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Review Article

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Reviewing the Efficiency of Field and Experimentally Utilized Vaccine Regimens Against Infectious Bronchitis Virus in Egypt (2000-2021)

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Abstract

Infectious bronchitis is an acute, highly contagious upper respiratory tract disease in chickens. Reduced egg production and quality are common, and nephritis can be caused by some strains. Attenuated live, killed, and recently recombinant vaccines are available, but different antigenic types of the avian coronavirus causing the disease do not cross-protect, complicating control efforts. Vaccination regimens against IBV often induce insufficient levels of cross-protection field challenge. In the current work, we reviewed the data outcomes of the field and experimental vaccine efficacy in view of the available literature during 2000–2021 in Egypt, as well as the geo-epidemiological distribution of the virus infection among different Egyptian provinces within the time frame of the study. Among seventeen provinces, Sharkia came in at the top of the list, with the highest IBV incidence in field-vaccinated flocks that received a single classic live vaccine. However, experimentally, the protective percentage for the same vaccine regime extremely varied from 50% to almost 100%. The introduction of variants with classics proved lower incidence in the field IBV isolates and higher protection in experimental trials, which varied according to the variant vaccine used and the strain of the challenge virus. In conclusion, the vaccination efficacy against IBV is a crucial issue, and we must keep in mind proper vaccine handling, application, and the maximal use of one classic beside one variant as a protectotype along the Egyptian farms to avoid the evolution of more variants.

KEYWORDS
Infectious Bronchitis virus, Vaccine regimens, Egypt, Classical strains, Variant strains.

Introduction

Infectious bronchitis (IB) is one of the major economically and extremely highly contagious poultry diseases distributed worldwide. It is caused by the infectious bronchitis virus (IBV) and affects both Galliformes and non-Galliformes birds. Its economic impact includes decreased egg production and egg quality in layers and breeders, poor growth, and mortality in broiler chickens, in addition to control and prevention costs. This disease usually occurs in both vaccinated and non-vaccinated chickens. Although primarily affecting the respiratory tract, IBV demonstrates a wide range of tissue tropisms, including the renal and reproductive systems (Pohuang *et al*., 2009; Yan *et al*., 2009; Bande *et al*., 2016).

The respiratory manifestation of the disease is the most common among clinical cases, and it is characterized by tracheal rales, coughing, and sneezing (Cook, 1995; Mahmoud *et al*., 2019). The infection may spread to the reproductive and renal systems, leading to oviduct and kidney lesions (Cavanagh and Naqi, 1997), as a result of some variants and several field isolates that affect the reproductive, renal, and digestive systems of chickens (Cavanagh, 2007).

The virus in Egypt is continually recorded in the growing chicks and co-infected with other respiratory pathogens such as the low-pathogenic avian influenza (LPAI) virus, subtype H9N2, Newcastle disease virus (NDV), pathogenic *Escherichia coli*, and *Mycoplasma* species. The commonly isolated IBVs are related to VAR 2 IBV (Abdel-Moneim *et al*., 2012; Fathy *et al*., 2015; Sultan *et al*., 2017; Mahmoud *et al*., 2019; Megahed *et al*., 2020). Moreover, frequent outbreaks occur in both unvaccinated and vaccinated birds because of the choice of insufficient vaccine candidates, the unceasing emergence of novel infectious bronchitis (IB) variants, improper vaccination, and failure of vaccination (Cook, 1995; Sultan *et al*., 2017; Mahmoud *et al*., 2019; Megahed *et al*., 2020). Accordingly, the current article potentiated a review of the field and experimental perspective of vaccine efficacy and failure in view of the available literature since the 2000s.

Etiology

Coronaviridae is a large family consisting of four genera, with varieties of animal and human coronavirus species. The first coronavirus discovered was the infectious bronchitis virus (IBV) in chickens in the 1930s (Schalk and Hawn, 1931).

IBV is an enveloped virus of about 120 nm in diameter with crown-like spikes of 20 nm length. It is one of the members in the order *Nidovirales*, family *Coronaviridae*, sub-family *Coronavirinae*, genus *Gammacoronavirus*, and subgenus *Igacovirus* (King *et al*., 2018). IBV possesses a single-stranded, positive-sense RNA of about 27.6 kb in length, comprising 13 open reading frames (ORFs) in order 5′-UTR-1a-1b-S-3a-3b-E-M-4b-4c-5a-5b-N-6b-UTR-Poly(A) tail-3′ (Payne, 2017). Coronaviruses have a limited

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proofreading capacity for this viral polymerase, which results in a high mutation rate with an average rate of 1.2×10^{-3} substitutions per site per year (Hanada *et al*., 2004; Holmes, 2009).

The viral genome encodes structural, nonstructural, and lineage-specific accessory proteins (Dent *et al*., 2015). Structural proteins contain spike glycoprotein (S), membrane glycoprotein (M), envelope protein (E), and nucleoprotein (N). The spike protein is cleaved into S1 and S2 subunits. Spike S1 plays a critical role in viral attachment, antibodies neutralizing, and diversity (Lai and Cavanagh, 1997; Cavanagh, 2007; Cavanagh *et al*., 1986; Koch *et al*., 1990; Niesters *et al*., 1987). Neutralizing and serotype-specific antibodies are mainly bound to the S1 glycoprotein (Cavanagh, 2007). Consequently, the identification of IB viruses is mostly focused on S1 gene analysis (Zanaty, 2014).

Host Susceptibility

Although domestic fowl (*Gallus gallus*) and pheasants (*Phasianus* spp.) are considered to be natural hosts for IBV (Cavanagh *et al*., 2002), antibodies against IBV have been confirmed in humans with close contact to poultry, but the virus has not been reported to cause human clinical disease (Miller and Yates, 1968). Regarding to the IBV-like coronaviruses were detected in pheasant, turkey, geese, pigeon, ducks, peafowl, teal, guinea fowl, partridge, and penguins (Dea and Tijssen, 1989; Jonassen *et al*., 2005; Cavanagh, 2005; Circella *et al*., 2007).

Age and Breed Susceptibility

Chickens of all ages and breed types are susceptible to IBV infection, but the extent and severity of the disease are more pronounced in young chicks compared to adults, and resistance to infection increases with age (Crinion and Hofstad, 1972). Experimental challenge proved that white leghorn chickens line C are more resistant to M41 compared to line 151, although both lines had similar virus shedding rates (Otsuki *et al*., 1990; Bumstead, 1998).

Incubation Period

Generally, the short incubation period for IBV varies with the infective dose and route of infection. For example, the infection via the tracheal route may take a course as short as 18 hours, while ocular inoculation leads to an incubation period of 36 hours (Cavanagh and Gelb, 2008).

Clinical Course and gross pathological findings

In the host, the initial infection occurs at the epithelia of the harderian gland, trachea, lungs, and air sacs. The virus then moves to the kidney and urogenital tract to establish systemic infection (Arshad *et al*., 2002; Cavanagh and Gelb, 2008). Infection of the respiratory system could include sneezing, nasal discharges, coughing, gasping, tracheal rales, listlessness, and dullness with ruffled feathers. Also, the affected birds may huddle together under a common heat source (Cavanagh and Gelb, 2008; Abou El-Fetouh *et al*., 2016; Ghanem *et al*., 2019; Mahmoud *et al*., 2019). Other clinical consequences associated with IB infection include frothy conjunctivitis, profuse lacrimation, edema, and cellulitis of periorbital tissues. Infected birds may also appear lethargic, with evidence of dyspnea and reluctance to move (Terregino *et al*., 2008). Nephropathogenic IBV strains are mostly recorded in broilers and are associated with depression, wet droppings, excessive water intake, and whitish diarrhoea (Mahmoud *et al*., 2019). The tracheitis, bronchitis, and congestion of the lungs followed by caseated plugs at the tracheal bifurcation and kidney damage in the form of nephrosis-nephritis with urate deposition in the ureters are the common gross lesions (Abou El-Fetouh *et al*., 2016; Ghanem *et al*., 2019; Mahmoud *et al*., 2019).

The morbidity of IBV infection is usually 100%, whereas mortality rates can vary from Zero to 82%, and this depends upon the immune status of the birds, age, type of virus strain, and if secondary pathogens are involved (Ramakrishnan and Kappala, 2019).

Infection of the reproductive tract with IBV, if it occurs at 1–14 days of age, the development of cystic oviduct may occurr without weakened ovarian functions, resulting in no egg production later (false layer syndrome) (Crinion and Hofstad, 1972; Broadfoot *et al*., 1956; de Wit *et al*., 2011). False layer syndrome prevents these birds from reaching their peak egg production, which leads to early culling (Cook *et al*., 2012; Broadfoot *et al*., 1956). Infection in laying hens is accompanied with decreased egg production, and poor- eggs quality, such as miscolored, misshapen, shell-less, thin, or rough-shelled eggs as well as eggs with watery albumin or blood spots (Crinion and Hofstad, 1972; Broadfoot *et al*., 1956; Sevoian and Levine, 1957; Winterfield *et al*., 1984; Cavanagh, 2007). Egg production of laying hens' cans descent by 35–90% (Broadfoot *et al*., 1956; Bisgaard, 1976). Within nine weeks, egg production bounds back to near normal, there may be a 6-12% drop in productivity compared to the normal level (Broadfoot *et al*., 1956; Bisgaard, 1976). Regression or degeneration of the ovaries and shorter, and hypogalndular oviducts may occur (Rohaim *et al*., 2019). Also, the swollen oviducts associated with egg peritonitis due to abdominal ovulation can be noticed (Crinion and Hofstad, 1972; Sevoian and Levine, 1957).

Egyptian IBV strains

IBV was divided into 6 different viral genotypes, 32 distinct lineages, and a number of unassigned recombinants with inter-lineage origin based on the S1-gene phylogenetic categorization. It's interesting to note that these IBV genotypes vary by geographic location in terms of distribution and diversity (de Wit *et al*., 2011; Valastro *et al*., 2016).

Four genotype lineages: GI-1, GI-23, GI-16, and GI-13 were reported to be circulating in chicken farms in Egypt. GI-1 includes the classic wild strains in addition to the vaccine-like strains; Massachusetts serotype vaccine strains like Mass/Mass41/41, Mass/H120/55, or Ma5. Previously, IBV variants have been identified in Egypt since the 1970s (Sheble *et al*., 1986; Eid, 1998). Consequently, variants related to Mass, other European IBVs and that related to Israeli variant have been recognised using genome analysis (Abdel-Moneim *et al*., 2006). Which, the GI-23 includes the two Egyptian variant subgroups (Egy/Var-1 and Egy/Var-2) (Abdel-Moneim *et al*., 2002; Abdel-Moneim *et al*., 2012).

The IB field- viruses undergo continuous evolution by genetic drift and recombination, either within the same genotype (intra-genotypic) or with different genotypes (inter-genotypic). GI-16 includes the newly introduced Q1-like strains. It is still unclear if this lineage is introduced from China, Europe, or Middle Eastern countries. Along with much that is yet unknown about the evolution of this genotype, GI-13, the 4/91-like strains could emerge from the currently used 4/91 vaccine strain (Valastro *et al*., 2016; Abozeid and Naguib, 2020).

IBV vaccines in Egypt

Like any country, the control of IB in Egypt is based on the

use of live-attenuated and inactivated IBV vaccines, in addition to good biosecurity. Live-attenuated vaccines are mainly used for the immunization of broilers and for priming future layer and breeder flocks. Live-attenuated IBV vaccines provoke good cellular and humoral immune responses that regularly provide good protection against homologous challenges (Ali *et al*., 2018). However, Sultan *et al*. (2019) stated that protection against heterologous challenges is limited. Combinations between two antigenically different IBV strains were suggested to provide a broader spectrum of protection against different variant strains (protectotype) (Cook *et al*., 1999). Inactivated vaccines are commonly used for boosting the layer and breeder flocks to ensure long-lasting humoral immunity during the period of egg production and to transfer maternal immunity from the breeders to their progeny (Cavanagh and Naqi, 2003). In Egypt, live-attenuated and inactivated IBV vaccines are extensively used to control the disease. Classic vaccine strains (H120, Ma5, and M41) have been widely used as a routine measure to control the disease in Egypt. Since

Table 1. Natural Outbreaks of Infectious bronchitis virus among vaccinated chickens during 2000-2021 in Egypt.

Vaccine regimen	Age of vaccination	No. of field IBVs	Total No	Chicken breeds	Age/ day	IBV–type	References
Single-Classic live H120/Ma5	Day 1	1	89	Avian 48	26	1 N/I	Mahmoud *et al*. (2019)
		9		Broilers	-	9 N/I	Awad *et al*. (2016)
		20		Broilers	-	4 classic, 6 Var1, 10 Var2	Zanaty *et al*. (2016b)
		9		Cobb, Rross Hubbard	22-33 21-37 10-36	9 N/I (5 cobb, 2 Ross, 2 Hubbard)	Megahed *et al*. (2020)
		3		Broilers	-	3 Variant	Mohamed and Ibrahim (2015)
		12		Broilers	-	12 Var2	El-Sayed and Zanaty (2019)
		34		Broilers	-	34 N/I	Zanaty (2014)
		1		Cobb	30	1 N/I	Mahmoud *et al*. (2021)
	Day 4	3	3	Cobb	20-45	3 N/I	Mahmoud *et al*. (2021)
	Day 6	1	1	Sasso	33	1 N/I	Hassan (2015)
	Day 7	10	14	Broilers	19-29	2 Var2, 8 N/I	Mourad (2012)
		2		Ross Cobb	22 25	2 Var2	Ghanem *et al*. (2019)
		2		Broilers	-	1 Classic, 1 Variant	Abozeid *et al*. (2017)
	Day 8	3	3	Sasso	33- 49	3 N/I	Mahmoud *et al*. (2021)
Double classic, H120+Ma5	Days 1 and 8	1	1	Sasso	25	1 N/I	Mahmoud *et al*. (2021)
Single Mixed classic and variant (H120+D274)	Day 1	1	2	Cobb	35	1 N/I	Mahmoud *et al*. (2019)
		1		Cobb	35	1 N/I	Mahmoud *et al*. (2021)
Double Mixed classic and variant (H120+D274) +(IB primer)	Days 1 and 14	1	2	Cobb	27	1 N/I	Mahmoud *et al*. (2019)
		1		Cobb	27	1 N/I	Mahmoud *et al*. (2021)
Double classic and variant (IB primer) 0	Days 1 and 14	1	11	Cobb	30	1 N/I	Mahmoud *et al*. (2019)
		10		Broilers		2 Classic 4 Variant 4 N/I	Abou El-Fetouh *et al*. (2016)
	Days 1 and 10	1	1	White	29	1 N/I	Mahmoud *et al*. (2019)
	Days 4 and 8	2	2	Cobb Sasso	30 25	2 N/I	Mahmoud *et al*. (2021)
Double classic and two variants (IB primer) +4/91	Days 1 and 14	2	4	Cobb Avian48	27 28	2 N/I	Mahmoud *et al*. (2019)
		2		Cobb Avian 48	27 28	2 N/I	Mahmoud *et al*. (2021)
Vaccinated (N/A)	-	9	12	Broilers	-	9 Variant	Kasem *et al*. (2015)
	-	3		Layers Broilers		3 Variant	El-Mahdy *et al*. (2011)
(H120, MA5, CR88)	-	3	3	Broilers	18-34	3 Var2	Sultan *et al*. (2017)
(H120, CR88)	-	2	2	Broilers	18-34	1 Var1 1 Var2	Sultan *et al*. (2017)
(MA5+Inactivated)	Days 7, 28, 49, 70, and 91 for Ma5 and Day 115 for inactivated	1	1	Layers	-	1 Variant	Rohaim *et al*. (2019)
Total		151			7 (Classic) 21 (Variant) 30 (Variant 2) 7 (Variant 1) 86 (N/I=not identified)		

2012, the variant vaccine strains D274, 793/B, 4/91, CR88, and attenuated IB-VAR2, representing GI-23, have been introduced to be encompassed within the vaccination schedules to control the IB outbreaks in Egypt. Despite the intensive vaccination, classic and variant IBV strains have been frequently isolated from IB outbreaks in chicken flocks (Zanaty *et al*., 2016a; Selim *et al*., 2012; Ghetas *et al*., 2016; Hassan *et al*., 2016; Elhady *et al*., 2018; Sultan *et al*., 2019).

Evaluation of IBV Vaccine programs applied in Egyptian chicken flocks (2000-2021)

IBV infection is a global problem, present frequently where poultry are reared. The virus spreads very rapidly, particularly in non-vaccinated birds. Although strict biosecurity and a one-age system are essential control procedures, vaccination is typically mandatory to protect chickens against challenges from IBV strains. This is very challenging to achieve because IBV exists in the form of many diverse antigenically or genotypically derived variants (Cavanagh and Gelb, 2008). Live vaccines similar to Mass are specifically used for priming in young birds to achieve early protection against challenge with IBV (de Wit *et al*., 2011). Adequate protection against a homologous IBV challenge for the well-vaccinated chicken is provided, but the defence against strains of different protectotypes is frequently only partial (Bijlenga *et al*., 2004), which may be due to the advent of novel variant serotypes.

Although the IBV vaccination is mandatory in Egypt still some

Table 2. Protective percentage of different vaccination programs against experimental challenges with different strains of infectious bronchitis virus among chickens during 2000–2020 in Egypt.

Vaccine program	Age of vaccination	Chicken breeds (vaccinal strain)	Age/ day of challenge	IBV–type-challenge	protection%	References
Single-Classic live H120/Ma5/M48	Day 1	Broiler (H120)	29	Egypt/F/03 (Classic strain)	58.30%	Abdel-Moneim *et al*. (2006)
		SPF (H120)	22	(IS/885) like variant strain	83%	El-Mahdy *et al*. (2012)
		SPF (Ma5)			100%	
		SPF (M48)			93%	
	Day 7	Broiler (H120)	21	1 Classic	100%	El-Shafey (2002)
				4 Variant	Not complete	
		Broiler (Ma5)	28	EG/CLLEVB-1/1BV/012/dose (Var2)	50%	Mourad (2012)
	Day 21	Broiler (H120)	49	Egypt/BeniSeuf/01 (Var1)	20%	Abdel-Moneim *et al*. (2002)
Single mixed classic +variant (IB primer)	Day 1	SPF	22	(IS/885) like variant strain	100%	El-Mahdy *et al*. (2012)
Single variant	Day 1	SPF (CR88)	22	(IS/885) like variant strain	100%	El-Mahdy *et al*. (2012)
		SPF (4/91)	22	(IS/885) like variant strain	93%	El-Mahdy *et al*. (2012)
Double variant	Day 1 (IB-VAR2) Day 14 (IB-VAR2)	SPF	28	Eg/1212B/2012) (Var2) accession number JQ839287	100%	Sultan *et al*. (2019)
(classic+variant) or (variant+classic)	Day 1 (H120) Day 14 (4/91)	Broiler	28	EG/CLLEVB-1/1BV/012 (Var2**)**	70%	Mourad (2012)
	Day 1 (H120) Day 14 (CR88)	Broiler	28	EG/CLLEVB-1/1BV/012 (Var2**)**	60%	Mourad (2012)
	Day 1 (H120) Day 14 (CR88)	SPF	30	Eg/1212B/2012) (Var2) accession number JQ839287	30%	Zanaty *et al*. (2013)
	Day 1 (H120) Day 14 (4/91)	SPF	30	Eg/1212B/2012) (Var2) accession number JQ839287	40%	Zanaty *et al*. (2013)
	Day 1 (H120) Day 14 (CR88)	Broiler	30	IS/885/00-like (IS/885)(1) (variant)	60%	Awad *et al*. (2015)
				IS/1494/06-like (IS/1494)(2)(variant)	80%	
	Day 1 (H120+CR88) Day 14 (CR88)	Broiler	30	IS/885/00-like (IS/885)(1) (variant)	83%	
				IS/1494/06-like (IS/ 1494)(2)(variant)	94%	
	Day 1 (M41) Day 14 (IB-VAR2)	SPF	28	Eg/1212B/2012) (Var2) accession number JQ839287	100%	Sultan *et al*. (2019)
	Day 21 (M41+IB-Var2) (Prepared vaccine) one shot	SPF	49	Variant IBV (Var-II) (KP729422_ IBVS1/VSVRI_G9/Egy 013)	100%	Shawky *et al*. (2020)
	Day 1 (MA5) Day 14 (IB-793B)	SPF	28	Eg/1212B/2012 (Var2) accession number JQ839287	60%	Sultan *et al*. (2019)
	Day 1 (IB-793B) Day 14 (MA5)	SPF	28	Eg/1212B/2012 (Var2) accession number JQ839287	50%	Sultan *et al*. (2019)
	Day 1 (IB-Var2) Day 14 (M41)	SPF	28	Eg/1212B/2012 (Var2) accession number JQ839287	80%	Sultan *et al*. (2019)
	Day 21 (Nobilis IB multi (M41+D274) one shot	SPF	49	Variant IBV (Var-II) (KP729422_ IBVS1/VSVRI_G9/Egy 013)	100%	Shawky *et al*. (2020)
Classic+ Mixed classic and variant (H120+D274)	Day1 (H120) Day 14 (IB primer)	Broiler	28	IS/1494/06-like (IS/ 1494)(2)(variant)	80%	Mourad (2012)
Classic+ Mixed classic and variant (H120+D274) (IB primer) plus variant	Day 1 (IB primer) Day 14 (CR88)	SPF	30	Eg/1212B/2012) (Var2) accession number JQ839287	32.50%	Zanaty *et al*. (2013)
	Day 1 (IB primer) Day 14 (4/91)	SPF	30	Eg/1212B/2012) (Var2) accession number JQ839287	42.50%	Zanaty *et al*. (2013)

chicken flocks (Backyard and small commercial) farmers did not apply any vaccination. Throughout the current search analysis of the available literature targeting IB outbreaks during the last two decades, a large number of unvaccinated broiler chickens were found ; 956 and yielded 400 IBV isolates (41.8%), accompanied by respiratory and renal troubles. The authors refereed to the exact location for only 72 IBV isolates from non-vaccinated. El-Shafey (2002) isolated only one classic and four variant IBVs from broiler chickens from Sharkia province. At the same year, Abdel-Moneim *et al.* (2002) isolated another variant from Beni-Sueif province. Later on ,all isolated IBVs were variants from different provinces along Egypt (El-Shafey, 2008; Zanaty, 2014; Lebdah *et al.*, 2017; Setta *et al.*, 2018, Ghanem *et al.*, 2019; Yehia *et al.*, 2021; Gado *et al.*, 2022). On the other hand also were hit by IBVs amongst 151 flocks under present investigation. The geo-incidence of IBVs was quantified among the vaccinated and non-vaccinated flocks all over the provinces under examination (Fig. 1 and 2).

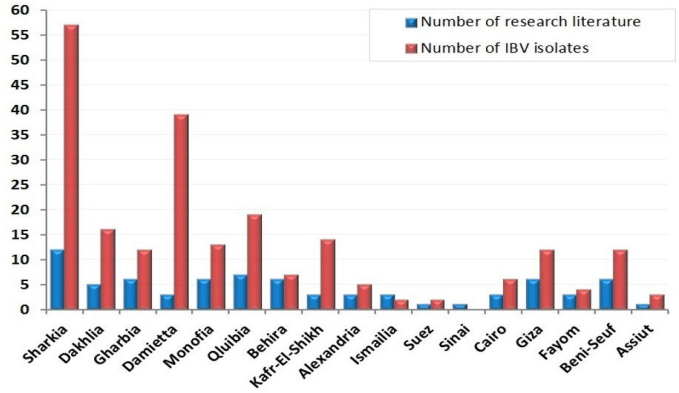

Fig. 1. The infectious bronchitis virus field strains from vaccinated and non-vaccinated chicken flocks in Egypt during 2000-2021 in view of the available literature which shows the number of literature with the number of IBV isolates.

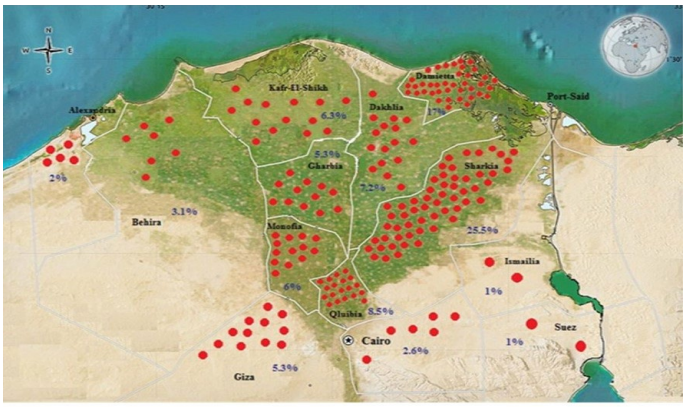

Fig. 2. The geographical incidence of infectious bronchitis virus isolated from vaccinated and non-vaccinated chicken flocks in Egypt during 2000-2021.

The descriptive data of the investigated field IBV fourteen vaccine programs were analyzed (Table 1 and Fig. 3) in view of the available literature. Through the current investigation of natural outbreaks of infectious bronchitis virus among chickens during 2000–2021 in Egypt, 151 IBVs were isolated from vaccinated birds. It was clear that the single classic vaccine at day one of the age program was broken with the highest number of field isolates between vaccinated flocks (89/151). These flocks yielded 64 untyped and 25 variant IBVs between possible novel variant strains, so the application of Mass vaccines alone is not able to provide complete protection against heterologous strains. El-Bouqdaoui *et al.* (2005) reported that Mass vaccines from time to time induce poor protection against field IBV challenges. The trials of the involvement of a variant vaccine with a classic one at 1 and 14 days of age reduced the risk of infection in most broiler chickens in Egypt. Recently, 4/91 and its related variant vaccines, e.g., CR88 and 793/B, succeeded in minimizing the hazard of IB more than other variant vaccines like D274. Abou El-Fetouh *et al.* (2016) isolated ten classic and variant strains from broiler flocks vaccinated by Double Classic and Variant, including D247. But Mahmoud *et al.* (2021) isolated only two IBVs from chickens receiving the same protocol and from broilers administered double doses of classic and variant 4/91.

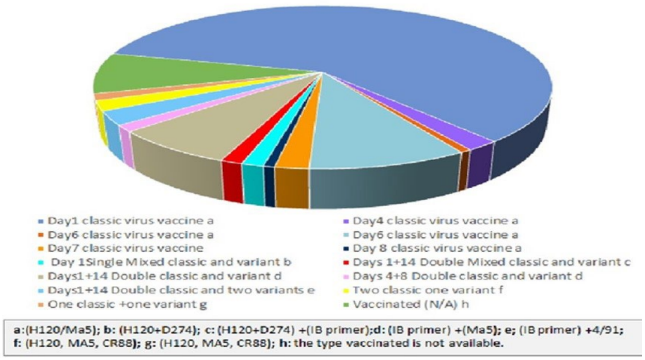

Fig. 3. The number of infectious bronchitis virus isolates from the natural outbreaks among the vaccinated chickens during 2000-2021 in Egypt.

On the other hand, the majority of flocks receiving well vaccination at the ages of 1 and 14 days with classic and variant 4/91 or related strains were relatively more efficacious (Sultan *et al.*, 2017; Mahmoud *et al.*, 2021). The variation in protection is not only related to the unsuitability of the protectotype but also may be due to errors during the immunisation process, especially with live vaccines, whose application is a very critical step. IBV is a sensitive virus that can be easily inactivated (Cavanagh and Gelb, 2008), which may result in inadequate efficacy of the vaccination under field conditions (Jackwood *et al.*, 2009; De Wit *et al.*, 2010). Also, interference with maternal-derived immunity (MDI) may leave the birds without a specific immune umbrella. The presence of vaccinated flocks adjacent to the vaccinated may complicate the control and result in the evolution of novel, diverse IBVs.

Protective worth of experimentally applied IBV vaccination regimes in Egypt (2002-2020)

Several studies in Egypt were done to catch on to the protective efficacy of different vaccination programs against challenge with variant strains of infectious bronchitis virus among chickens during 2002–2020 in Egypt (Table 2), which the most challenge viruses used in these studies are closely related to Var 2, the commonly circulating field virus in Egypt. Moreover, the percentage of protection achieved against the challenge of IBV strains through the application of different vaccination programs under experimental conditions is shown in Fig. 4. Earlier studies concluded that using the classic vaccine alone gives complete protection if the challenged virus is homologous to the vaccine (classic), as occurred in El-Shafey (2002), but soon Abdel-Moneim *et al.* (2006) recorded a less protective percent of 58.3% with the use of the homologous classic vaccine and challenge virus. The difference in the findings may be attributed to the possible mutation started in the field challenge virus. On the other hand, the protective percentage speckled from high to low according to the challenged strain; if the virus is heterologous, there is a wide range of protection and may be as low as 20% (Abdel-Moneim *et al.*, 2002); and this returned to the totally diverse viruses with a high virus load under experimental conditions of the infection

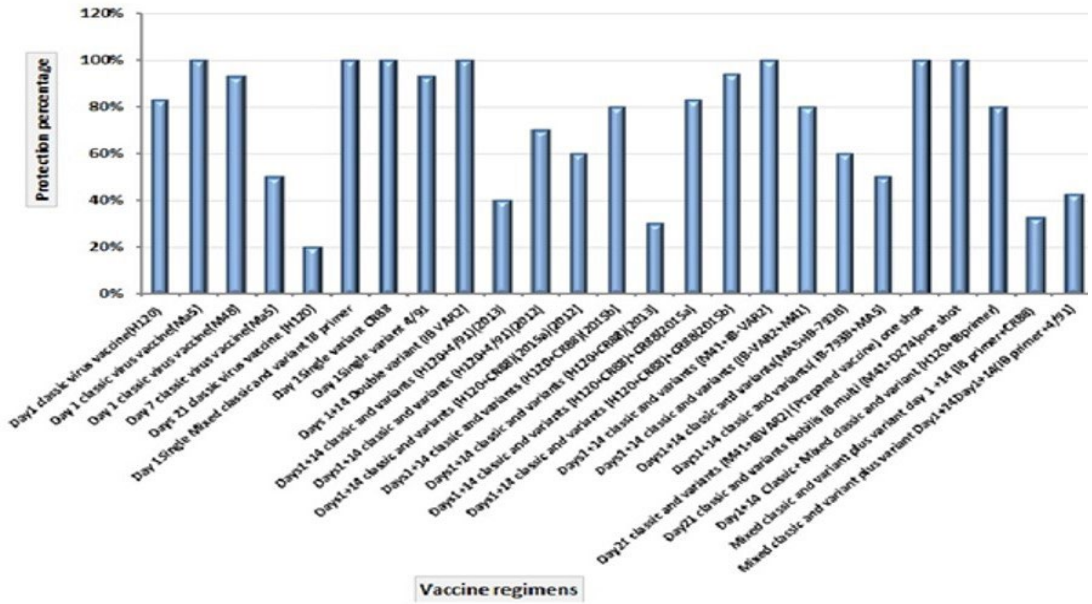

Fig 4. Protective percent of different vaccination programs against challenge with different strain of infectious bronchitis virus among chickens during 2000-2021 in Egypt.

dose. Consequently, most authors switched to using variant vaccines (D274-CR88-793B 4/91 and attenuated Var2) to shelter all aspects of immunity against different variant stains, but the pro tective percent widely varied from 32.5% (Zanaty *et al*., 2013) to 100% (Sultan *et al*., 2019; Shawky *et al*., 2020), in correspondence with the difference in SPF birds versus commercial ones with MDI, in addition to the difference in the challenge virus doses and type, as well the variant strains that were included in the vaccine program and priming with time frame. But in general, the good vaccination program under experimental conditions in recent studies revealed that twice doses with primed classical and boostered with variant strains, could accomplish more than 80 % protection in commercial birds under experimental conditions (Awad *et al*., 2015; Sultan *et al*., 2019).

Conclusion

Although in field application, no practical combination of IB vaccine strains provide full protection against all heterologous challenges, combinations of classic and variant vaccines could broaden the coverage with a condition of updated identification of the prevalent in Egypt. Bioinformatics of genotypes could help in anticipation of protectotype vaccines and including recombinant IBV vaccines to enhance the target multiple serotypes particularly in ovo vaccination approaches. All chicken flocks must be vaccinated with classic and only one variant to avoid more emergence of novel IBV.

Conflict of interest

The authors declare that there is no conflict of interest.

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