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Avian Immune System Unveiled: A Comprehensive Prospective

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ABSTRACT

Aim of the Study: This study focuses on the immunological mechanisms of avian species specifically of poultry species, which are vital for global food security. Avian immune responses mechanism is like other animals' immune response mechanism, but they have also developed distinct characteristics that are due to their unique physiology.

Methodology: As this is a review article, it focuses on comprehensive review of all available and possible literature regarding avian immune system including innate immunity, adaptive immunity and over all functioning of immune response.

Findings: The innate immune system serves as the primary defense mechanism, characterized by immediate reactions through physical barriers and cellular components such as macrophages. These innate defenses are promptly activated by pattern recognition receptors that identify pathogen-associated molecular patterns and damage-associated molecular patterns. The bursa of Fabricius plays a pivotal role in humoral immunity by enabling the differentiation of B lymphocytes into plasma cells responsible for antibody production. Conversely, T lymphocytes undergo maturation in the thymus and are vital for cell-mediated immunity. Helper T cells stimulate B cells, while cytotoxic T cells target and eliminate infected or cancerous cells. These processes result in efficient immune defenses, but with limitations on immune gene rearrangements distinct from those in mammals, resulting in variations in B-cell receptor diversity. This limitation may influence vaccine efficacy and increase susceptibility in case of stress or chronic infections.

Conclusion: Avian immunology plays a vital role in vaccination strategies that enhance health management practices in poultry production systems which results in enhanced global food security.

Keywords: Avian Immunity, Innate Immunity, Adaptive Immunity, B cells and T cells, Vaccination Strategies.

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1. INTRODUCTION

The general principles governing the normal operation of the avian and mammalian immune systems are same. An immunological response that involves cellular cooperation, particularly between macrophages, B lymphocytes, and T lymphocytes, is triggered by antigenic stimulation (Wilting et al., 2001). After processing the antigen, macrophages deliver it to the lymphocytes. The main cells that mediate humoral immunity i.e. B lymphocytes that develop into plasma cells and generate antibodies. For cellular immunity the most important components are T lymphocytes (Mehrzad et al., 2024). Using monoclonal reagents, the subpopulations of avian T cells have been seen, and they seem to resemble those of mammalian T cells. The avian and mammalian immune systems operate according to the same general principles. Although research is being done on several other bird species, most notably the turkey, geese and quills, the immune system of the chicken has been studied the most.

2. IMMUNE SYSTEM

Domestic poultry, including ducks, turkeys, and chickens, are essential sources of protein for humans. They get infections from parasites, fungus, viruses, and bacteria. To resist harmful microorganisms, birds are equipped with complex immune systems made up of many organs, cells, and chemicals (Mehrzad et al., 2024). All vertebrate species share the same basic principles of the immune response; however, birds have different immune organs/tissues, cells, and chemicals than mammals. The main lymphoid organs in birds are the bursa of Fabricius, thymus, and bone marrow. The immune cells originate from undifferentiated mesenchyme components in the yolk sac during the embryonic stage, while all other lymphoid organs are secondary (Drayton et al., 2006). The first three days of life and the time before hatching are when those undifferentiated immune cells go to other organs. The lymphoid organs are categorized as primary and secondary after hatching. Here, we talk about the immunological or defensive mechanisms that birds have against invasive microorganisms.

3. ORGANS OF IMMUNITY

3.1. Bursa of Fabricus

In birds, the Bursa of Fabricius is a pouch-like projection situated above the rectum that is joined to the cloaca by a brief duct. There are numerous folds on its inner surface that are home to lymphoid follicles. It has epithelium covering it and is packed with B-lymphocytes that undergo bursa-mediated modulation to develop into terminally differentiated plasma cells that can generate local and circulating antibodies. the BF, a major lymphoid organ, amplifies and develops B-lymphoid progenitors. About 12,000 follicles, including B-lymphocytes, dendritic cells, macrophages, and epithelial cells, are found in the bursa. As the embryo develops, interactions between its many components result in the formation of bursal follicles, into which dendritic cells and B-cell precursors migrate (Glick et al., 1956).

The formation of the specific B-cell repertoire is the BF's primary and most important role. It is essential for the bursa's conversion of stem cells (pre-bursal) into bursal ones up until the fifth week of birth. The development of antibodies and the restoration of bursal morphology are both possible with B cells; this process represents a unique phase in the gradual maturation of avian cells that produce antibodies (Tizard, 2017).

3.2. Thymus

The thymus is a pair of organs with five lobules that are in the neck on either side of the trachea. T cells, an essential biological component of immunity, multiply in the thymus. The thymus is unique in birds, consisting of multiple discrete oval tissue lobes in the neck that are close to the jugular vein and vagus nerve. The thymus's peak activity happens in the very early stages, and its removal is linked to delayed skin reactions and the rejection of allogeneic grafts. It is also strongly related to the erythropoietic function and breeding cycle of birds (Ciriaco et al., 2003). The thymus can be divided structurally into cortical and medulla regions. Its cellular makeup, particularly its lymphocytes in different stages of maturation, and stromal cells, including epithelial cells, dendritic cells, macrophages, and fibroblasts, provide an ideal environment for lymphocyte differentiation and maturation, suggesting a similar mechanism of lymphocyte development in avian and mammalian thymuses (SM et al., 2014).

3.3. Spleen

Despite certain physiological and structural variations, the spleen is a major lymphoid organ and plays a critical role in the immune response in birds, much like in other vertebrates. It also actively participates in hormone and cell-mediated responses and is the main location for lymphocyte development and proliferation. Furthermore, the spleen plays a crucial role in coordinating both innate and adaptive immune responses in birds, underscoring its importance in immunological control. Birds lack lymph nodes, hence the spleen is the main site for a variety of immunological responses, even if their immune responses to systemic antigens are like those of mammals (Vali et al., 2023). Many plasma cells that produce antibodies are found in the bright red pulp of the spleen of birds, especially in the vicinity of major arteries and veins. These cells are then transported throughout the body by the bloodstream.

3.4. Harderian Gland

The Harder's gland, the predominant eye-associated lymphoid tissue/periocular/orbital gland in birds, is essential for the local immunity of the eyes and upper respiratory tract in addition to its lubricating and cleansing duties. In birds, the Harderian gland's location varies very little and stays ventromedial to the eyeball. All the birds under study have comparable innervation and blood supply to the Harderian gland, with the inferior branch of the oculomotor nerve providing innervation and the ophthalmotemporal branch of the external ocular artery providing blood supply (Burns, 1992).

3.5. Lymphatic System

Poultry have a sophisticated network of lymphatic nodes, lymphatic arteries, and the spleen that work together to fight infections. Its main job is to filter lymphatic fluid to get rid of infections. White blood cells, such as B and T lymphocytes, which are essential for the immune response against a variety of (non) infectious pathogens, are then produced or multiplied by the spleen and diffuse lymphoid tissue (Wilting et al., 2001). There are numerous more unknown immunological organoids in birds, such as the heart lymphatic organs, whose structure and functional functions need more research.

4. TYPES OF IMMUNITY:

The defenses of birds against diseases brought on by the invasion of different microbes and poisons are extremely robust. In avian species immunity is divided into two type i.e., innate immunity (humoral immune response) and acquired immunity known as cell mediated immunity. The inherent ability to fend off disease is known as innate immunity (Mehrzad et al., 2024). It consists of a sequence of events that begin as soon as the invading pathogen is recognized by the host's non-specific defenses, which identify it through its outer surface proteins (antigens). Almost 98% of all multicellular species have only an innate immune system to protect them against infections, although all multicellular organisms have some form of innate defense (Trenchi, 2013).

4.1. INNATE IMMUNITY

Birds' initial line of defense against infections is their innate immune system, a sophisticated system with cellular, chemical, and physical components. Every day, host cells are exposed to a lot of pathogens. These infections do not have a significant impact on birds despite this exposure (Wang et al., 2022). The birds' innate immune system initiates early defense response which is the main cause of this. An individual's initial line of defense against illnesses is their innate immunity. This form of immunity includes several non-specific disease response mechanisms for example respiratory cilia, normal microflora, body temperature, genetic component, and anatomical features. Innate immunity also starts tissue repair and aids in the elimination of damaged cells. Activating adaptive immune responses is one of innate immunity's other vital functions (Hincke et al., 2019). The innate immune system's cells and molecules mature before the adaptive immune system's cells. Polymorphonuclear cells continue to proliferate throughout the body, particularly in the intestine, during the first two weeks following hatching. By identifying conserved microorganism patterns and markers of host cellular damage known as pathogen-associated molecular patterns (PAMPs) and damage-associated molecular patterns (DAMPs), innate immunity offers prompt protection (Zindel & Kubes, 2020). Most innate immune responses are not pathogen-specific; they work similarly against different infections. The innate immune system uses the complement system, phagocytes, non-phagocytic innate immune cells, bacteriolytic enzymes, and antimicrobial peptides to ward off microbes.

4.1.1. Components of First Line of Defense:

a) **Genetic components:** Some species of birds lack specific genetic components that are mandatory to initiate the infection for instance lymphoid leukosis is resistant in many strains of chickens because they are devoid of the cell membrane receptor molecules required for the glycoproteins in the alpha retrovirus envelope (Rehman et al., 2021).

b) **Body temperature:** The chicken's elevated body temperature protects it against multiple diseases for example, poultry typically do not suffer blackleg disease, unlike cattle, since the bacteria that causes the disease cannot survive at the higher body temperature of poultry. This illness could develop if the chicken's body temperature is decreased.

c) **Anatomical features:** Many pathogens are trapped in mucus membranes or are unable to pass through intact body membranes like skin and mucous membranes for example the integrity of the body coverings is compromised by certain dietary deficits like a biotin deficiency, injuries, or infectious disorders, which permits disease organisms to infiltrate.

d) **Normal microflora:** The microbial population in the skin and gut is typically dense and constant. Because of this steady microflora, invasive disease organisms are unable to establish themselves. The balance of the microflora might be upset by improper antibiotic use or inadequate sanitation.

e) **Respiratory tract cilia:** Cilia are tiny, hair-like projections that border parts of the respiratory tract and are responsible for clearing debris and disease organisms. The ciliary system may become overworked and ineffectual if the air in the chicken house is low quality because of high dust or ammonia levels (Reese, Dalamani, & Kaspers, 2006).

4.1.2 Components of Innate Immune System:

Some of the main components of innate immune system are discussed below:

a) **Defensins:** Defensins are a class of tiny, cystine-rich peptides that have antibacterial qualities and can combat enveloped viruses, bacteria, fungi, and protozoa. They can be found in both plants and mammals. They differ in structure even though they have numerous similarities (Liu et al., 2018). The range of length for these cystine-rich peptides is 18–45 amino acids. They are made up of cationic and hydrophobic amino acid residues. There are almost three main types of defensins in turkey while 13 in chicken (Selsted & Ouellette, 2005).

b) **Toll like receptors:** Within the family of pattern recognition receptor (PRR) is the subfamily known as transmembrane toll-like receptors (TLRs) (Ciraci & Lamont, 2011). Drosophila was the first to be found to have them. TLRs were expressed by immune and non-immune cells, including dendritic cells, macrophages, lymphocytes, and epithelial cells. TLRs identify PAMPs, same as other PRRs, histones, extracellular ATP and other chemicals that show anomalous events in the host cells that point to cell damage (Philbin et al., 2005).

c) **Antigen Presenting Cells:** Antigen-presenting cells (APCs), including dendritic cells and macrophages, are activated and matured when PAMPs or DAMPs attach to TLRs. These cells are arranged differently to monitor pathogen invasion. After developing, these cells release cytokines that promote pro-inflammatory reactions and raise TNF-α, IL-1, and IL-6 gene expression (Mantovani, Dinarello, Molgora, & Garlanda, 2019). Furthermore, immature T lymphocytes are exposed to antigens by APCs, which causes them to differentiate into effector T cells. The avian TLR family is made up of ten structurally and functionally distinct TLRs that are intended to recognize various ligands. TLR1A and B, TLR2A and B, TLR3, TLR4, TLR5, TLR7, TLR15, and TLR21 are among them. There are two chTLRs known to exist that have no analogs in mammalian TLRs: chTLR15 and chTLR21 (Jie et al., 2013).The immune system gathers data about the antigenic environment through a process known as antigen presentation. Traditionally, this technique is how B- and T cells detect environmental antigens. Antigen presentation may result in tolerance or lymphocyte activation, depending on the situation. Antigen presentation, for instance, might cause tolerance to self-antigens or stimulate lymphocytes to react to a pathogen challenge (Wu & Kaiser, 2011). APCs attached to either major histocompatibility complex (MHC) class I or class II molecules express the peptides that are produced when an antigen is processed either endogenously or exogenously. Like mammals, nearly every cell in birds has MHC-I heterodimer molecules expressed on the outside. Peptides produced from endogenous antigens extracted from the nucleus or cytoplasm are expressed by means of the specific MHC peptide binding cleft (Grygiel-Górniak, Limphaibool, & Puszczewicz, 2019).

Dendritic cells:

T cell activation in mixed lymphocyte responses (MLRs) requires dendritic cells. It has recently been recognized that the initial DCs found belong to a unique cell lineage that, depending on their ontogeny, can be distinguished from related mononuclear phagocyte system (MPS) cells (Kushwah & Hu, 2011). To differentiate them from other cell lineages such as monocyte-derived DCs or bone marrow-derived DCs, these cells are now referred to as "classical" or "conventional" cDCs. The two subsets of mammalian cDCs, cDC1 and cDC2, each have distinct roles to play. The cDC1 subset oversees presenting antigens cross-presentation and triggering Th1 responses, while the cDC2 subset is focused on triggering Th2 (T helper 2) and Th17 (T helper 17) immune responses. DCs, macrophages, and professional antigen-presenting cells are incredibly versatile and adaptable plus these three are avian professional APCs. They perform a variety of tasks, including endocytosis and exocytosis, foreign material degradation, cytokine production, and antigen presentation to naive T-lymphocytes. These processes take place in both diseased and healthy circumstances. It is well recognized that DCs and macrophages share a hematopoietic stem cell progenitor that expresses CD45+ (See et al., 2017).

Macrophages:

Because they function primarily as APCs, macrophages are essential for both innate immune responses and the development of adaptive immunity, making them vital for defending birds against microbial infections. To eradicate the invasive pathogens and communicate with other immune cells to initiate a suitable response to the infection, they have the ability to ingest bacteria and generate wide antimicrobial chemicals including reactive oxygen species (ROS), nitric oxide (NO), and cytokines (Alam et al., 2002). Natural killer cells (NK) and T lymphocytes produce IFN-γ, which causes macrophages to release NO, forming peroxynitrite, a powerful antimicrobial oxidant (Li, Xue, Geng, & Chen, 2012).

The binding of microbes prior to macrophage phagocytosis requires receptor-mediated recognition. Macrophages have a variety of receptor systems that aid in both opsonic and nonopsonic recognition, including scavenger receptors, complement receptors, Fc receptors, C-type lectins, and mannose receptors. Particles are internalized into phagosomes during phagocytosis, and these phagosomes then combine with lysosomes to form phagolysosomes (Withanage, Mastroeni, Brooks, Maskell, & McConnell, 2005). Acid phosphatase and β-glucuronidase are among the antimicrobial proteins and enzymes found in lysosomes. Mature macrophages express enzymes at high constitutive levels, whereas myeloblasts express them at low levels.

Heterophils:

Heterophils belong to the granulocyte subtype. When fully grown, their nucleus is lobed, and their cytoplasm contains eosinophilic granules. Heterophils are the ones that kill germs. Heterophils can be categorized as harmful, immature, or mature. When the severity of an illness increases, toxic heterophils exhibit alterations (Farnell et al., 2003).

Like neutrophils in animals and humans, heterophils in chickens are essential for protecting the body against inflammatory and pathological diseases. Many heterophils are secreted from the spleen in the first seven days of hatching, while the innate immune system is still developing. However, after that, their numbers start to decrease (Wells, Lowry, Deloach, & Kogut, 1998). Therefore, in comparison to older hens, heterophils' function is likewise restricted. As a result, in the early post-hatch phase, young chicks are more susceptible to illnesses (Genovese et al., 2000).

Heterophils in chickens produce chromatin-like molecules and granules in response to stimulation, forming extracellular traps. DNA, histone-DNA complexes, and elastase from heterophil cytoplasmic granules are all present in these traps. It is microbial compounds that promote degranulation. The body of the bird releases cytokines including interleukin (IL)-6, IL-8, and IL-18 to combat diseases when it is exposed to them. A large population of heterophils, which are primed and efficient in reacting to infections, may result from this enhanced synthesis of cytokine RNAs and proteins. The generation of local chemoattractants determines how many heterophils are drawn to the infection site (Kogut, 2002).

d) Acute Phase Proteins: Acute-phase proteins (APP), one of the most important subsets of innate immunity, are generally defined as proteins that experience a change in plasma concentrations of at least 25% during an acute-phase response (APR). Depending on whether the protein levels rise or fall, this response is categorized as either positive or negative APP. Although the liver is where chicken APPs are mostly produced, APP mRNA has also been found in other healthy chicken tissues (Eckersall & Bell, 2010).

Chicken C-reactive proteins (CRPs):

Another essential part of the innate immune system are CRPs, which are cyclic oligomers that bind to phosphocholine in a way that is dependent on Ca2+. It is essential for preventing autoimmunity, removing damaged tissue, controlling the inflammatory response, and defending against infection (Sproston & Ashworth, 2018). According to a report, Ascaridia galli-infected hens showed a modest rise in CRPs in their spleen at the mRNA level (Dalgaard et al., 2015).

Fibrinogen:

Fibrinogen (FB), which serves as a substrate for the synthesis of fibrin, is important for physioimmunological hemostasis. By offering a matrix for cells linked to inflammation to migrate through, it also aids in tissue repair. The plasma levels of FB in hens more than doubled during an APR induced by turpentine (Davalos & Akassoglou, 2012). Similarly, it is evident that infection with E. coli or E. tenella raises plasma FB levels; this broad, non-specific immune response may aid in preventing the spread of infection or invasive pathogen (Georgieva et al., 2010).

Ovotransferrin:

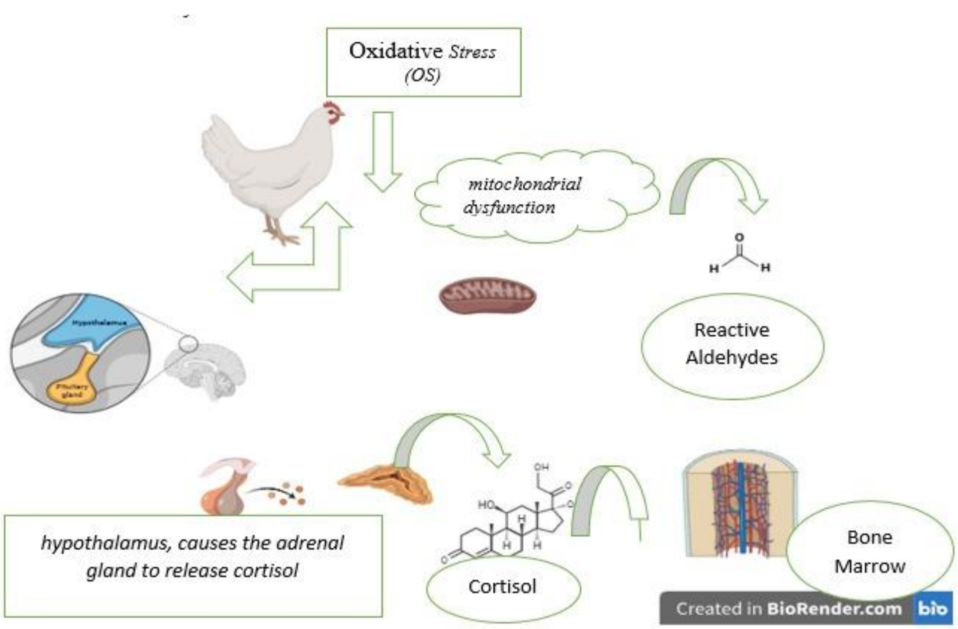
OVT is an only soluble glycoprotein belonging to the transferrin family found in chickens. Although the glycosylation of this protein varies, it is present in both plasma and eggs. In contrast to mammals, transferrin is a positive APP in chickens, and an APR increases both its mRNA and protein production (Giansanti, Leboffe, Pitari, Ippoliti, & Antonini, 2012). This is especially true when OVT and APR are overexpressed in the oviduct at the same time. After the challenge with ILTV, E. coli, FPV, ARV, IBDV, and IBV, the hens' plasma levels of OVT and APP rose seven days later (Williams, 1968).

4.1.3. Inflammation:

Inflammation is a key element of innate immunity and is required for proper classical immunity. When immunogenic material is introduced into an animal, a complex set of local and systemic changes in circulation, metabolism, endocrine profiles, neurologic and vascular parameters, and numerous cellular processes take place instantly. These changes are referred to as the inflammatory response (Harmon, 1998). Immunogens are usually administered intraperitoneally or subcutaneously to birds used in research.

When the immunogen is recognized, a variety of local inflammatory mediators are produced, which initiates the first step of the inflammatory response. In response to chemotactic stimuli, phagocytic cells migrate from the bloodstream and attach to endothelial cells in the venules (Van Loo & Bertrand, 2023). Phagocytes are fully activated when they are stimulated by local inflammatory mediators and the immunogen's detection. They consume and eliminate the invasive pathogen, causing the inflammatory site to release ROS and hydrolytic enzymes.

Phagocytic cells, especially macrophages, release cytokines that are essential for coordinating the systemic acute phase response and attracting and activating particular elements of the traditionally acquired immune responses, including lymphocytes (Genovese et al., 2000). Furthermore, chicken peripheral blood adherent cells trigger humoral and cellular immune responses by presenting antigens to T-cells in the context of molecules encoded by MHC II.



Oxidative stress (OS) in birds was caused by stressors. a) This route causes mitochondrial dysfunction and a rise in serum ROS (cytotoxic chemicals) like OH-, O2-, and H2O2. Then, apoptosis and necrosis result from a decrease in the energy needed by cells. MDA, which is created when lipid peroxidation in the cell membrane occurs after OS, is one of the elements that can show OS in cells. b) Stress also affects the hypothalamus, which in turn causes the adrenal gland to release cortisol. Known for its ability to down-regulate immune cells, cortisol plays a variety of roles in immunity. Cortisol causes lymphocytes to hominate and neutrophils to migrate to the bone marrow. It suppresses inflammation early on by preventing the synthesis of pro-inflammatory cytokines such TNF-α, IL-1, and IL-6. However, if the stress condition persists (appearance of stable chronic stress), resistance to the corticosteroid may manifest. Eventually, this process results in immunosuppression and increased vulnerability to both infectious and non-infectious avian diseases. MDA stands for malondialdehyde, ROS for reactive oxygen species, and PUFA for polyunsaturated fatty acids (Adapted from Mehrzad et al., 2024).

4.2. ADAPTIVE IMMUNITY:

Chickens' immune systems have evolved several defense mechanisms to fend off a wide range of infections. Chickens have different immune genes, chemicals, cells, and tissues than mammals, even though the basic concepts of the immune response and environments are the same for all vertebrate species. This includes features of innate immunity such cellular and soluble components prepared to eliminate invasive infections as well as physical and chemical barriers that keep the pathogen out. The immune system is a sophisticated network that uses a wide range of elements to identify and get rid of different infections. It finds and eliminates disease-causing substances using cells, molecules, and organs. The humoral and cell-mediated arms of the avian immune system work together to protect against pathogens and avoid illness. Nevertheless, several bird conditions can affect one or both arms, increasing the bird's susceptibility to numerous illnesses and causing either temporary or chronic immunosuppression.

Despite its great effectiveness, innate immunity is unable to produce immunological memory or elicit immune responses. To protect against specific invasive pathogens and develop memory in a targeted manner, adaptive immunity is required. This results in the pathogen's eradication and offers defense against it in the future. For this reason, avian medicine research and development has significantly advanced vaccinations and vaccinology (Mantovani et al., 2019). Like mammals, the processing and presentation of antigens initiates the adaptive immune response in chickens.

The immune system of the host then reacts by starting either a cell-mediated response or a humoral response (The manufacture of antibodies). Specificity and memory are two traits of these reactions, which are generated by T- and B cells and are essential for a successful vaccination. The immune system of chickens is made up of several immune organs, tissues, cells, and chemicals that work together to provide the right immune responses and immunological memory.

4.2.3. Immunoglobins:

Immune system depends heavily on immunoglobulins, commonly referred to as antibodies. They are made by B cells and have a special three-dimensional form that enables them to bind to foreign substances only. To eradicate the infection, this interaction sends a signal to other immune cells and molecules. Effective production methods are required because of their significance in biomedical and biotechnological applications. Essential proteins called immunoglobulins have a big impact on the adaptive immune response.

The most efficient way for antibodies to eliminate antigens from the bloodstream and secretions is outside of cells. An antibody's interaction with an antigen triggers defense systems against invasive microorganisms. These methods include coating, clumping, or precipitating the antigen more effectively and quickly, mostly by phagocytes (opsonization, neutralization, and restricting the spread), as well as directly activating the classical complement pathway on the antigen (Olarte et al., 2011).

Antibodies can aid in the removal of potentially malignant or contaminated cells. This mechanism is known as cellular cytotoxicity that is dependent on antibodies. By binding to the target cell's antigen with its antigen-binding parts and to the killer cells' Fc receptors with its Fc section, the antibody establishes a connection between the target cell and the killer cells. The killer cell is activated, and the target cell is destroyed as a result of this antibody-mediated connection between the killer and the target cell (Kovacs-Nolan & Mine, 2004).

Three classes of avian immunoglobulins that resemble mammalian IgM, IgA, and IgG have been discovered by researchers using immunocytochemical and genetic methods. The most prevalent B-cell antigen receptor and the first isotype to be produced during embryonic development is chicken IgM. Chicken IgM functions and is structurally like its mammalian equivalent. Like mammals, IgM is the most common isotype generated during the humoral response, which is usually transient, following initial exposure to a novel antigen. IgM, however, can continue to function for several weeks in situations involving a persistent bacterial infection, such as Bordetella avium in Turkey (Reynaud et al., 1985).

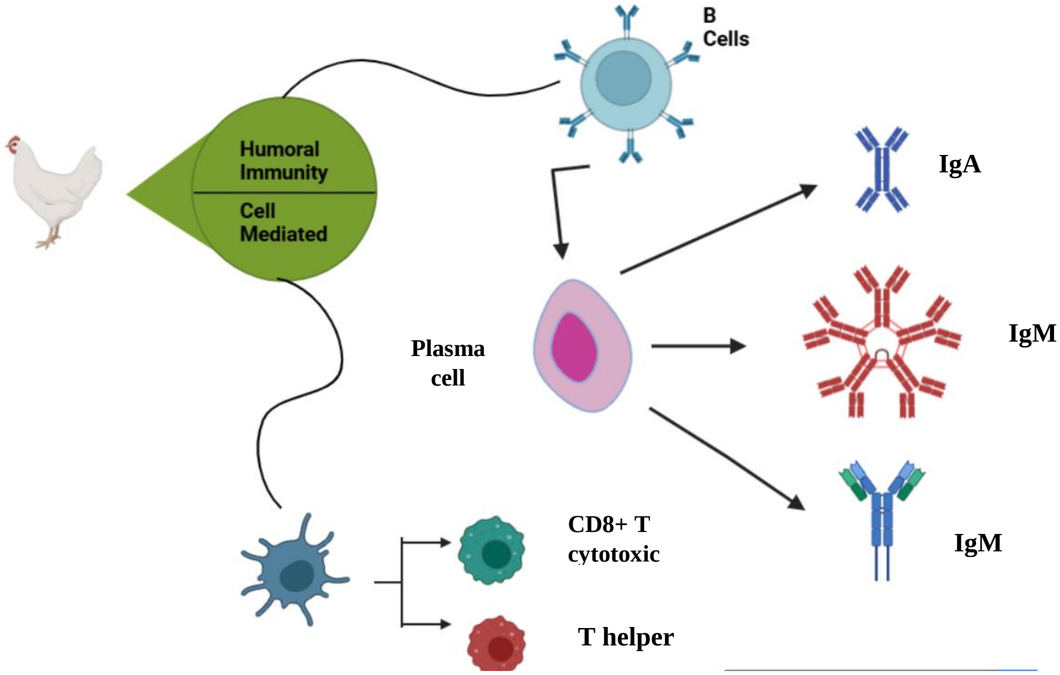
One kind of avian immunoglobulin that is comparable to mammalian IgG and IgE is called IgY (nearly similar to IgG). The major form of immunoglobulin in sera and egg yolk is IgY, which is the principal isotype produced in the secondary antibody response and comes after IgM in the primary antibody response.The longer H chain in the chicken molecule is the primary distinction between the mammalian homolog and chicken IgY. Mammalian IgG has four domains, but avian IgY has five (V, C1–C4). Although its evolutionary origins are uncertain, IgA is found in all bird species, similar to mammals, according to molecular genetic evidence from chicken and duck. In chicken secretions, particularly bile, a structurally and functionally similar version of mammalian IgA has been found. It is widely acknowledged that there is no avian counterpart for Igδ, with the majority of chicken B cells producing IgM, despite some early reports of a chicken homolog of IgD on the surface of chicken lymphocytes (Parvari et al., 1988).

Compared to mammals, chickens exhibit markedly distinct B-cell development and variety creation. Because the rearrangement of Igs genes only happens once during early embryonic development rather than continuously, the diversity of B-cell receptors in chickens is restricted.

4.2.4. Cell Mediated Immunity:

One kind of immune response known as "cell-mediated immunity" is eliminating foreign agents, such as viruses, from infected cells. This is accomplished by effector cells (like activated T-cells) coming into direct contact with target cells; T lymphocytes, commonly referred to as T-cells, are essential for cell-mediated immunity. They belong to two main classes: helper T-cells, which control and guide the reactions of other effector cells, such as B-cells or macrophages, by producing chemical signal molecules, and cytotoxic T-cells, which have the ability to kill tumor or infected cells directly. Additionally, lymphocytes serve as memory cells for the immune system, remembering information about an antigen exposure and triggering a stronger and quicker secondary immune response when the same antigen is encountered again.

A subset of T cells known as T helper (Th) cells is essential for adaptive immunity in both mammals and birds. On their surface, these cells often express CD4 molecules. When Th cells use their TCR to identify a particular antigen, they release soluble substances like cytokines and express molecules on the cell surface that give innate and adaptive immune cells vital activation. There are two varieties of Th cells seen in various animals. While type-2 Th (Th2) cells prefer a humoral response, type-1 Th (Th1) cells guide the adaptive immune response to a cell-mediated response. But after T helper immune cells are activated in rejoinder to antigens present in interacellular environment, the effector pathways that Th cells start that result in the antigen or target cell being destroyed seem to be quite similar in mammals and poultry.



The humoral and cellular arms, the two functional components of the avian immune system, cooperate to ward off dangerous infections and disease-causing microbes. Each of these two arms is also made up of different parts. A) The components of humoral immunity, which primarily consist of three major groups of antibodies in birds. B) Cell-mediated immunity and its constituents, primarily various T cell and cytokine types (Adapted from Mehrzad et al., 2024).

5. CONCLUSION

The avian immune system is a complex, yet basic defense system specifically designed to protect birds against harmful pathogens, while also incorporating fundamental principle seen in mammalian immunity. In this discussion, we examine both the innate and acquired immunity in birds, focusing on poultry which plays an increasingly crucial role in ensuring human food security. Intrinsic immunity acts as the primary defense against infections in birds, characterized by immediate responses involving physical barriers, antimicrobial peptides like defensins, molecular pattern recognition receptors, and cellular components including heterophils and neutrophils. Birds have evolved unique anatomical adaptations to prevent infections, such as their respiratory system with cilia that trap pathogens and their higher body temperature which inhibits the growth of certain bacteria. Rapid immune responses are initiated through the activation of pattern recognition receptors (PRRs), particularly toll-like receptors (TLRs), by pathogen-associated molecular patterns (PAMPs) and damage-associated molecular patterns (DAMPs. These mechanisms illustrate the dual role of intrinsic immunity in eliminating invading organisms and triggering subsequent acquired responses. The coordinated efforts of B and T cells drive acquired immunity in birds. B lymphocytes primarily mature in the bursa of Fabricius, a bird-specific organ, and evolve into plasma cells that generate antibodies crucial for humoral immunity. Avian immunoglobulins (IgM, IgY like IgG, and IgA) function to mammalian antibodies but possess distinct structural properties enabling effective pathogen neutralization within specific contexts. On the other hand, T lymphocytes originate from maturation in the thymus, acquiring vital functions for cell-mediated responses. Helper T cells play a key role in activating B cells and cytotoxic T lymphocytes through cytokine signaling pathways. Despite the advanced mechanisms assisting poultry in mounting substantial immune defenses against infections, limitations arise from divergent immune gene rearrangements compared to mammals, resulting in reduced diversity of B-cell receptors. This limitation may impact vaccine efficacy or increase susceptibility under certain stress conditions or during prolonged infections.

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