated immunity in host organism to facilitate cytokine secretion and lymphoproliferation in birds after infection mostly these are prepared as they contain Chitosan nanoparticles as adjuvants which are an excellent tool for passing immunogenic multivalent antigens to Antigen Presenting Cells (APCs) that stimulate protective immune response against infection. Vaccination with plasmid mixture encoding HA from both subtypes of H5 and H7) induced protection against HPAI (Highly Pathogenic Avian Influenza) virus (Hajam, Senevirathne, Hewawaduge, Kim, & Lee, 2020).

6. BIOCHEMICAL FLOCK PROFILING

Biochemical profiles could help in balancing the effects of changes in nutrition, ingredient prices and management on the welfare and production efficiency. A biochemical profile is basically a blood testing procedure used to examine the functional capacity of numerous important organs in poultry, including the liver and kidneys. It can be used to assess a variety of factors, such as metabolic pH and blood gas balance. Samples of blood or other bodily fluids from a representative group of birds are analyzed in order to spot possible health problems and improve flock management. The primary parameters that are measured are,

6.1. Parameters:

- Kidney function tests: Urea, Creatinine
- Electrolytes: Sodium, Potassium, Chloride
- Protein profiles: Albumin, Globulin
- Lipid profiles: Cholesterol, Triglycerides
- Mineral profiles: Calcium, Phosphorus
- Enzyme activities: Alkaline phosphatase, Acid phosphatase, Alanine aminotransferase (ALT), Aspartate aminotransferase (AST) etc.

Scheduling profiling is essential for regularly tracking changes and trends across time. Gather samples for this purpose from a variety of birds, ranging in age, breed, and stage of development. Additionally, use consistent sampling methods to reduce variability and work with a poultry specialist or veterinarian to assess results and create plans of action.

7. CONCLUSION

Although active surveillance is conducted in many of the larger poultry-producing countries, many privately owned broiler producers frequently hire their own private veterinarians and then send samples for disease investigations to private labs. This review identifies knowledge gaps from a pathogen and a country perspective for targeting surveillance activities, but it is unclear whether this lack of data is caused by reluctance to report the presence of disease or a lack of local diagnostic capacity and capability within countries. Poultry farmers may improve their business performance by collecting and analyzing data on health, performance, behavior, and more. Technology is essential in modern flock profiling because it allows for easier monitoring and optimization of all aspects of chicken production. Without a full physical assessment of the flock, it is nearly impossible to give comprehensive and balanced managerial advice for both the individual patient and the flock as a whole. Today, due to complexity in data analysis by active surveillance and machine learning analytical technologies it is possible to gather a large amount of data of larger flocks and determine health and infectious status of birds by retrieving information from that data. It is the need of hour to develop a harmonized system for predicting an outbreak and mitigating the possible damages with data governance and use of latest technology in commercial poultry setups to meet national and international requirement. The private aviculture industry's breeding collection of nondomestic birds is, in many respects, the most significant and underappreciated patient in avian medicine today.

Acknowledgments

None.

Disclosure Statement

No potential conflict of interest was reported by the authors.

Funding Source

The authors received No funding to conduct this study.

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REFERENCES:

Barbieri, N. L., Oliveira, A. L. d., Tejkowski, T. M., Pavanelo, D. B., Matter, L. B., Pinheiro, S. R. S., Brito, B. G. d. (2015). Molecular characterization and clonal relationships among Escherichia coli strains isolated from broiler chickens with colisepticemia. *Foodborne Pathogens and Disease, 12*(1), 74-83. https://doi.org/10.1089/fpd.2014.1815

Ben Sassi, N., Averós, X., & Estevez, I. (2016). Technology and poultry welfare. *Animals, 6*(10), 62. https://doi.org/10.3390/ani6100062

Brown Jordan, A., Gongora, V., Hartley, D., & Oura, C. (2018). A review of eight high-priority, economically important viral pathogens of poultry within the Caribbean region. *Veterinary sciences, 5*(1), 14. https://doi.org/10.3390/vetsci5010014

Colles, F. M., Cain, R. J., Nickson, T., Smith, A. L., Roberts, S. J., Maiden, M. C., . . . Dawkins, M. S. (2016). Monitoring chicken flock behaviour provides early warning of infection by human pathogen Campylobacter. *Proceedings of the Royal Society B: Biological Sciences, 283*(1822), 20152323. https://doi.org/10.1098/rspb.2015.2323

Course, C. E., Boerlin, P., Slavic, D., Vaillancourt, J.-P., & Guerin, M. T. (2021). Factors associated with Salmonella enterica and Escherichia coli during downtime in commercial broiler chicken barns in Ontario. *Poultry Science, 100*(5), 101065. https://doi.org/10.1016/j.psj.2021.101065

Du, X., & Zhou, J. (2018). Application of biosensors to detection of epidemic diseases in animals. *Research in veterinary science, 118*, 444-448. https://doi.org/10.1016/j.rvsc.2018.04.011

Dungu, B., & Donadeu, M. (2021). Veterinary Vaccines. *Gerrit Viljoen*, 49-61. https://doi.org/10.1002/9781119506287

Fontana, I., Tullo, E., Butterworth, A., & Guarino, M. (2015). An innovative approach to predict the growth in intensive poultry farming. *Computers and Electronics in Agriculture, 119*, 178-183. https://doi.org/10.1016/j.compag.2015.10.001

Fontana, I., Tullo, E., Carpentier, L., Berckmans, D., Butterworth, A., Vranken, E., Guarino, M. (2017). Sound analysis to model weight of broiler chickens. *Poultry Science*, *96*(11), 3938-3943. https://doi.org/10.3382/ps/pex215

Garcia, R. G., & Caldara, F. R. (2014). Infrared thermal image for assessing animal health and welfare. J Anim Behav Biometeorol, 2(3), 66-72. http://dx.doi.org/10.14269/2318-1265/jabb.v2n3p66-72

Gopinath, S. C., Tang, T.-H., Chen, Y., Citartan, M., Tominaga, J., & Lakshmipriya, T. (2014). Sensing strategies for influenza surveillance. *Biosensors and Bioelectronics, 61*, 357-369. https://doi.org/10.1016/j.bios.2014.05.024

Hajam, I. A., Senevirathne, A., Hewawaduge, C., Kim, J., & Lee, J. H. (2020). Intranasally administered protein coated chitosan nanoparticles encapsulating influenza H9N2 HA2 and M2e mRNA molecules elicit protective immunity against avian influenza viruses in chickens. *Veterinary research, 51*, 1-17.

Hauck, R., Carrisosa, M., McCrea, B. A., Dormitorio, T., & Macklin, K. S. (2019). Evaluation of next-generation amplicon sequencing to identify Eimeria spp. of chickens. *Avian diseases*, *63*(4), 577-583. https://doi.org/10.1016/j.mimet.2016.02.018

Hein, R., Koopman, R., García, M., Armour, N., Dunn, J. R., Barbosa, T., & Martinez, A. (2021). Review of poultry recombinant vector vaccines. *Avian diseases*, *65*(3), 438-452. https://doi.org/10.1637/0005-2086-65.3.438

Jorge, S., & Dellagostin, O. A. (2017). The development of veterinary vaccines: a review of traditional methods and modern biotechnology approaches. *Biotechnology Research and Innovation, 1*(1), 6-13. https://doi.org/10.1016/j.biori.2017.10.001

Jørgensen, S. L., Stegger, M., Kudirkiene, E., Lilje, B., Poulsen, L. L., Ronco, T., Pedersen, K. (2019). Diversity and population overlap between avian and human Escherichia coli belonging to sequence type 95. *MSphere, 4*(1), e00333-18. https://doi.org/10.1128/msphere.00333-18

Karash, S., Wang, R., Kelso, L., Lu, H., Huang, T. J., & Li, Y. (2016). Rapid detection of avian influenza virus H5N1 in chicken tracheal samples using an impedance aptasensor with gold nanoparticles for signal amplification. *Journal of virological methods, 236*, 147-156. https://doi.org/10.1016/j.jviromet.2016.07.018

Morota, G., Ventura, R. V., Silva, F. F., Koyama, M., & Fernando, S. C. (2018). Big data analytics and precision animal agriculture symposium: Machine learning and data mining advance predictive big data analysis in precision animal agriculture. *Journal of animal science*, *96*(4), 1540-1550. https://doi.org/10.1093/jas/sky014

Neethirajan, S. (2017). Recent advances in wearable sensors for animal health management. *Sensing and Bio-Sensing Research, 12*, 15-29. https://doi.org/10.1016/j.sbsr.2016.11.004

Rizwan, M., Carroll, B. T., Anderson, D. V., Daley, W., Harbert, S., Britton, D. F., & Jackwood, M. W. (2016). *Identifying rale sounds in chickens using audio signals for early disease detection in poultry*. Paper presented at the 2016 IEEE Global Conference on Signal and Information Processing (GlobalSIP).

Roth, J. A., & Sandbulte, M. R. (2021). The role of veterinary vaccines in livestock production, animal health, and public health. *Veterinary vaccines: Principles and applications*, 1-10. https://doi.org/10.1002/9781119506287.ch1

Sassi, N. B., Averós, X., & Estevez, I. (2016). Technology and Poultry Welfare. *Animals 6*, 1-21.

Shriner, S., Root, J., Lutman, M., Kloft, J., VanDalen, K., Sullivan, H., Chandler, S. (2016). Surveillance for highly pathogenic H5 avian influenza virus in synanthropic wildlife associated with poultry farms during an acute outbreak. *Sci Rep 6*, 36237. https://doi.org/10.1038/srep36237

Sid, H., Benachour, K., & Rautenschlein, S. (2015). Co-infection with multiple respiratory pathogens contributes to increased mortality rates in Algerian poultry flocks. *Avian diseases*, *59*(3), 440-446. https://doi.org/10.1637/11063-031615-Case.1

Wolfert, S., Ge, L., Verdouw, C., & Bogaardt, M.-J. (2017). Big data in smart farming–a review. *Agricultural systems, 153*, 69-80. https://doi.org/10.1016/j.agsy.2017.01.023

Zhuang, X., & Zhang, T. (2019). Detection of sick broilers by digital image processing and deep learning. *Biosystems Engineering*, *179*, 106-116. doi:https://doi.org/10.1016/j.biosystemseng.2019.01.003