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REVIEW ARTICLE

Infectious Bursal Disease: Distribution, Pathogenesis and Pathology

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A B S T R A C T

Infectious bursal disease (IBD) or Gumboro disease is caused by the genera *Avibirnavirus* and the family *Birnaviridae.* For the last 66 years, this disease has been causing huge morbidity and mortality leading to huge economic losses throughout the world. For this review, we collected data from PubMed, CNKI, and Google Scholar, especially for the last decade. Articles containing significant information were thrashed, extracted, and information being presented. IBD virus (IBDV) could be attenuated, virulent (vIBDV), and very virulent (vvIBDV). The host range is very wide including chickens, turkeys, Baltic ducks, pigeons, speckled pigeons, Herring gulls, ostriches, pied cordon blues, laughing doves, Antarctic penguins, and sparrows. The incubation period is very short, i.e., 2-3 days. The virus occurs worldwide, and prevalence varies from 8 to 100%. IBDV has a great affinity with lymphatic tissues. This disease is characterized by lesions of bursal hemorrhagic and inflamed lesions followed by atrophy thus leading to immunosuppression. Effective vaccination programs and strict biosecurity measures are mandatory for its prevention and control. The starring role of wild birds in the epidemiology of the IBD needs to be clarified as wild birds have indirect or direct contact with commercial chicken rearing. We concluded that infectious bursal disease is still a havoc in the poultry industry throughout the world. Vaccination is a successful tool to control and inhibit IBD. Vaccination failure could occur; however, farmers' education is necessary for successful vaccination and disease prevention/control.

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INTRODUCTION

Commercial poultry production in Pakistan started in the 1960′s and has been playing a key role in decreasing the difference between the demand and supply of animal protein as well as providing an efficient source of income at a small scale (Gul and Alsayeqh, 2022). The poultry industry is an important part of the livestock sector and affords employment chances to over 1.5 million people in Pakistan. This sector has undergone extraordinary growth (7.3% annual growth rate) with investments of more than Rs 1,056 billion (Anonymous, 2022-2023).

Poultry meat is a cheap source of rich proteins (Akhtar *et al.*, 2023), however, so many diseases are hampering it such as bacterial, viral, parasitic, or fungal in origin (Mehmood *et al.*, 2020; Lebdah *et al.*, 2022; Ahmed *et al.*, 2022; Raza *et al.*, 2022; Tchoupou-Tchoupou *et al.* 2022; Bastamy *et al.*, 2022; Ahmed *et al.*, 2023; Du *et al.*, 2023; Mehnaz *et al.*, 2023; Qadir and Irum, 2023). Poultry farming is facing complicated disease complexes out of which Infectious bursal disease possesses an important place around the globe (Dey *et al.*, 2019).

Infectious bursal disease (IBD) or Gumboro disease, among the top five poultry diseases, has been a socio-economically important, and immunosuppressive disease of the poultry industry throughout the world (Orakpoghenor *et al.*, 2020; Kapoor *et al.*, 2022; Adino and Bayu, 2022; Shah *et al.*, 2022; Zhang and Zheng, 2022; Hayajneh and Araj, 2023). In 1957, it was reported for the first time in broiler flocks around Gumboro, Delaware, USA (Kegne and Chanie, 2014; Liew *et al.*, 2016; Adino and Bayu, 2022; Zhang *et al.*, 2022). The disease is acute and also an extremely infectious and transmissible disease of poultry caused by IBD virus (IBDV) (Mwenda *et al.*, 2018; Orakpoghenor *et al.*, 2020). IBD is characterized by lesions in the FB and atrophy of the FB, which ultimately leads to immunosuppression in birds between the ages of 3 weeks to 3 months (Orakpoghenor *et al.*, 2020). Mortality due to IBD has been reported to be the highest (53.9%) during 3-4 weeks of age followed by 18.3, 17.9, 7.4, and 2.5% in 2-3, 6-7, 8-9, and ≥10 weeks of age (Fig. 1). The etiological agent, IBDV is a non-enveloped icosahedral double-stranded RNA virus with a bi-segmented genome. IBDV belongs to the genera *Avibirnavirus* and the family *Birnaviridae* (Baxendale, 2002; Jackwood *et al.*, 2018; Ferrero *et al.*, 2021; Nooruzzaman *et al.*, 2022; Adino and Bayu, 2022). The IBDV is a split dsRNA genome (segments A and B) packed into a single-virus particle with a diameter of 70nm (Escaffre *et al.*, 2013). Five proteins in IBDV have been identified. These proteins are called VP1-VP5 (Mirbagheri *et al.*, 2020; Shah *et al.*, 2022). IBDV displays discriminatory tropism for lymphoid tissue and has affinity for immature B lymphocytes (Mwenda *et al.*, 2018). The IBDV has been reported to destroy lymphoid tissues which then results in the diminution of lymphoid tissues in the FB in birds (AHA, 2009).

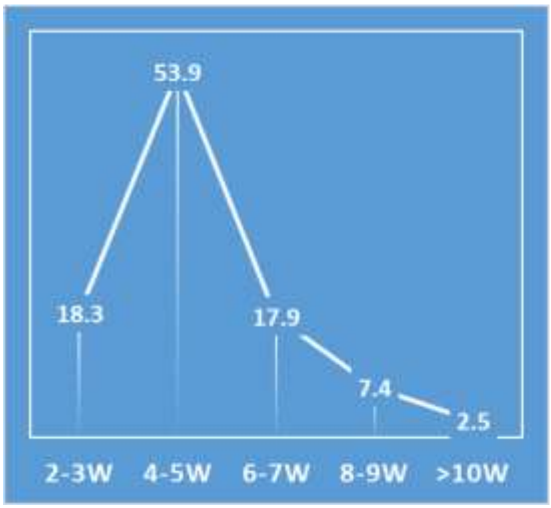

Fig. 1: Age-wise mortality (%) in broiler chicks (Badau *et al.*, 2023).

Serotypes of IBDV: There are two serotypes of IBDV (1 and 2) and have substantial antigenic distinctions within the serotype separately (Jackwood *et al.*, 2018). It is reported that serotype 1 is only pathogenic to poultry chicks. Based on antigenicity, serotype 1 is divided into classical and variant. As per pathogenicity, IBDV can be attenuated, virulent (vIBDV), and very virulent (vvIBDV) (Jackwood *et al.*, 2018). vvIBDV infections (highly virulent IBD virus) are characterized as the per-acute onset of severe clinical disease with extreme mortality (Van den Berg *et al.* 1991). The tendencies of mortality differ within strains of serotype 1 IBDV ranging from zero deaths in variant strains. Classical strains render about 20% mortality (Müller *et al.*, 2003), whereas vvIBDV leads to more than 50% mortality (Escaffre *et al.*, 2013). Although these new serotype 1 viruses have enhanced virulence and have the ability to break existing maternal immunity and are antigenically parallel to the classic strains of IBDV (Arega, 2018). The occurrence of new variants of IBDV can endanger poultry health as well as production worldwide rendering huge financial fatalities while IBDV serotype 2 is naturally avirulent, thus, clinical disease in turkeys and chickens is not produced (Motohiko *et al.*, 1998). Serotype 1 IBDV infection has been found in wild birds, thus, as reservoirs wild birds can play a role in the spread of IBDV (Gilchrist, 2005). It is documented that strains of vvIBDV promptly dispersed to every poultry-producing country, except Australia, Canada, New Zealand, and Mexico (van den Berg, 2000; Arega, 2018).

Host range of IBDV: It is reported that IBDV is host specific. Natural hosts of IBDV are turkeys and chicks (Mosad *et al.*, 2020; Bakacs *et al.*, 2023). Other than chickens and turkeys, IBDV infection has been tested in Baltic ducks, pigeons, speckled pigeons, Herring gulls, ostriches, pied cordon blues, laughing doves, Antarctic penguins, and sparrows (Gardner *et al.*, 1997; Hollmen *et al.*, 2000; AHA, 2009; Adamu *et al.*, 2017; Orakpoghenor *et al.*, 2020; Kapoor *et al.*, 2022; Behboudi, 2022; Samad *et al.*, 2022). However, IBDV inoculation experimentally to pheasants, quails, and partridges did not show any signs, symptoms, or lesions (Van den Berg *et al.*, 2001; Xu *et al.*, 2019). In several other birds, IBDV or IBDV-specific Abs have been reported, such as in pigeons, village weavers, coturnix quail, pheasants, shearwaters, magpie geese, common noddy, soothy terns, silver gulls and black ducks (McFerran, 1993; Behboudi, 2022).

In wild birds, indirect IBDV infection can occur via foraging of infected dead birds, exposure to polluted water, or contact with contaminated materials of conjunctival or respiratory membranes (Orakpoghenor *et al.*, 2020). This is boosted by unhindered connections between poultry and free-living wild birds (AHA, 2009; Orakpoghenor *et al.*, 2020).

IBD Prevalence and Distribution: The virus occurs worldwide (Fig. 2; Table 1) and prevalence varies from 8 to 100% (Eregae *et al.*, 2014; Zachar *et al.*, 2016; Khan *et al.*, 2017; Moryani *et al.*, 2020; Sajid *et al.*, 2021; Kapoor *et al.*, 2022; Omer and Khalafalla, 2022; Parveen *et al.*, 2022; Pikuła *et al.*, 2023; Hishamund *et al.*, 2023). Despite rigorous vaccination, IBD outbreaks are often. At the end of the 1980s, vvIBDV appeared at the start in Europe, and afterward in South America, Asia, and the Middle East. In China, IBD was first detected in Beijing and Guangdong in 1979 and rapidly spread to the main poultry areas of this country (Li and Wu, 1991; Zhang *et al.*, 2022). As IBD is rendering high mortality and severe immunosuppression, vvIBDV is considered one of the most important threats to the health and development of the poultry industry in China for the last 30 years (Cao *et al.*, 1998; Wang *et al.*, 2004; Jiang *et al.*, 2021; Zhang *et al.*, 2022). Classical IBDVs are present worldwide excluding New Zealand (Becht, 1994; Behboudi, 2022). In the USA, Abs against IBDV serotype 2 is common in turkey and chicken flocks (Behboudi, 2022). vvIBDVs in acute forms have been reported in Japan (Ogawa *et al.*, 1998). Currently, vvIBDVs have been isolated in Russia, Central Europe, Asia, South America, and the Middle East (Liu *et al.*, 2001; Behboudi, 2022). Roughly estimated

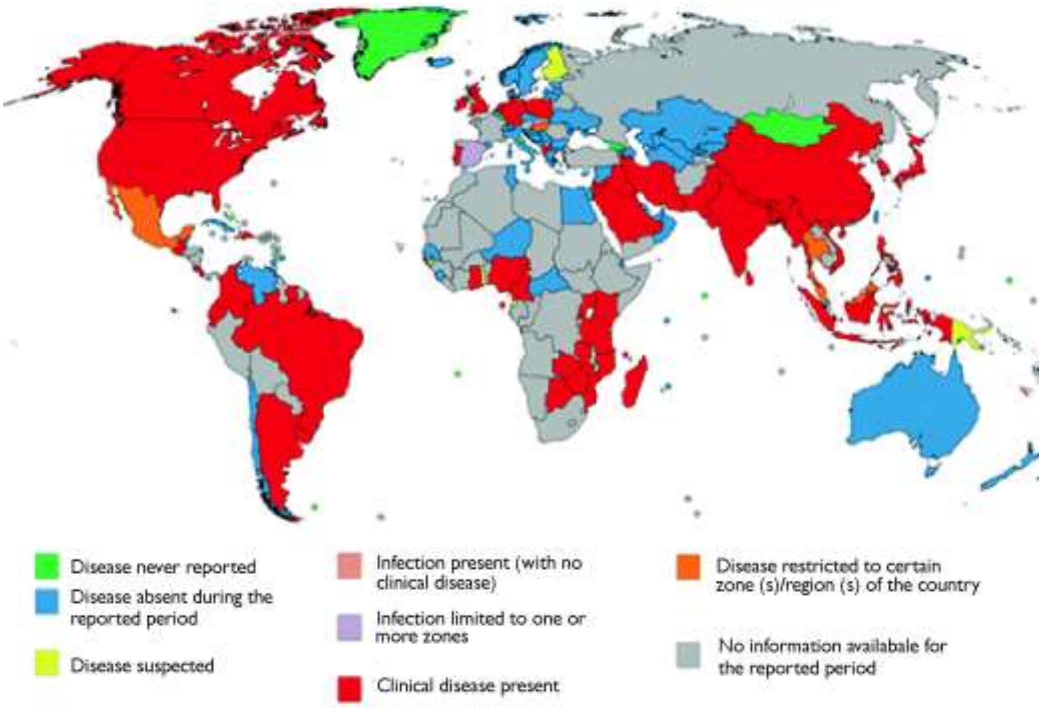

Fig. 2: Worldwide distribution of IBD and status of the disease according to the latest available reports (July–December 2016) in the World Animal Health Information System (WAHIS) from the World Organization for Animal Health (OIE). http://www.oie.int/wahis_2/public/wahid.php/Disease information/status list. Image created with https://mapchart.net (Gómez *et al.,* 2018).

Table 1: Presence/absence of IBD in different countries

Continent	Countries Where IBD Absent or Present	
	Absent	Present
Africa	Gabon (OIE, 2012); Angola, Burundi, Liberia and Libya (OIE, 2018); Central African Republic, Burkina Faso, Congo, Namibia, Niger and Tunisia (OIE, 2019); Algeria, Cabo Verde, Djibouti, Egypt, Eswatini, Ethiopia, Lesotho, Réunion, Somalia and Sudan (OIE, 2020)	Cameroon (OIE, 2012); Botswana, Gambia, Malawi, and Rwanda (OIE, 2018); Comoros (OIE, 2018a); Mali, Mauritius, Mozambique, Senegal, South Africa, Tanzania, Togo, Uganda, and Zimbabwe (OIE, 2019); Benin, Ghana and Madagascar (OIE, 2019a); Kenya, Mayotte, Nigeria and Zambia (OIE, 2020)
Asia	Tajikistan (OIE, 2009), Georgia, Kazakhstan, Lebanon, Uzbekistan, and Belarus (OIE, 2019); Kyrgyzstan, Laos, Maldives, Mongolia (OIE, 2019a); Armenia, Azerbaijan, Bahrain, Brunei, Hong Kong, Kuwait, Malaysia, Syria, Singapore, Thailand, Taiwan, United Arab Emirates and Turkmenistan (OIE, 2020)	Oman (OIE, 2009); China and Sri Lanka (OIE, 2018), Indonesia, Myanmar, Palestine, Philippines, and Qatar (OIE, 2019); India (OIE, 2019a); Afghanistan, Bangladesh Bhutan, Iran, Iraq, Israel, Japan, Jordan, Nepal, Pakistan, Saudi Arabia, South Korea, and Vietnam (OIE, 2020)
Europe	Greece (OIE, 2018a); Belarus, Bosnia and Herzegovina, Cyprus, Croatia, Finland Serbia Czechia, Liechtenstein, Montenegro, Norway (OIE, 2019); Malta (OIE, 2019a); Bulgaria, Denmark, Estonia Iceland, Latvia, Italy, Lithuania, Netherlands, Moldova, Russia, Portugal, Romania, Slovakia, Slovenia, Sweden, Switzerland, and Ukraine (OIE, 2020)	Belgium and North Macedonia (OIE, 2019); Hungary, Germany, Poland, Ireland, Russia (Europe), Spain, and the United Kingdom (OIE, 2020)
North America	Bahamas, Greenland, Jamaica, and Saint Lucia (OIE, 2018); Trinidad and Tobago (OIE, 2018a); Belize (OIE, 2019); Cuba (OIE, 2019a); Barbados, Honduras, and Mexico (OIE, 2020); Panama (OIE, 2020a)	Anguilla (McFerran 1993); Haiti and United States (OIE, 2019); Dominican Republic and Guatemala (OIE, 2019a); Canada, Costa Rica, and Martinique (OIE, 2020)
Oceania	Timor-Leste (OIE, 2018); Australia and Tonga (OIE, 2019); Fiji, Marshall Islands, Samoa, and Vanuatu (OIE, 2019a); Palau (OIE, 2020)	New Caledonia (OIE, 2019); French Polynesia (OIE, 2019a); New Zealand (OIE, 2020)
South America	Venezuela (OIE, 2019a); Bolivia and Chile, Falkland Islands, French Guiana and Peru (OIE, 2020);	Guyana (OIE, 2018); Suriname (OIE, 2019a); Argentina, Brazil, Colombia, Ecuador Paraguay and Uruguay (OIE, 2020)

that vvIBDVs are prevalent in 95% of OIE member countries (Behboudi 2022). It has been proposed that, worldwide, about 60–76% of IBDV isolates are vvIBDV (Dey *et al.*, 2019).

Economic losses: In many countries, IBD is a threat to the poultry industry (Aregitu, 2018). Economic losses due to IBD are high and are demonstrated in two ways, i.e., i) with classical IBD, in chickens of 3-6 weeks mortality is high and ii) persisted immunosuppression leading to secondary infections and failure of vaccination (Ingrao *et al.*, 2013; Sharma *et al.*, 2000; Behboudi, 2022). A study conducted by Fan *et al*. (2020) indicated that the weight of broilers infected with novel variant strains of IBDV was reduced by approximately 16% compared to that of the control at 42 days of age indicating huge economic losses to the farmer (Zhang *et al*., 2022). Coinfection of other pathogens with vvIBDV usually aggravates damage (Xu *et al*., 2021). Another aspect of economic losses is the condemnation of carcasses due to skeletal muscle, thigh, and pectoral muscle hemorrhages (Van den Berg *et al.*, 2004; Arega, 2018; Azzam *et al.*, 2019; Buzdugan *et al*., 2021).

Pathogenesis: The fecal-oral path via ingestion of polluted water and feed comprised the most common ways by which IBDV infection ensues in turkeys and chickens (Orakpoghenor *et al.*, 2020; Wagari, 2021). Subsequent host entry IBDV may bind to proteins of the host cell such as N-glycosylated polypeptide(s) articulated on the cell membrane of juvenile IgM+ B-cells all through the viral entry process. This virus has a 2–3-day short incubation period, during this period a pore-forming virus peptide (pep46) is linked with the external capsid which assists the entry of the virus into the cell cytoplasm (Wagari, 2021). A lipid draft facilitates endocytic mechanism was proposed for the entry of attenuated IBDV to the cells established based on in vitro experiment results (Yip *et al.*, 2012).

IBDV has a great affinity with lymphocytes (Raja, 2020; Liu *et al.*, 2022), thus starting illness and proliferation in macrophages and lymphocytes of GALT (Wagari, 2021). At this stage, viral replicates and viremia take place. IBDV is lugged to the BF by macrophages that are infected, where IBDV endures intracytoplasmic multiplication in IgM+ B lymphocytes (Hiraga *et al.*, 1994). After 16hrs of infection, viremia occurs as a second wave leading to the onset of clinical disease and death of the tissues, or may the virus extinguish the lymphoid follicles in the FB and circulating B-cells in the cecal tonsils and BALT, CALT, and GALT (Eterradossi and Saif, 2008; Trapp and Rautenschlein, 2022).

While looking at cytokines involved in IBDV infection, it is reported that when the virus is brought to FB by infected macrophages, IBDV replicates in IgM+ B lymphocytes (Hiraga *et al.*, 1994). In the bursa Fabricius, interferon-γ (IFN-γ) is produced by activated macrophages (Jain *et al.*, 2013; Song *et al.*, 2017) which is supplemented by the proclamation of proinflammatory cytokines such as nitric oxide (NO) and interleukin-6 (IL-6) (Zhang *et al.* 2019). Bursal lesions could be the outcome of these cytokines (Huang *et al.*, 2021). Of all these, apoptosis of healthy and infected B-cells could occur because of IFN-γ produced by IBDV infection (Qin *et al.*, 2017; Li and Zheng, 2020).

Virus spreading to lymphoid organs such as the spleen, thymus, cecal tonsils, Harderian glands, and payer's patches, may take place mainly during vvIBDV infection (Wagari, 2021; Ghetas *et al.*, 2022). During the acute lytic phase, IBDV replication drastically reduces flowing IgM+ cells and also continues the inhibition of the elementary antibodies' reaction (Arega 2018). Deaths in the acute phase could be due to the necrotizing consequence of IBDV on the host tissues (Orakpoghenor *et al.*, 2020). In case of surviving or recovering from this phase of IBD, the bird continues immunocompromised restrains defensive reactions of common vaccines against other pathogens, and portrays birds as vulnerable to cunning diseases (Trapp and Rautenschlein, 2022). IBDV especially affects vigorously distinguishing and multiplying B-lymphocytes that result in immuno-suppression which is age-dependent (OIE, 2004; Pikuła and Lisowska, 2022).

Active and proficient lymphocytes will grow as an effect of stimulus by the IBDV; however, the juvenile lymphocytes will extinguish. FB is penetrated by inflammatory cells such as heterophils and endures hyperplasia of the inter-follicular tissue as well as RE cells (OIE, 2004). T cells are sturdy to IBDV and may restrain the pathogenesis of the virus by restricting viral replication in the BF during the initial stage, by encouraging damaged bursal tissue and pausing recovery, probably via the proclamation of cytokines and their associated cytotoxic outcomes. However, IBDV infection can rigorously reduce in vitro multiplication of T cells to mitogens, suggesting that cellular immune reactions are also conceded (Sharma *et al.*, 2000). Generally, the sequelae of IBDV infection such as the harshness of clinical signs, lesions and immunosuppression are correlated with immune status, age, and genetic credentials of impinged birds along with virus strain virulence (Kim *et al.*, 2000).

Immunosuppression: IBDV infection in chicks initiates all segments of the immune system. However, the degree of initiation differs conditional on the virulency virus strains, the age of the bird, the bird's immune status, and the genetic background of the infected bird (Wagari, 2021). Maternal antibodies can alter immune reactions, and the stronger vaccinal strains can overthrow greater concentrations of antibodies. If the vaccine is prepared from classical strains of the IBD virus and has been used for vaccination of parent flocks, then the progeny of parent flocks may have poor maternal immunity against IBDV strains (Ignjatovic *et al.*, 2001). Young chicks are usually protected against vvIBDV up to 3 weeks post-hatching if it has a high level of maternal antibodies. This is shown by the tremendous inactive defense bestowed by parental antibodies hostile to bursal lesions, immuno-suppression, or mortality. Passive antibodies have a half-life of 3-5 days, usually depending on breeds, for broiler chicks three days, and for laying hens five days. Hence, if the antibody titer of a newly hatched chick is at its highest, it is suspected that the flock's vulnerability to the wild or vaccinal virus will be negligible (Van den Berg, 2000).

Clinical disease due to the IBD virus: Route of IBD infection, immune status and age of the morbid chickens (Iván *et al.*, 2005), and nature of the infecting viruses (Elankumaran *et al.*, 2002) are usually important factors for the onset of clinical signs and IBDv shedding. It is reported that the incubation period varies between 2 to 4 days (Orakpoghenor *et al.*, 2020) and severe clinical signs are recorded between 3 and 6 weeks of age (Eterradossi and Saif, 2008). It has been reported that chickens younger than 2 weeks and older than 6 weeks rarely exhibit clinical signs (Orakpoghenor *et al.*, 2020). In prone chicken, classical IBDV acute clinical outbreaks are characterized by the abrupt start of the disease, excessive morbidity, run-through high mortality, and healing between 5-7 days after the clinical signs (Van Den Berg *et al.*, 2000; Orakpoghenor *et al.*, 2020).

Within 2-3 days after contacting classical virulent and vvIBDV strains, there is a sudden onset of depression in susceptible chickens with loathness to move with ruffled feathers (Van Den Berg *et al.*, 2004). Chickens with high maternal MAB on exposure to vvIBDV usually did not exhibit clinical signs and mortality (Arega, 2018; Orakpoghenor *et al.*, 2020). In naturally infected chickens, IBDV shedding in feces for up to 2 weeks has been reported (Kabell *et al.*, 2005). Up to 4 weeks of age, RT-PCR can be applied for the detection of IBDV in feces (Kabell *et al.*, 2005).

IBD gross pathological lesions: The severity of IBD lesions and the extent of tissue distribution of IBDV depends on the IBD strain and its pathogenicity (Regenmortel, 2003). Those birds that died of acute IBD exhibit dehydration of pectoral muscles as well as subcutaneous fascia (Orakpoghenor *et al.*, 2020). Hemorrhages in the pectoral and thigh muscles, at the junction of proventriculus-ventriculus and on the serosal surface and plica of the bursa Fabricius are often seen (Hanson, 1962; Oluwayelu *et al.*, 2002).

The bursa Fabricius is the main organ showing pathological changes during IBDV infection (Orakpoghenor *et al.*, 2020). There is rapid bursal atrophy with inflammation or without inflammation following IBDV infection, while hemorrhagic inflammation is seen following vvIBDV infection (Orakpoghenor *et al.*, 2020). The bursal atrophy renders IBDV-induced lymphoid cell depletion that is evident 7–8 days post-infection (Cheville, 1967). The serosal surface of the bursa Fabricius shows yellowish coloration may be due to the deposition/accumulation of serous transudate as a result of marked inflammation (Lukert and Saif, 2003). As a result of urates deposition, ureters, kidneys as well as tubules appear distended (Confer and MacWilliams, 1982). Splenomegaly has been reported (Morales and Boclair, 1993).

IBD Histopathological lesions: Among the lymphoid organs, most affected are bursa Fabricius, thymus, spleen, cecal tonsils, Harderian glands, GALT, and HALT (Orakpoghenor *et al.*, 2020). Lymphocytic degeneration followed by necrosis of bursa Fabricius in the medullary region is the primary lesion observed on 1-day post-infection (Regenmortel, 2003). These lesions are followed by replacing depleted lymphocytes with heterophils, hyperplastic RE cells, and tissue debris (Oluwayelu *et al.*, 2002; Orakpoghenor *et al.*, 2020). In later stages, the bursal follicles are changed by columnar epithelium-lined cysts along with interfollicular stroma made by fibroblasts (Okoye and Uzoukwu, 1990). Cystic cavities contain mucin that implies recession of reaction of inflammation, and lymphocytic foci appear in the follicles of bursa Fabricius during healing (Eterradossi and Saif, 2008).

IBD diagnosis: Diagnosis of IBD requires an understanding of the flock's history, clinical signs, and lesions (Adino and Baye, 2022). Gross and histological assessments of the bursa Fabricius are cardinal lesions for the diagnosis of IBD in young chickens (Lukert and Saif, 2003) and immunohistochemistry can confirm the IBD lesions (Zeleke *et al.*, 2005). Other methods for the identification of IBR are cell culture, isolation, and detection of IBD virus in embryonated eggs, AGID, AGPT, VNT, ELISA, PCR, RT-PCR, and RLFP (Abdel-Alim and Saif, 2001; Yousif, 2005; Mawgod *et al.*, 2014; Zahid *et al.*, 2016; Msomi *et al.*, 2018; Sali, 2019; Ghetas *et al.*, 2022) and serology (AHA, 2009). Ghetas *et al.* (2022) characterized two isolates of vvIBDV by RT-PCR. They obtained nucleotide sequences of a partial portion of the VP2 gene of 2 isolates that revealed 97.0-100% and 91.2-92.5% identity with the Egyptian strains and vaccine strains, respectively. Multiplex RT-PCR differentiates between serotypes of the IBDV virus (Moody *et al.*, 2000). Zheng *et al.* (2022) have established a naked-eye visual IBDV detection method "RPA-Cas12aDS", by merging recombinase polymerase amplification (RPA) with CRISPR-Cas12a-based nucleic acid detection. This method detects IBDV within 50min.

IBD vaccination and control measures: As IBDV is contagious, mostly spread by contact with IBD ill chickens/birds and even infected fomites (AHA, 2009; Zhang and Zheng, 2022). Its spread can be limited via the application of exact/strict biosecurity processes (Lukert and Saif, 2003). Treatment is of no use (Lukert and Saif, 2003).

Vaccination is a successful tool to control and inhibit IBD outbreaks globally (Dey *et al.*, 2019; Kajal *et al.*, 2023). Vaccines have a significant role in disease prevention and control worldwide. Most IBD-modified live vaccines (MLVs) originated from attenuated strains of IBDV serotype 1 (Dey *et al.*, 2019). Live attenuated and inactivated vaccines are available against IBDV, though the use of recombinant and subunit vaccines has been implied in some countries (Jackwood and Sommer-Wagner, 2002; Birhane and Fesseha, 2020; Ravikumar *et al.*, 2022; Kajal *et al.*, 2023). Live vaccines persuade strong cellular and humoral immunity and are satisfactory when mass application is required in drinking water (Müller *et al.*, 2003; 2012; Dey *et al.*, 2019). Besides live vaccines, several commercial recombinant vector IBDV vaccines have also been developed (Ravikumar *et al.*, 2022).

Sometimes vaccination failure happens in IBD vaccines when birds are unable to raise satisfactory antibody titers and/or are at risk of a disease (Mutinda *et al*., 2014). According to different research outputs (Butcher and Yegani, 2009; Müller *et al*., 2012; Mutinda *et al*., 2014; Jakka *et al*., 2014), vaccination failure usually occurs on broiler farms that failed to meet standard procedures for vaccine storage, reconstitution, and/or administration, thus farmers education is necessary for successful vaccination, disease prevention, and disease management (Enahoro *et al*., 2021). There could be other factors for vaccination failure such as untimely vaccine plan/timing, quality of vaccine, vaccine strain/serotype, and inadequate quantity of antibodies titers post-vaccination that prejudices the chickens to a disease outbreak. Moreover, maternal antibodies, immuno-suppression, stress, and managing practices were also known causes of vaccination failure in poultry flocks (Müller *et al*., 2012; Birhane and Fesseha, 2020).

Conclusions: Infectious bursal disease is a major obstacle in the development of the poultry industry, as it is rendering huge economic losses. Infectious bursal disease is characterized by lesions of the bursa Fabricius such as first inflammation and then atrophy thus leading to immunosuppression and thus creating an opportunity for secondary infections. IBDV is a universal problem and an effective vaccination program and strict biosecurity measures are mandatory for its prevention and control.

The starring role of wild birds in the epidemiology of the IBD needs to be clarified as wild birds have indirect or direct contact with commercial chicken rearing.

Abbreviations

Abs:	Antibodies
AGID:	Agar Gel immunodiffusion
AGPT:	Agar gel precipitin/precipitation test
BALT:	Bronchial-associated lymphoid tissues
BF:	Bursa of Fabricius
CALT:	Conjunctiva-associated lymphoid tissues
CNKI:	China National Knowledge Infrastructure
ELISA:	Enzyme-linked immunosorbent assay
GALT:	Gut-associated lymphoid tissue
HALT:	Head-associated lymphoid tissues
IBD:	Infectious bursal disease
IBDV:	Infectious bursal disease virus
IgM:	Immunoglobulin M
MAB:	Maternal antibodies
MLVs:	Modified live vaccines
OIE:	Office International Des Epizooties
RE cells:	Reticuloendothelial cells
RFLP:	Restriction fragment length polymorphism
RPA:	Recombinase polymerase amplification
RT-PCR:	Reverse transcription PCR
VNT:	Virus neutralization test
vvIBDV:	Very virulent Infectious bursal disease virus

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Authors contribution: AK conceived the idea and tailored, designed, and supervised the study. XD, LA, BW, MD, HW, and JY collected the literature. AK, LA, and XD analyzed the literature and wrote the manuscript. FGE and AK revised the manuscript. All authors read and approved the final version of the manuscript.

REFERENCES

Abdel-Alim GA and Saif YM, 2001. Pathogenicity of cell culture-derived and bursa-derived infectious bursal disease viruses in specific-pathogen-free chickens. Avian Dis 45:844-52.

Adamu HU, Balami AG and Abdu PA, 2017. Avian influenza, gumboro and Newcastle disease antibodies and antigens in apparently healthy wild birds in Kano Metropolis, Nigeria. Nigeria Vet J 38:69-77.

Adino GW and Bayu MD, 2022. Review of diagnostic and vaccination approaches of infectious bursal disease of poultry. Vet Med Open J 7:22-8.

AHA (Animal Health Australia), 2009. Disease Strategy: Infectious bursal disease caused by very virulent IBD virus or exotic antigenic variant strains of IBD virus (Version 3.0), Australian Veterinary Emergency Plan (AUSVETPLAN), Edition 3, Primary Industries Ministerial Council, Canberra, ACT. Accessed 14 May 2010. http://www.animalhealthaustralia.com.au/fms/Animal%20 Health%20Australia/AUSVETPLAN/IBD22PROOF(2Jun09).pdf

Ahmed HM, Amer SA, Abdel-Alim GA, *et al.*, 2022. Molecular characterization of recently classified Newcastle disease virus genotype VII.1.1 isolated from Egypt. Int J Vet Sci 11:295-301.

Ahmed T, Amjad H, Mehwish, Jamil R and Anwar A, 2023. Conjugation of quantum dot (CDS) with antibodies for identification of Ornithobacterium rhinotracheale. Int J Agri Biosci 12:128-35.

Akhtar T, Shahid S, Asghar A, *et al.*, 2023. Utilisation of herbal bullets against Newcastle disease in poultry sector of Asia and Africa (2012-2022). Int J Agri Biosci 12:56-65.

Anonymous, 2022-2023. Pakistan economic Survey 2022-2023. Chapter 2: Agriculture. Finance Division, Government of Pakistan, Islamabad, Pakistan, pp:19-30.

Arega AM, 2018. Review on infectious bursal disease: Threat for Ethiopian poultry industry. Int J Adv Life Sci 11:52-65.

Aregitu M, 2018. Review on infectious bursal disease: Threat for Ethiopian poultry industry. Int J Adv Life Sci 11: 52-5.

Azzam MM, Jiang SQ, Chen JL, *et al.*, 2019. Effect of soybean isoflavones on growth performance, immune function, and viral protein 5 mRNA expression in broiler chickens challenged with infectious bursal disease virus. Animals 9:247.

Badau SJ, Igbokwe IO, Hassan SU and El-Yuguda AD, 2023. Outbreaks of acute infectious bursal disease of chickens in Maiduguri, Nigeria (2008-2018): retrospective survey. Research Square. https://doi.org/10.21203/rs.3.rs-2305788/v1

Bakacs T, Sandig V and Kovesdi I, 2023. Combination therapy for the treatment of shingles with an immunostimulatory vaccine virus and acyclovir. Pharmaceuticals 16:226.

Bastamy M, Raheel I, Ellakany H, *et al.*, 2022. Study of minimum inhibitory concentration against a local field isolates of Mycoplasma gallisepticum and Mycoplasma synoviae from Egyptian broiler and layer chicken flocks. Int J Vet Sci 11:98-103.

Baxendale W, 2002. Birnaviridae. In: Poultry Diseases. 5th Ed, Frank J, Mark P, Dennis A, *et al.* (eds), W.B. Saunders, USA, pp:319-23.

Becht H, 1994. Birnaviruses - Animal. In: Webster RG, Garnoff A (eds). Encyclopedia of Virology, Academic Press London, UK, 1:143-9.

Behboudi S, 2022. Infectious bursal disease. CABI Compendium. https://doi.org/10.1079/cabicompendium.806

Birhane N and Fesseha H, 2020. Vaccine failure in poultry production and its control methods: A review. J Sci Tech Res 29:22589.

Butcher GD and Yegani M, 2009. Investigating vaccination failure in poultry flocks. EDIS (http://edis.ifas.ufl.edu) 2009:VM174.

Buzdugan SN, Alarcon P, Huntington B, *et al.*, 2021. Enhancing the value of meat inspection records for broiler health and welfare surveillance: longitudinal detection of relational patterns. BMC Vet Res 17:1-3.

Cao YC, Yeung WS, Law M, *et al.*, 1998. Molecular Characterization of Seven Chinese Isolates of Infectious Bursal Disease Virus: Classical, Very Virulent, and Variant Strains. Avian Dis 42:340-51.

Cheville NF, 1967. Studies on the pathogenesis of gumboro disease in the bursa of Fabricius, spleen and thymus of the chicken. Am J Pathol 51:527-51.

Confer AW and MacWilliams PS, 1982. Correlation of hematological changes and serum and monocyte inhibition with the early suppression of phytohemagglutinin stimulation of lymphocytes in experimental infectious bursal disease. Can J Comp Med 46:169-75.

Dey S, Pathak DC, Ramamurthy N, *et al.*, 2019. Infectious bursal disease virus in chickens: prevalence, impact, and management strategies. Vet Med: Res Rep 10:85-97.

Du XX, Gul ST, Ahmad L, *et al.*, 2023. Fowl typhoid: Present scenario, diagnosis, prevention, and control measures. Int J Agri Biosci 12:172-9.

Elankumaran S, Heckert RA and Moura L, 2002. Pathogenesis and tissue distribution of a variant strain of infectious bursal disease virus in commercial broiler chickens. Avian Dis 46:169-76.

Enahoro D, Galiè A, Abukari Y, *et al.*, 2021. Strategies to upgrade animal health delivery in village poultry systems: perspectives of stakeholders from northern Ghana and central zones in Tanzania. Front Vet Sci 8:611357.

Eregae ME, Dewey CE, McEwen SA, *et al.*, 2014. Flock prevalence of exposure to avian adeno-associated virus, chicken anemia virus, fowl adenovirus, and infectious bursal disease virus among Ontario broiler chicken flocks. Avian Dis 58:71-7.

Escaffre O, Le Nouën C, Amelot M, *et al.*, 2013. Both Genome Segments Contribute to the Pathogenicity of Very Virulent Infectious Bursal Disease Virus. J Virol 87:2767-80.

Eterradossi and Saif YM, 2008. Infectious Bursal Disease. In: Saif YM, Fadly AM, Glissen JR, *et al.*, (eds), Diseases of Poultry, 12th Ed, pp:185-208.

Fan L, Wu T, Wang Y, *et al.*, 2020. Novel variants of infectious bursal disease virus can severely damage the bursa of Fabricius of immunized chickens. Vet Microbiol 240:108507.

Ferrero DS, Busnadiego I, Garriga D, *et al.*, 2021. Structure and dsRNA-binding activity of the Birnavirus Drosophila X Virus VP3 protein. J Virol 95:e02166-20.

Gardner H, Kerry K, Riddle M, *et al.*, 1997. Poultry virus infection in antarctic penguins. Nature 387:245-8.

Ghetas AM, Sedeek DM, Fedawy HS, *et al.*, 2022. Molecular identification of IBDV from naturally infected chicken flocks. Adv Anim Vet Sci 10:864-70.

Gilchrist P, 2005. Involvement of free-flying wild birds in the spread of the viruses of avian influenza, Newcastle disease and infectious bursal disease from poultry products to commercial poultry. World's Poult Sci J 61:198-210.

Gómez E, Lucero MS, Richetta M, *et al.*, 2018. Infectious bursal disease virus. In: MacDonald J (eds), Prospects of Plant-Based Vaccines in Veterinary Medicine. Springer, pp:169-87.

Gul ST and Alsayeqh AF, 2022. Probiotics as an alternative approach to antibiotics for safe poultry meat production. Pak Vet J 42:285-91.

Hanson BS, 1962. Post-mortem lesions diagnostic of certain poultry. Vet Record 80:109-22.

Hayajneh FMF and Araj SA, 2023. Infectious bursal disease (Gumboro) in backyard chicken in Jordan. Int J Vet Sci 12:810-4.

Hiraga M, Nunoya T, Otaki Y, *et al.*, 1994. Pathogenesis of highly virulent infectious bursal disease virus infection in intact and bursectomized chickens. J Vet Med Sci 56:1057-63.

Hishamund P, Emikpe BO and Shyakaa A, 2023. Seroprevalence and associated factors of infectious bursal disease (IBD) in indigenous chicken in eastern province in Rwanda. J Immunoassay Immunochem 44:296-308.

Hollmen T, Franson JC, Docherty DE, *et al.*, 2000. Infectious bursal disease virus in eider ducks and herring gulls. The Condor 102:688-91.

Huang X, Liu W, Zhang J, *et al.*, 2021. Very virulent infectious bursal disease virus-induced immune injury is involved in inflammation, apoptosis, and inflammatory cytokines imbalance in the bursa of Fabricius. Develop Comp Immunol 114:103839.

Ignjatovic J, Sapats S and Gould G, 2001. Detection of vvIBDV strains and Australian variants in poultry. Rural Industries Research and Development Corporation, Australia.

Ingrao F, Rauw F, Lambrecht B, *et al.*, 2013. Infectious Bursal Disease: A complex host–pathogen interaction. Develop Comp Immunol 41:429-38.

Iván J, Velhner M, Ursu K, *et al.*, 2005. Delayed vaccine virus replication in chickens vaccinated subcutaneously with an immune complex infectious bursal disease vaccine: quantification of vaccine virus by real-time polymerase chain reaction. Canadian J Vet Res 69:135-42.

Jackwood DJ and Sommer-Wagner SE, 2002. Virulent vaccine strains of infectious bursal disease virus not distinguishable from wild-type viruses with the use of a molecular marker. Avian Dis 46:1030-2.

Jackwood DJ, Schat KA, Michel LO, *et al.*, 2018. A proposed nomenclature for infectious bursal disease virus isolates. Avian Pathol 47:576-84.

Jain P, Singh R, Saxena VK, *et al.*, 2013. In vitro rapid clearance of infectious bursal disease virus in peripheral blood mononuclear cells of chicken lines divergent for antibody response might be related to the enhanced expression of proinflammatory cytokines. Res Vet Sci 95:957-64.

Jakka P, Reddy YK, Kirubaharan JJ and Chandran NDJ, 2014. Evaluation of immune responses by live infectious bursal disease vaccines to avoid vaccination failures. Eur J Microbiol Immunol 4:123-7.

Jiang N, Wang Y, Zhang W, *et al.*, 2021. Genotyping and molecular characterization of infectious bursal disease virus identified in important poultry-raising areas of China during 2019 and 2020. Front Vet Sci 8:759861.

Kabell S, Handberg KJ, Li Y, *et al.*, 2005. Detection of vvIBDV in Vaccinated SPF Chickens. Acta Vet Scand 46:219-27.

Kajal S, Narang G, Jangir BL, *et al.*, 2023. Studies on immunopathological changes induced by commercial IBD live vaccines in poultry birds. Sci Rep 13:12379.

Kapoor S, Kaur H, Rehman AU, *et al.*, 2022. Infectious bursal disease: Overview. J Med Pharmaceut Allied Sci 11:4661-5.

Kegne T and Chanie M, 2014. Review on the incidence and pathology of infectious bursal disease. Brit J Poult Sci 3:68-77.

Khan RSA, Sajid S, Habib M, *et al.*, 2017. History of Gumboro (infectious bursal disease) in Pakistan. Saudi Pharmaceut J 25:453-9.

Kim I, You S, Kim H, *et al.*, 2000. Characteristics of bursal T lymphocytes induced by infectious bursal disease virus. J Virol 74:8884-92.

Lebdah M, Tantawy L, Elgamal AM, *et al.*, 2022. Molecular Detection and Characterization of virulent Newcastle disease viruses from different avian species in Egypt. Int J Vet Sci 11:189-95.

Li D and Wu Z, 1991. Isolation and preliminary identification of a supervirulent strain of infectious bursal disease virus. Chinese J Prev Vet Med 6:3-6.

Li J and Zheng SJ, 2020. Role of MicroRNAs in Host Defense against Infectious Bursal Disease Virus (IBDV) Infection: A Hidden Front Line. Viruses 12:543.

Liew PS, Mat Isa N, Omar AR *et al.*, 2016. Vaccines and vaccination against infectious bursal disease of chickens: Prospects and challenges. Pertanika J Scholar Res Rev 2:23-39.

Liu A, Pan Q, Wang S, *et al.*, 2022. Identification of chicken CD44 as a novel B lymphocyte receptor for infectious bursal disease virus. J Virol 96:e0011322.

Liu HJ, Huang PH, Wu YH, *et al.*, 2001. Molecular characterization of very virulent infectious bursal disease viruses in Taiwan. Res Vet Sc 70:139-47.

Lukert PD and Saif YM, 2003. Infectious bursal disease. In: Saif, YM, Glisson JR, Fadly AM, McDougald LR and Swayne DE (eds), Diseases of Poultry, 11th Ed, Iowa State University Press, Ames, USA, pp: 61-180.

Mawgod SA, Arafa AS and Hussein HA, 2014. Molecular genotyping of the infectious bursal disease virus (IBDV) Isolated from broiler flocks in Egypt. Int J Vet Sci Med 2:46-52.

McFerran JB, 1993. Infectious bursal disease. In: Virus infections of birds; McFerran JB, McNulty M (eds). Elsevier Amsterdam, Netherlands, pp:213-28.

Mehmood K, Bilal RM and Zhang H, 2020. Study on the genotypic and phenotypic resistance of tetracycline antibiotic in Escherichia coli strains isolated from free ranging chickens of Anhui Province, China. Agrobiol Records 2:63-8.

Mehnaz S, Abbas RZ, Kanchev K, *et al.*, 2023. Natural control perspectives of *Dermanyssus gallinae* in poultry. Int J Agri Biosci 12:136-42.

Mirbagheri A, Hosseini H, Hojabr Rejeoni A, *et al.*, 2020. Molecular surveillance of infectious bursal disease virus in live bird market, Tehran, Iran. Iranian J Virol 14:63-5.

Moody A, Sellers S and Bumstead N, 2000. Measuring infectious bursal disease virus RNA in blood by multiplex real-time quantitative RT-PCR. J Virol Methods 85:55-64.

Morales OE and Boclair W, 1993. Morphometric relations bursa/spleen in infectious bursal disease. Proc 42nd Western Poult Dis Conf, Sacramento, California, pp:91-2.

Moryani AA, Rajput N, Rajput MN and Shah AH, 2020. Prevalence of common poultry diseases in chicken and influence of different medicinal herbs on the growth of broiler chicken. Pure Applied Biol 9:1199-208.

Mosad SM, Eladl AH, El-Tholoth M, *et al.*, 2020. Molecular characterization and pathogenicity of very virulent infectious bursal disease virus isolated from naturally infected turkey poults in Egypt. Trop Anim Health Prod 52:3819–31.

Motohiko O, Takashi W and Tsuyoshi Y, 1998. Seroprevalence of Infectious Bursal Disease in Free-living Wild Birds in Japan. J Vet Med Sci 60:1277-9.

Msomi S, Kandusi N, Kasanga CJ, *et al.*, 2018. Molecular characterization of infectious bursal disease virus detected in Morogoro, Tanzania. Tanzania Vet J 35:29-35.

Müller H, Islam MR and Raue R, 2003. Research on infectious bursal disease–the past, the present and the future. Vet Microbiol 97:153-65.

Müller H, Mundt E, Eterradossi N and Islam MR, 2012. Current status of vaccines against infectious bursal disease. Avian Pathol 41:133-9.

Mutinda WU, Nyaga PN, Mbuthia PG, *et al.*, 2014. Risk factors associated with infectious bursal disease vaccination failures in broiler farms in Kenya. Trop Anim Health Prod. 46:603-8.

Mwenda R, Changula K, Hang'ombe BM, *et al.*, 2018. Characterisation of field infectious bursal disease viruses in Zambia: evidence of co-circulation of multiple genotypes with predominance of very virulent strains. Avian Pathol 47:300-13.

Nooruzzaman M, Hossain I, Rahman MM, *et al.*, 2022. Comparative pathogenicity of infectious bursal disease viruses of three different genotypes. Microbial Pathog 169:105641.

Ogawa M, Wakuda T, Yamaguchi T, *et al.*, 1998. Seroprevalence of infectious bursal disease virus in free-living wild birds in Japan. J Vet Med Sci 60:1277-9.

OIE, 2004. Infectious bursal disease (Gumboro disease): Manual of diagnostic test and vaccine for terrestrial animals. Office International des Epizooties, Paris, France.

OIE, 2009. World Animal Health Information Database - Version: 1.4., Paris, France: World Organisation for Animal Health. https://www.OIE,.int/

OIE, 2012. World Animal Health Information Database. Version 2., Paris, France: World Organisation for Animal Health. https://www.OIE,.int/wahis_2/public/wahid.php/Wahidhome/Home

OIE, 2018. World Animal Health Information System (WAHIS): Jul-Dec. In: OIE,-WAHIS Platform, Paris, France: OIE, (World Organisation for Animal Health). unpaginated. https://wahis.OIE,.int/

OIE, 2018a. World Animal Health Information System (WAHIS): Jan-Jun. In: OIE,-WAHIS Platform, Paris, France: OIE, (World Organization for Animal Health). unpaginated. https://wahis.OIE,.int

OIE, 2019. World Animal Health Information System (WAHIS): Jul-Dec. In: OIE,-WAHIS Platform, Paris, France: OIE, (World Organisation for Animal Health). unpaginated. https://wahis.OIE,.int/

OIE, 2019a. World Animal Health Information System (WAHIS): Jan-Jun. In: OIE,-WAHIS Platform, Paris, France: OIE, (World Organization for Animal Health). unpaginated. https://wahis.OIE,.int/

OIE, 2020. World Animal Health Information System (WAHIS): Jul-Dec. In: OIE,-WAHIS Platform, Paris, France: OIE, (World Organisation for Animal Health). unpaginated. https://wahis.OIE,.int/

OIE, 2020a. World Animal Health Information System (WAHIS). Jan-Jun. In: OIE,-WAHIS Platform, Paris, France: OIE, (World Organisation for Animal Health). unpaginated. https://wahis.OIE,.int/

Okoye JOA and Uzoukwu M, 1990. Pathogenesis of infectious bursal disease in embryonally bursectomised chickens. Avian Pathol 19:555-69.

Oluwayelu DO, Emikpe BO, Ikheloa JO, *et al.*, 2002. The pathology of infectious bursal disease in crossbred Harco cocks and indigenous Nigerian hens. Afr J Clin Exp Microbiol 3:95-7.

Omer MG and Khalafalla AI, 2022. Epidemiology and laboratory diagnosis of very virulent infectious bursal disease virus in vaccinated chickens in Khartoum, Sudan. Open Vet J 12:33-43.

Orakpoghenor O, Oladele SB and Abdu PA, 2020. Research Note: Detection of infectious bursal disease virus antibodies in free-living wild birds in Zaria, Nigeria. Poult Sci 99:1975-7.

Parveen S, Mahmood A, Azad A, *et al.*, 2022. Prevalence of concurrent infections in broiler population of district Chakwal, Pakistan. Sarhad J Agri 38:480-8.

Pikuła A and Lisowska A, 2022. Genetics and pathogenicity of natural reassortant of infectious bursal disease virus emerging in Latvia. *Pathogens* 11:1081.

Pikuła A, Lisowska A and Domańska-Blicharz K, 2023. Epidemiology of infectious bursal disease virus in Poland during 2016–2022. Viruses 15:289.

Qadir MF and Irum A, 2023. Epidemiological and diagnostic status of Mycoplasma synoviae in in Pakistan and India: A review. Agrobiol Rec 11:39-47.

Qin Y, Xu Z, Wang Y, *et al.*, 2017. VP2 of infectious bursal disease virus induces apoptosis via triggering oral cancer overexpressed 1 (ORAOV1) protein degradation. Front Microbiol 8:1351.

Raja P, 2020. Chapter 20: Infectious Bursal Disease. In: Khalaf MN, Smirnov MO, Kannan P and Haghi AK (eds), Environmental Technology and Engineering Techniques. Apple Academic Press.

Ravikumar R, Chan J and Prabakaran M, 2022. Vaccines against major poultry viral diseases: Strategies to improve the breadth and protective efficacy. Viruses 14:1195.

Raza QS, Saleemi MK, Gul ST, *et al.*, 2022. Role of essential oils/volatile oils in poultry production - A review on present, past and future contemplations. Agrobiol Records 7:40-56.

Regenmortel V, 2003. Virus Taxonomy. 7th Report of the international committee on taxonomy of virus. Academic Press.

Sajid S, Rahman Su, Mohsin Gilani M, *et al.*, 2021. Molecular characterization and demographic study on infectious bursal disease virus in Faisalabad District. PLoS ONE 16:e0254605.

Sali K, 2019. Overview of methods used in the diagnosis of infectious bursal disease. Vet Med Open J 4:9-17.

Samad A, Hamza M, Muazzam A, *et al.*, 2022. Policy of control and prevention of infectious bursal disease at poultry farm. Afr J Biol Chem Phys Sci 1:1-7.

Shah AU, Wang Z, Zheng Y, *et al.*, 2022. Construction of a Novel Infectious Clone of Recombinant Herpesvirus of Turkey Fc-126 Expressing VP2 of IBDV. Vaccines (Basel) 10:1391.

Sharma JM, Kim IJ, Rautenschlein S and Yeh HY, 2000. Infectious bursal disease virus of chickens: Pathogenesis and immunosuppression. Develop Comp Immunol 24:223-35.

Song B, Li X, Ma J, *et al.*, 2017. Prokaryotic Expression and Anti-IBDV Activity of Chicken Interleukin-18 and Interferon-γ. Cytogen Genome Res 153:36-45.

Tchoupou-Tchoupou EC, Ndofor-Foleng HM, Nwenya JM, *et al.*, 2022. Effects of hexane extract of garlic on hematological, biochemical and histological parameters in F1 crossbred chicks non-infected and infected with *Salmonella typhimurium*. Int J Vet Sci 11:435-42.

Trapp J and Rautenschlein S, 2022. Infectious bursal disease virus' interferences with host immune cells: what do we know? Avian Pathol 51:303-16.

Van den Berg TP, 2000. Acute infectious bursal disease in poultry: a review. Avian Pathol 29:175-94.

Van Den Berg TP, Eterradossi N, Toquin D, *et al.*, 2000. Infectious Bursal Disease (Gumboro Disease). Rev Sci Technol 19:527-43.

Van Den Berg TP, Gonze M and Meulemans G, 1991. Acute infectious bursal disease in poultry, isolation and characterization of a highly virulent strain. Avian Pathol 20:133-43.

Van Den Berg TP, Morales D, Eterradossi N, *et al.*, 2004. Assessment of genetic, antigenic and pathotypic criteria for the characterization of IBDV strains. Avian Pathol 33:470-6.

Van Den Berg TP, Ona A, Morales D and Rodriguez JF, 2001. Experimental inoculation of game/ornamental birds with a very virulent strain of IBDV.COST839. Rauischholzhausen, Germany, pp:236-46.

Wagari A, 2021. A review on infectious bursal disease in poultry. Health Econ Outcome Res Open Access 7:167.

Wang XM, Zeng XW, Gao HL, *et al.*, 2004. Changes in VP2 Gene during the Attenuation of Very Virulent Infectious Bursal Disease Virus Strain Gx Isolated in China. Avian Dis 48:77-83.

Xu A, Sun L, Tu K, *et al.*, 2021. Experimental co-infection of variant infectious bursal disease virus and fowl adenovirus serotype 4 increases mortality and reduces immune response in chickens. Vet Res 52:61.

Xu ZY, Yu Y, Liu Y, *et al.*, 2019. Differential expression of pro-inflammatory and anti-inflammatory genes of layer chicken bursa after experimental infection with infectious bursal disease virus. Poult Sci 98:5307-14.

Yip W, Hon C, Zeng UF and Leung C, 2012. Cell culture-adapted IBDV uses endocytosis for entry in DF-1 chicken embryonic fibroblasts. Virus Res 165:9-16.

Yousif MGO, 2005. Evaluation of Various Techniques Used for the Diagnosis of Infectious Bursal Disease and its Prevalence in Khartoum State. [master's thesis]. Khartoum, Sudan: University of Khartoum; pp:99.

Zachar T, Popowich S, Goodhope B, *et al.*, 2016. A 5-year study of the incidence and economic impact of variant infectious bursal disease viruses on broiler production in Saskatchewan, Canada. Canadian J Vet Res 80:255-61.

Zahid B, Aslam A, Tipu Y, *et al.*, 2016. Conventional and molecular detection of infectious bursal disease virus in broiler chicken. Pak J Zool 48:601-3.

Zeleke A, Gelaye E, Sori T, *et al.*, 2005. Investigation on Infectious Bursal Disease outbreak in Debre Zeit, Ethiopia. Int J Poult Sci 4:504-6.

Zhang S and Zheng S, 2022. Host combats IBDV infection at both protein and RNA levels. Viruses 14:2309.

Zhang W, Wang X, Gao Y and Qi X, 2022. The Over-40-Years-Epidemic of Infectious Bursal Disease Virus in China. Viruses 14:2253.

Zhang Y, Yu Y, Ou C, *et al.*, 2019. Alleviation of infectious-bursal-disease-virus-induced bursal injury by betaine is associated with DNA methylation in IL-6 and interferon regulatory factor 7 promoter. Poult Sci 98:4457-64.

Zheng SY, Ma LL, Wang XL, *et al.*, 2022. RPA-Cas12aDS: A visual and fast molecular diagnostics platform based on RPA-CRISPR-Cas12a method for infectious bursal disease virus detection. J Virol Methods 304:114523.