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Impact of Farm Biosecurity on Broiler Meat Quality and Shelf-Life

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Abstract

From the farm to the customer's plate, bacterial contamination can occur at any point in the food chain, including farm production, live poultry catching and transportation, slaughtering, storage, distribution, handling, and preparation. Farm biosecurity is among the best indicators of broiler meat safety, quality, and shelf-life. By lowering initial contamination and delaying spoilage, farm biosecurity enhances meat safety, and quality (e.g. color, odor, water-holding, cooking loss, and tenderness) and refrigerated shelf-life. It achieves by reducing microbial loads, disease infection and transmission, stress, and antibiotic use. The main pathways leading to microbial contamination are fecal/environmental contaminations, raising surface contamination at slaughter, pre-slaughter stress, affecting post-mortem muscle biochemistry, and antibiotic use, driving the evolution of resistant microbes. Implementing biosecurity and complementary measures significantly reduces microbial contamination and related public health risks.

1. Introduction

Poultry meat is an important source of nutrients and provides many health benefits. It provides consumers with high-quality, affordable protein, low fat, essential vitamins and minerals **(Farrell, 2013).** The biosecurity level of commercial poultry farms can highlight areas for improvement. Improving biosecurity on poultry farms boosts poultry health, increases productivity, and is key to reducing the spread of zoonotic diseases **(Akter *et al.*, 2025).** The key principle for implementing farm biosecurity is to avoid the disease infection and transmission, either between farms or within the farms worldwide, there by safeguarding animal health, public health, and environment

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(Waktole *et al.*, 2023).

2. Biosecurity in Poultry farms

On farms, biosecurity refers to the steps implemented to control the entry and transmission of disease-causing pathogens. These actions are in line with the concepts of bio-containment control, which stops infectious pathogens from infecting the farm. Traffic management which arranges the flow of people and goods, as well as includes housing and personal protection, sanitation which upholds hygienic measures, and disinfection, which are essential components of biosecurity **(Conan *et al.*, 2012).** Effective cleaning and disinfection programs should based on a sequential approach; initially dry cleaning to remove organic material, followed by wet cleaning with detergents to eliminate visible contamination from surfaces; disinfection to inactive pathogenic agents; after which rinsing to remove residual disinfectants. In addition to surface sanitation, comprehensive hygiene programs include biosecurity measures as usage of hygiene locks, the availability of disinfection baths or boot washers, the application of hand hygiene, and cleaning and disinfection of vehicles, equipment and transporting crates entering or leaving the farm premises **(Makovska *et al.*, 2024).**

Biosecurity in poultry production involves health protocols and measures implemented to protect against transmissible infectious agents. These protocols serve as the primary defense against diseases that may compromise food safety, animal welfare, and the economic sustainability of the farm. Commonly implemented biosecurity measures consist of farm sanitation, infrastructure maintenance, efficient cleaning, and using effective equipment disinfectants and procedures **(Tilli *et al.*, 2022).** Biosecurity in poultry farming includes physical, biological, and managerial components aimed at preventing disease transmission **(Mohammed, 2024).** These measures include restricting farm access, sanitizing equipment and vehicles, isolating new flocks, vaccinating birds, and controlling the movement of personnel and animals **(Robertson, 2020; Butucel *et al.*, 2022).** The physical biosecurity programs aim to restrict the entrance or limit the transmission of pathogenic agents that cause infectious diseases, through combination of physical barriers like fences and mesh wire with good practices like footbath use, car wash deep cleaning, and equipment disinfection in the farm **(Aiyedun *et al.*, 2018).** In addition, traffic control, segregation, and sanitation are the three core measures of biosecurity recognized by **Kouam *et al.* (2018).**

Avian influenza outbreaks were substantially related with prior outbreaks on neighboring farms, farmers or workers visiting multiple farms, and farm management by labor or individuals rather than owners. Epidemics on farms were similarly associated with veterinarian visits, which may indicate reporting tendency rather than causality **(Islam *et al.*, 2025).** Therefore, improper biosecurity can lead to the spread of low-pathogenic as well as high-pathogenic avian influenza, decreasing farm production, and increasing the risk of human infection.

Understanding why established biosecurity measures are inconsistently implemented by poultry producers remains a significant challenge. Compliance with biosecurity protocols is influenced by a multifactorial set of elements that extend beyond technical considerations to include economic and psychosocial dimensions. Previous studies have identified several contributors to inadequate biosecurity implementation on poultry farms, including limited training and awareness regarding the importance of biosecurity practices, as well as economic limitations **(Vaillancourt and Carver, 1998).** In addition, insufficient knowledge of disease transmission pathways both within and between farms has been highlighted as a critical barrier **(Cui and Liu, 2016; Delpont *et al.*, 2021).** Behavioral characteristics, particularly those related to responsibility and conscientiousness, have also been shown to affect farmers' adherence to biosecurity measures (**Delpont *et al.*, 2021)**

3. Biosecurity and Microbial Contamination of Carcasses

Poultry meat can become contaminated with foodborne pathogens at any stage of the supply chain, from production to distribution, which often occurs during processing, through contact with equipment, workers, or polluted envi-

ronment. Bacterial levels on poultry carcasses can change throughout various stages of processing **(Wardhana *et al.*, 2021).** Furthermore, poultry meat can be contaminated by a range of microorganisms, including those responsible for spoilage during cold storage, as well as harmful foodborne pathogens **(Salama and Chennaoui, 2024).** Biosecurity is the fundamental component of disease prevention and control in poultry farms, and it encompasses a series of practices designed to minimize the risk of infectious diseases being introduced and spread **(Mallioris *et al*., 2023; Poudel *et al*., 2024).** Infectious diseases have persisted as a result of the increase of chicken production to satisfy the rising demand, which continues to be a significant barrier with detrimental effects. So, biosecurity is one of the primary strategies employed to mitigate this problem. **(Vougat Ngom *et al.*, 2025).**

Biosecurity is a essential preventive measure to lower the risk of enterance of animal infectious agents (external biosecurity), as well as their growth and spread (internal biosecurity) from and within an animal production premises **(Gelaude *et al.*, 2014; OIE, 2019).** Inadequate implementation of biosecurity measures may lead to both symptomatic or asymptomatic disease, which significantly affect the production, profit and long term economic sustainability of the poultry production **(Sharma, 2010).** Poultry farms with lack the implementation of biosecurity principles show significantly higher prevalence of pathogens such as Salmonella spp. **(Messens *et al.*, 2009),** Campylobacter spp. **(Royden, 2021),** and *E. coli* **(Singer *et al.*, 2000).** Therfore, the most effective tool to mitigate the risk of disease introduction between farms and subsequent internal and external spread and transimision is biosecurity **(Van Limbergen *et al.*, 2018).**

Fresh poultry meat is frequently linked to foodborne pathogens as well as spoilage bacteria. Poultry meat contamination by foodborne microorganisms remains a serious public health concern. Human sickness can result from improper handling of raw meat, undercooking, or improper handling of prepared goods **(Salama and Chennaoui, 2024).** Consumption of contaminated poultry meat is the primary source of foodborne illness outbreaks in the USA between 1998 and 2012 **(Anjaria *et al.*, 2024).** Bacteria from the animal microbiome, the slaughterhouse environment, and the equipment used during and after slaughter contaminate carcasses, the cuts that follow, and processed meat products **(Ovuru *et al*., 2024).** Only those bacteria initially present on meat surface, will be able to contribute to the spoilage bacteria. Furthermore, the microbiota diversity declines as the number of microbes rises during storage in comparison to the starting state **(Zhang *et al.*, 2024).**

In recent times, poultry production has been heavily impacted by successive outbreaks of highly pathogenic agents **(EFSA Journal, 2023),** highlighting the urgent need to strengthen disease prevention and control strategies. While biosecurity practices are widely recognized in the poultry sector, evaluating their actual implementation at the farm level remains challenging. The most frequently implemented biosecurity measures declared by the farmers were daily inspection and monitoring of birds, rodent control and feed storage protection **(Souillard *et al.*, 2024).** Implementing suitable biosecurity practices not only control the risk of pathogen enterance to poultry farms, particularly avian influenza virus **(Duvauchelle *et al.*, 2013; Ssematimba *et al.*, 2013; Guinat *et al.*, 2020)** and foodborne zoonotic agents, *e.g.*, *Salmonella* spp. **(Huneau-Salaün *et al.*, 2009; Snow *et al.*, 2010)** and Campylobacter spp. **(Hald *et al.*, 2000),** but also could eliminate the accumelation of antimicrobial residues **(Dhaka *et al.*, 2023).**

The microbiological quality of poultry meat is directly impacted by the introduction and spread of disease-causing organisms in poultry farms, which can be avoided by farm-level biosecurity measures. The risk of infectious diseases is decreased by implementing and monitoring of daily biosecurity protocols. By regulating movement, restricting access, and maintaing proper hygiene; these measures aim to mitigate infectious pathogens from entering and presisting on farms. Together, they eliminate the overall disease transmission risk **(Conan *et al.*, 2012).**

3.1.Temperature sensitivity

Microorganisms can be categorized or grouped according to many factors including their temperature requirements for growth. Although low-temperature storage promotes the growth of psychrophilic and psychrotrophic bacteria **(Kanekar and Kanekar, 2022),** psychrotrophic have the extraordinary capacity to survive at typical refrigeration temperatures and for psychotrophs to thrive as best they can, the temperature must be 20°C or greater. It's crucial to remember, though, that some psychrotrophs might not do well in temperatures between 35°C and 37°C, It appears that it is thrive on chilled meat **(Liu *et al.,* 2021),** but mesophiles can thriving at high temperatures and cannot live or procreate below 5°C to 7°C, whereas they thrive in temperatures between 30°C and 40°C **(Kristjansson and Stetter, 2021).** The total mesophilic aerobic bacteria is a great way to estimate the food safety and quality index **(Fahim, 2020).** Total coliforms might be indirectly linked to fecal pollution, they have long been utilized as markers of microbiological water quality **(Dhatwalia, 2024).** While the presence of faecal coliforms typically implies fecal contamination, some faecal coliforms originate from contaminated workers' hands or from water rich in organic matter, such as industrial effluents from the pulp and paper industry or food production facilities **(Edberg *et al.*, 2000).**

According to numerous investigations, the particular spoilage organisms found in chilled poultry are Enterobacteriaceae, Pseudomonas, *Brochotrix-thermosphacta* **(Al-Nehlawi *et al.*, 2013; Katiyo *et al.*, 2020; Rouger *et al.*, 2017; Wang *et al.*, 2017)** Additionally, **(Yang *et al.*, 2022)** revealed the presence of several novel Enterococcus or Lactobacillus species in poultry meat products, such as *E. viikkiensis*, *E. saigonensis*, and *L. oligofermentans* due to the low levels of fermentable carbohydrates in meat carcasses, spoilage bacteria gain energy by using alternative nutrients. The key psychrotrophic spoilage bacteria in meat carcasses are lipolytic and proteolytic bacteria, because their proliferation can alter sensory attributes like color and flavor **(Wang *et al.*, 2017).** Proper hygiene practices, temperature control, effective processing techniques and efficient storage conditios are very important to minimize bacterial growth and prevent foodborne illnesses **(Salama and Chennaoui, 2024).**

The quality attributes of chilled broiler meat during the shelf-life of 0, 1, 2, 4, 6, 8, and 10 days at 4 °C were clarified in a study by Ju *et al.*, 2025 using conventional techniques for determining physicochemical characteristics, gas chromatography-ion mobility spectrometry, electronic nose, and electronic tongue. The screening and validation of deterioration markers of broiler meat were performed using non-targeted and targeted metabolomics. The findings showed that chilled chicken's texture altered first, then its volatile tastes. When broiler meat is stored, important aldehydes break down and ketones and alcohols rise. The main mechanism affecting the decline in meat quality was found to be purine metabolism, and inosine monophosphate where found to be possible indicators of this decline. This study established a scientific base for quality control and shelf-life prediction of broiler meat through, systematically examined the change pattern of broiler meat during its shelf-life and screened markers that indicative the broiler meat deterioration.

3.2. Oxygen requirements

The way that microorganisms react to oxygen can be used to specify organism grouping, Pseudomonads and other aerobic microbes may effectively use oxygen through a process called respiration. A respiratory chain that includes cytochromes facilitates the substrate oxidation and the subsequent oxygen reduction in this process **(Leevongcharoen *et al.*, 2018).** Morover, facultative anaerobes like Enterobacteriaceae are able to regulate their metabolism according to the oxygen availability (Rincon-**Gamboa *et al.*, 2021).** On the other hand, *Campylobacter jejuni* (coli) and other microaerophilic organisms do best in environments with lower oxygen contents than the atmosphere. The growth of these organisms can actually be inhibited or negatively impacted by the air's oxygen content **(Leevongcharoen *et al.*, 2018).** while Obligatory anaerobes lack the ability to produce catalase and superoxide dismutase, two enzymes necessary for their metabolic activities that neutralize dangerous super-

oxide and hydrogen peroxide radicals **(Lúquez *et al.*, 2021).**

4. Pre-Slaughter Environment on The Farm Level

Poultry meat quality is highly affected by the pre-slaughter environment. Therefore, sequences that happen before slaughtering like crating, transportation, heat stress, shackling and struggling on the shackle line, all have an effect **(Ali *et al.*, 2008).** One of common pre-slaughter treatments and has an adverse impact on meat quality is acute heat stress **(Debut *et al.*, 2003). Also, Shim *et al.* (2006)** stated that heat stress lead to a substantial increase of total cholesterol level in the liver of broiler chicken. Birds under heat stress had more abdominal fat. The first challenges on the shackle line sped the procedure. It increases the rate of pH drop and breast flesh redness. Once more, the lactate level in chicken breast muscle rose as the intensity of the struggle increased. Longer distance birds had lighter flesh than those that stayed put or only traveled a little bit **(Ali *et al.*, 2008).**

Microbial growth is the main cause of poultry meat spoilage and reduced shelf-life. The initial microbial load on broiler carcasses is a significant factor affecting storage stability. Higher initial contamination levels cause meat to spoil more quickly **(EFSA, 2016).** Good biosecurity significantly extends shelf-life by reducing the microbial load on birds before processing. According to **EFSA (2023),** improving biosecurity protocols can extend the shelf-life of chilled broiler meat by three to seven days, depending on the storage environment. Additionally, biosecurity indirectly prolongs shelf-life by improving physiological health, reducing stress-induced meat malformations, and preventing antibiotic-resistant bacterial infection.

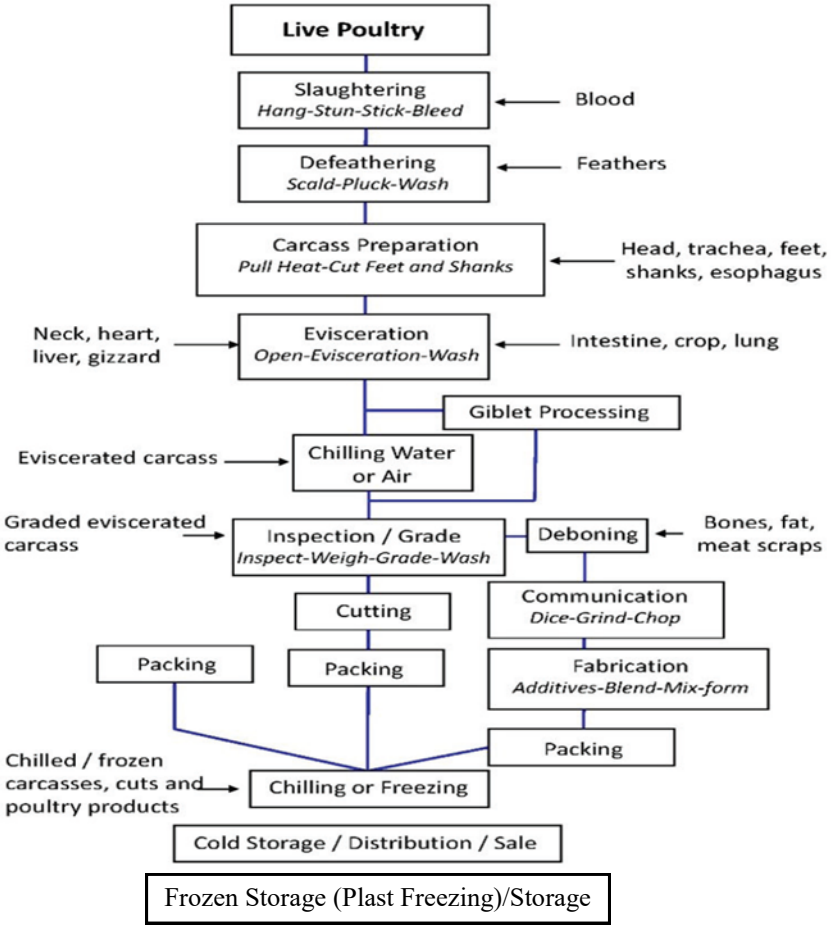


Figure (1). Flow process diagram for chilled and frozen raw whole broiler carcasses, cuts and products **(Hui, 2012).**

5. Slaughter Environment

5.1. Mechanism of meat muscle transformation

Proteins, fats, and minerals make up the majority of raw poultry meat in amounts from 18.4 to 23.4%, 1.3 to 6.0%, and 0.8 to 1.2%, respectively. Dark meat (thigh) has an average fat content of 5-7 g/100 g, while breast meat has a fat content of less than 3 g/100 g **(Farrell, 2013).** Collagen, myosin, and myostroin are the primary ones. Meat get its distinctive red hue from myoglobin, which oxidizes to brown. The amount of lipids varies greatly depending on the animal and the piece **(Pereira and Vicente, 2013).** The initially flexible muscle undergoes numerous changes to become flesh when the animal slaughtered. The panting, rigor mortis, and maturation phases are typically experienced by these changes. The panting phase, also known as the panting state, starts when blood circulation stops, suppressing the oxygen supply and external energy sources (fatty acids, glucose, and amino acids) **(Pearce *et al.*, 2011).**

5.2. Meat pH and Water-Holding Capacity

Meat quality characteristics like tenderness, water-holding capacity, color, juiciness, and shelf-life are directly impacted by pH. Compared to meat with a lower pH, higher pH breast meat has a greater ability to bind water. The pH of broiler meat is determined by the glycogen amount in muscles prior to slaughter and the conversion rate of glycogen to lactic acid following slaughter. Meat's pH can be simply ascertained by color identification. Dark meat color indicates high meat's pH and light meat color indicates low meat's pH **(Anadon, 2002).** The initial pH of the lighter-than-normal fillets was 5.8, their marinating moisture absorption was 6%, their drip loss was 5.88%, and their cooking loss was 34.4%. With an initial pH of 6.02, marinating pick-up of 7.67%, cooking loss of 32.9%, and drip loss of 3.34%, darker-than-normal fillets demonstrated a notable influence on drip loss. Low water-binding capacity in poultry meat has been linked to higher drip loss, cooking loss, cooking duration, storage, and a decrease in softness **(Barbut, 1993).**

5.3. Color, Odor, Texture, and Spoilage Indicators

Meat's color, flavor, juiciness, and tenderness all contribute to its sensory quality. The first quality feature that is noticed while buying meat is its color. Myoglobin, the muscle's oxygen carrier, is the primary pigment that gives meat its color **(Renand *et al.*, 2002).** The muscle physical structure and specifically its acidity level (pH), which alters the product's brightness (more or less light red), are linked to the structural component of color. Less light meat with a higher red intensity is linked to a higher heme iron concentration **(Renand *et al.*, 2002).** The structural and quantitative elements barely alter during conservation. The poultry meat texture is primarily affected by age, genotype, raising system, slaughtering conditions and post-mortem carcass processing techniques which will influence the development of pH and rigor mortis while feeding has insignificant effect **(Baéza *et al.*, 2022).** Unwanted alterations in the color, flavor, and odor of meat are brought on by bacterial growth during preservation **(EFSA, 2016).**

5.4. Lipid oxidation

Essential polyunsaturated fatty acids, particularly x-3 fatty acids, are found in poultry meat. Although there may be detrimental consequences on oxidative stability, it is easier to raise their levels, particularly long-chain polyunsaturated fatty acids, in chicken meat than in other farmed meats **(Farrell, 2013).** A sensory deterioration of the product takes place during the sereactions, leading to customer rejection. Controlling oxidative processes is crucial for the meat business because there is a nutritional loss that results in the production of harmful chemicals. However, despite decades of extensive research, the mechanisms underlying lipid oxidation remain incomplete due to the interactions contributed to the process, as well as the multiple paths and influencing elements **(Domínguez *et al.*, 2019).** In actuality, oxidative processes can be stimulated or inhibited by both inherent (meat composition) and non inherent (processing and preservation circumstances) variables **(Banerjee *et al.*, 2017).** Since fatty acids serve as the primary substrate for the development of lipid oxidation, they are

among the most significant intrinsic factors. However, the development of oxidative processes is determined by the presence of various prooxidant substances, such as metals, prooxidant enzymes, heme-proteins, or antioxidant compounds, such as antioxidant enzymes, vitamins, or peptides **(Králová, 2015).** The promotion of lipid oxidation is greatly influenced by temperature, light, and oxygen **(Wasowicz *et al.*, 2004).** Procedures like chopping, deboning, grinding, or heating, specially in non controlled healthy environment hasten the onset of lipid oxidation **(Cheng, 2016).**

6. Conclusion

Biosecurity is a crucial factor in determining the broiler meat quality and shelf-life, in addition to being a tool for disease prevention. Strong biosecurity stabilizes the pH and color of meat, reduces bacterial contamination, enhances flock health, and postpones meat spoilage. The scientific data clearly show that investing in farm biosecurity leads to higher-quality meat and longer shelf-life, which eventually improves public health and economic sustainability.

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