Immunological evaluation of inactivated Newcastle disease vaccine depending on adjuvant composition

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Introduction

Newcastle disease (ND) is an international problem recorded in most countries around the world and also a serious obstacle to exchange of genetic material of poultry in various countries of the world. Control of the Newcastle disease comprises correct injection of efficacious vaccines so as to decrease or eliminate the clinical disease. Our goal was to perform comparative studies of the vaccines against Newcastle disease of water in oil type, the adjuvant being mineral oil mixed with emulsifiers (Span-80 and Tween-80) and ready-to-use adjuvant system (Montanide ISA 70), and study the impact of composition of adjuvant constituent on physical-chemical and immunogenic properties of inactivated vaccines. To reproduce virus-containing material and carried out titration of the viruses, we used chicken embryos free of pathogenic microflora. Aqueous phase for the preparation of emulsion-based vaccines of water in oil type consisted of antigen to Newcastle disease of La-Sota strain, manufactured by Biotestlab Ltd, and phosphate-saline buffer.

To evaluate the effectiveness of the vaccine and induce immune response, we used 1-day old pathogen-free chickens, which were obtained from chicken embryos free of pathogenic microflora. As the positive control in the experiment, we used commercial vaccine. One-day chickens were divided into 3 groups (I, II, III) comprising 12 individuals each and one group (IV) consisting of 8 individuals as the control group with individual numeration. Chickens in groups I, II and III were divided into two subgroups (n = 8 and n = 4) to determine immunogenic efficiency and safety of the vaccine. Immunization was carried out through single subcutaneous injections in the region of the neck. To study immunogenic efficiency, the chickens were immunized with the dose of 0.1 mL (1 dose), and 0.2 mL (2 doses) to determine safety. After the immunization of 1-day old pathogen-free chickens with 0.1 mL dose, the obtained level of antibodies in the serum of vaccinated chickens on days 14, 21, 28, 35 and 42 after the vaccination indicated the ability of provoking the immune response to Newcastle disease at high level and safety of the vaccine.

Keywords: poultry; Newcastle disease; inactivated vaccine; adjuvant; postvaccinal immune response; reaction of hemagglutination.

Newcastle disease is a global problem that is being recorded in most countries and also a serious obstacle to exchange of genetic material of poultry in various countries of the world. Control of the Newcastle disease comprises correct injection of efficacious vaccines so as to decrease or eliminate the clinical disease. Our goal was to perform comparative studies of the vaccines against Newcastle disease of water in oil type, the adjuvant being mineral oil mixed with emulsifiers (Span-80 and Tween-80) and ready-to-use adjuvant system (Montanide ISA 70), and study the impact of composition of adjuvant constituent on physical-chemical and immunogenic properties of inactivated vaccines. To reproduce virus-containing material and carried out titration of the viruses, we used chicken embryos free of pathogenic microflora. Aqueous phase for the preparation of emulsion-based vaccines of water in oil type consisted of antigen to Newcastle disease of La-Sota strain, manufactured by Biotestlab Ltd, and phosphate-saline buffer.

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All the recipes of the examined series of the vaccines and the commercial vaccine produced appropriate level of viscosity according to the criterion equaling ≤ 200 mm²/s at Р <0.05, promoting fluidity of the vaccine and providing easier passage through the needle during the application. Both of the studied vaccines may be used in poultry farming for prophylaxis of Newcastle disease among chickens.

Keywords: poultry; Newcastle disease; inactivated vaccine; adjuvant; postvaccinal immune response; reaction of hemagglutination.
vaccines is that they require a withdrawal period before the vaccinated birds can be processed for consumption by humans and each vaccine needs to be subcutaneously or intramuscularly injected individually. However, inflammatory reactions often occur in the places where injection has been made. Also, unfavourable local reactions after injecting emulsion-based vaccines, such as granulomas, are the main factor that should be taken into account when using liquid paraffin as an adjuvant (Fukano et al., 2001). Nonetheless, birds vaccinated with inactivated vaccines usually have a high level of humoral antibodies compared with birds vaccinated with live anti-ND vaccines (Miller et al., 2013; Schijns et al., 2014). Furthermore, birds were observed to have no specific side effects after immunization with anti-ND vaccines. In all the experimental birds, mild conjunctivitis was observed, which was gone in 2 days (Miller et al., 2009).

Despite decades of studies and development of an optimum vaccine against ND and presence of sufficient amount of commercial vaccines, improvement of the recipe would be still relevant. Improvement of the vaccine consists of developing antigen variations (Sedeik et al., 2019) and various emulsion adjuvants. Also, to prevent safety-related problems, one should pay special attention to the quality of selected surfactants and natural oils which are being implemented (Arous et al., 2013). A study was made of serologic reaction of chickens, which varied 10–100 times after vaccination with different types of adjuvants or emulsifiers of ordinary homogenization (Brugh et al., 1983). Emulsion adjuvant accounts for a large part of the formulation of efficient inactivated vaccine for birds. Safe water-in-oil adjuvants induce humoral immune response, production and potentiation of antibodies, increase duration of antibodies' response, reduce frequency of vaccination and the amount of necessary antigen in each dose of vaccine, and therefore are broadly used in the compound of inactivated vaccines (Jafari et al., 2017; Yuan et al., 2020). Search of new adjuvants that would increase the cellular response or decrease the dose of injected vaccine and number of necessary vaccinations, or antigenic load in vaccine, may help enlarge the cross protection against various virulent strains or serotypes (Arous et al., 2013; Gharanjali et al., 2020). The assortment of registered vaccines against Newcastle disease in Ukraine is represented by 6 leading foreign producers and one domestic one, developed by Biotestlab Ltd, which were developed in the form of emulsion and contain various emulsion adjuvants.

Studies often focus on implementing effective ready-to-use adjuvants based on specific mineral oils such as Montanide ISA 71 VG or ISA 70, or application of well-known available oils, such as palm oil, with addition of antioxidants (Wanasawaeng et al., 2009; Arous et al., 2013). A study was made of scrologic reaction of chickens, which varied 10–100 times after vaccination with different types of adjuvants or emulsifiers of ordinary homogenization (Brugh et al., 1983). Emulsion adjuvant accounts for a large part of the formulation of efficient inactivated vaccine for birds. Safe water-in-oil adjuvants induce humoral immune response, production and potentiation of antibodies, increase duration of antibodies' response, reduce frequency of vaccination and the amount of necessary antigen in each dose of vaccine, and therefore are broadly used in the compound of inactivated vaccines (Jafari et al., 2017; Yuan et al., 2020). Search of new adjuvants that would increase the cellular response or decrease the dose of injected vaccine and number of necessary vaccinations, or antigenic load in vaccine, may help enlarge the cross protection against various virulent strains or serotypes (Arous et al., 2013; Gharanjali et al., 2020). The assortment of registered vaccines against Newcastle disease in Ukraine is represented by 6 leading foreign producers and one domestic one, developed by Biotestlab Ltd, which were developed in the form of emulsion and contain various emulsion adjuvants.

This study was performed according to the principles described in the guidelines of maintenance and use of experimental animals, according to the ethic norms written in Order No. 3447-IV of 21.02.2006 “On Protection of animals against abuse”. To prepare the experimental series of vaccine, we used local vaccine Newcastle disease virus strain La-Sota, obtained from the strain bank Biostestlab Ltd and replicated using the method of inoculation into the chorioallantoic membrane of 9–11 days old pathogen-free chicken embryos produced by VALO BioMedia, Germany. Correspondence of the strain was confirmed using the method of real time polymerase chain reaction. Hemagglutinin activity of Newcastle disease virus La-Sota strain was determined in hemagglutination reaction (OIE Terrestrial Manual, 2018) by preparing sequential two-fold dilutions of the material in 96-well plates with following addition of 1% suspension of erythrocytes from rooster. To prepare the series of vaccines, we used oil adjuvants: 1) mixture of mineral oil (Panulift® GmbH, Germany) combined with emulsifiers Span-80 (Shenzhen Ruiqi Import&Export Co., Ltd, China) and Tween-80 (Shenzhen Ruiqi Import & Export Co., Ltd, China); 2) Montanide ISA 70 (Seppic, France).

Specific free pathogen (SPF) chicken embryos manufactured by VALO BioMedia, Germany were used for replication of virulent material and titration of the viruses. To assess the efficiency of the vaccine and induction of the immune response, we used 1 day-old SPF chickens, obtained using SPF chicken embryos. All experimental studies of the poultry were conducted at the basis of BIOTESTLAB Ltd vivarium. The vivarium was equipped according to the sanitary hygienic norms (19–24 °C temperature, moisture no higher than 50%, in daylight regime “day–light”). During the experiment, chickens of all the studied groups were kept in SPF boxes for isolated maintenance (Qingdao, China). Maintenance, feeding and watering were the same for all the poultry groups. Throughout the monitoring of the immunogenic efficiency and safety, the chickens were kept on a balanced fodder diet and had free access to food and water. All the procedures with the animals were performed following the International Rules and Norms of Bioethics.

Emulsion-based vaccines of water-in-oil type were prepared with the concentration of virus antigen equivalent to 109.0 ELD50 (average lethal dose for embryo) per 0.1 mL of vaccine (1 dose) (Reed et al., 1938). The aqueous phase for preparation of emulsion-based vaccines of water-in-oil type consisted of an inactivated antigen of Newcastle disease, La-Sota strain, manufactured by Biostestlab Ltd and phosphate-saline buffer (hereinafter – PSB). The antigen was accumulated in SPF chicken embryos aged 10 days, the incubating regime being 72–96 h in 37–38 °C temperature and 40–70% moisture. Inactivation of the antigen was carried out by introducing physiological saline in the dose of 0.05% of the final concentration to the amount of antibody, which was then kept for 24 h in 20–25 °C temperature, being regularly stirred (Hongzhuan et al., 2020). Complete- ness of inactivation of the virus was performed using the methods according to E.P.9.3.01/2017:0870 Newcastle disease vaccine (inactivated). 2.5.1. The residual live virus was made by infecting 10 chicken embryos aged 9–10 days and three subsequent “blind” passages using a mixture of allantoic fluid, taken in equal amounts from each embryo of the previous passage, for the purpose of infecting. Collected allantoic fluid was examined in accelerated qualitative reaction of hemagglutination using 5% suspension of erythrocytes from rooster.

The oil phase for preparation of series I–WO PST of the emulsion-based vaccine consists of a mixture of mineral oil with surfactants Tween-80 (manufactured by Shenzhen Ruiqi Import & Export Co., Ltd) and Span-80 (manufactured by Shenzhen Ruiqi Import & Export Co., Ltd). For II–WO MISA series of the vaccine, we used the ready-to-use adjuvant system Montanide ISA 70 for emulsification.

The vaccines were prepared by homogenizing the emulsion with laboratory homogenizer IKA ULTRA–TURRAX T manufactured by IKA® – Werke GmbH & Co. KG, Germany. The aqueous phase was added to the oil phase in small portions, while constantly stirring the oil phase using magnate (anchor) stirrer for 10–15 min until the formation of pre-emulsion. After mixing the oil and water phases, the mixture was emulsified again.

Oil adjuvants were mixed with aqueous phase in the proportion that would provide the formation of stable emulsion of reverse type water in oil. Recipes of the series of emulsion-based vaccines are provided in Table 1.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Recipe of experimental series of emulsion-based inactivated vaccines of overall volume measuring 250 mL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Studied materials</strong></td>
<td><strong>Aqueous phase, mL</strong></td>
</tr>
<tr>
<td>Series I–WO PST</td>
<td>97.5</td>
</tr>
<tr>
<td>Series II–WO MISA</td>
<td>75.0</td>
</tr>
<tr>
<td>Commercial vaccine</td>
<td>commercial inactivated vaccine</td>
</tr>
<tr>
<td>Control (PSB)</td>
<td>250.0</td>
</tr>
</tbody>
</table>

Note: series I–WO PST – vaccine prepared using mineral oil mixed with Tween-80 and Span-80 as adjuvant; series II–WO MISA – vaccine prepared using Montanide ISA 70 as adjuvant; “–” – not used.
The prepared experimental series of inactivated vaccine against Newcastle disease corresponded to the quality control according to the following parameters: sterility, safety, kinetic viscosity, stability of emulsion, immunogenic efficiency, residual amount of formaldehyde.

The greater is fluidity, the thicker (more viscous) is the fluid, which makes the passage of the emulsion through the needle harder and may be a factor for the duration of vaccination of a large population of poultry. Kinematic viscosity was determined using capillary viscosimeter VPH-1 (manufactured by Ecros, Russia). The temperature of the tested liquid was 20 °C. Time for the liquid to pass from one mark of the viscosimeter to another was measured using a stopwatch with accuracy up to 0.2 s. The obtained data were considered favourable if two subsequent measurements were different by no higher than 1%. Time of leaking of the liquid was determined as mean value of no less than three measurements. Kinematic viscosity was calculated using the formula \( v = \frac{l}{t} \) and expressed in square millimeters per second (mm²/s). Kinematic viscosity of the vaccine should be ≤200 mm²/s.

Stability of vaccine’s emulsion was tested using the centrifugation method with employment of laboratory centrifuge Centrisart G-16C (manufactured by Sartorius, Germany). The flacon with the vaccine was thoroughly shaken, and then we added 8.0 mL of the vaccine to each centrifuge test tubes and centrifuged at 3,000 rpm for 20 min. The height of the column of transparent fraction was measured in mm. The emulsion was considered stable if the test tubes were observed to have no development of transparent fraction in the upper part or if the height of the column of the transparent fraction, which could develop in the upper part, did not exceed 10% of the volume, and the divided fractions easily formed homogenous emulsion after shaking.

Safety was determined using the method developed according to the European Pharmacopoeia 9.3, 04/2013:50206 Evaluation of safety of veterinary vaccines and immunosera. Safety of 1 administration of an overdose. The vaccine in the volume of 0.2 mL (2 doses) was injected to the chickens aged one day with the SPF status into the region of the neck. The monitoring of chickens lasted for 14 days. The vaccine was considered safe if all the chickens stayed healthy for 14 days of the monitoring and had no clinical manifestations that are characteristic of Newcastle disease. The tissues’ reaction in the place of the vaccine injection was determined by dissection on the 14th day after the vaccination. We evaluated the condition of the neck muscles in the region of the injection and determined the tissues’ reaction according to the following gradation: moderate level (pale muscles in the region of injection and absence of vaccine residuals), intermediate level (the surface muscles were pale to red and a small amount of the vaccine was present as drops), severe level (inflammation of the surface and deep muscles and residuals of the vaccine in the regions of injections, observed during autopsy) (Wanasawang et al., 2009).

Pathogen-free chickens, obtained from SPF embryos, were kept in boxes for isolative maintenance (Qingdao, China). Single-day SPF chickens were divided into three groups (I, II, III) each comprising 12 individuals (n = 12) and one group (IV) containing 8 individuals as the control group with individual numeration. Chickens in groups I, II and III were divided into two subgroups (n = 8 and n = 4) to determine immunogenic efficiency (a) and safety (b) of the vaccine. Immunization was carried with single subcutaneous injection in the region of the neck. To study the immunogenic efficacy, the chickens were immunized with the dose of 0.1 mL (1 dose), to study safety – in the dose of 0.2 mL (2 doses). Groups Ia, Ib were vaccinated with series І–WO PST. Groups Ia, Ib received series II–WO MISA. Groups IIIa, IIIb were vaccinated with the commercial vaccine. Group IV – the control – was vaccinated with PSB. Immunization matrix of poultry is presented in Table 2.

**Table 2**

<table>
<thead>
<tr>
<th>Group of studied animals</th>
<th>Number of chickens in group</th>
<th>Examined parameter</th>
<th>Vaccination at 1 day of age</th>
<th>Study method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ia</td>
<td>8</td>
<td>immunogenic efficiency</td>
<td>subcutaneously in the region of the neck (series I–WO PST)</td>
<td>blood draw</td>
</tr>
<tr>
<td>Ia</td>
<td>8</td>
<td>safety</td>
<td>(dose of 0.1 mL; 1 dose)</td>
<td>dissection of chickens</td>
</tr>
<tr>
<td>Ila</td>
<td>8</td>
<td>immunogenic efficiency</td>
<td>subcutaneously in the region of the neck (series I–WO PST)</td>
<td>blood draw</td>
</tr>
<tr>
<td>Ila</td>
<td>8</td>
<td>safety</td>
<td>(dose of 0.2 mL; 2 doses)</td>
<td>dissection of chickens</td>
</tr>
<tr>
<td>IIIa</td>
<td>8</td>
<td>immunogenic efficiency</td>
<td>subcutaneously in the region of the neck (commercial vaccine)</td>
<td>blood draw</td>
</tr>
<tr>
<td>IIIa</td>
<td>8</td>
<td>safety</td>
<td>(dose of 0.2 mL; 2 doses)</td>
<td>dissection of chickens</td>
</tr>
<tr>
<td>IV</td>
<td>8</td>
<td>control of the study of immunogenic efficiency</td>
<td>subcutaneously in the region of the neck (sterile PSB)</td>
<td>blood draw</td>
</tr>
</tbody>
</table>

**Note:** see Table 1.

Blood of chickens was drawn every 7 days starting from the 14th day after the vaccination, in particular days 14, 21, 28, 35 and 42. Blood samples were taken from the ulnar wing in the amount of 0.2–2.5 mL using a sterile 5.0 mL syringe, transferred to test tubes and centrifuged at 1,500 rpm for 10–15 min. We separated the serum for serologic studies.

To evaluate the immunogenic efficiency of the vaccine, we studied blood serum of chickens in the reaction of hemagglutination inhibition (HI) according to the generally accepted methods, recommended by the OIE (OIE Terrestrial Manual, 2018) and method of enzyme-linked immuno sorbent assay, ELISA. The studies using the hemagglutination inhibition reaction are based on the fact that antibodies form an antigen-antibody complex when they meet the virus and neutralize hemagglutinins of the virus. Titer of antibodies to Newcastle disease was studied using 96-well plates, testing the samples against their homologic antigens of the vaccines (Rahman et al., 2017).

Of the studied blood serums of chicken, we prepared subsequent two-fold dilutions with additions of PBS. Then, equal amounts of operating dilution in concentration of 4 HA of ND virus were added to each well. The plate was incubated at the temperature of 37 °C for 30 min to achieve interaction between the examined serum and viruses. After the exposure, an equal amount of 1% suspension of rooster’s erythrocytes was added to each well and the plates were incubated in 20 °C temperature for 20–30 min. Erythrocytes were the indicator of presence of the virus in the mixture. Agglutination of erythrocytes indicated the presence of the virus in the mixture, while its absence indicated the absence of the virus because the antibodies had completely neutralized the hemagglutination activity of the virus. HI titer is the greatest dilution of the serum which causes complete inhibition of 4 HA antigen. Agglutination was assessed by tilting the plates. The result was considered positive after sedimentation of erythrocytes at the bottom of the plate’s wells. Significance of the result was assessed by comparing it to the control serum (negative control) that contained no antibodies to virus hemagglutinin of Newcastle disease. Only the wells in which erythrocytes leaked at the same rate as the control were considered as those that demonstrated the inhibition (OIE Terrestrial Manual, 2018). Titer was recorded as log₂ of greatest dilution of serum, at which the hemagglutination inhibition (absence of hemagglutination) was observed, i.e. presence of homogeneous layer of erythrocytes as sediments at the bottom of the wells of the plate. Titer of antibodies to ND 1:16 (4 log₂) and more was considered protective. ELISA is based on the main immunological concept of antibody that binds to its specific antigen, the-
rely allowing an identification of the amount of antibodies in the sample. ELISA has been developed on the general immunologic concept of specific interaction between antibody and antigen which allows assessment of the level of antibodies in sample of blood serum (Gan et al., 2013). Blood serum of chickens drawn 14, 21, 28, 35 and 42 days after the immunization was examined using a commercial ELISA test kit (IDEXX Newcastle Disease Virus Antibody Test Kit, USA) to determine specific antibodies to the Newcastle disease virus of chickens. The kit contained 96-well plates, the wells coated with antigen of Newcastle disease virus. The serum samples were prepared in 1:5,000 dilution and incubated in 96-well plates according to the manufacturer’s recommendations concerning the ELISA. After introduction of ND antibodies-holding serum to the wells, immune reaction occurred, forming a specific antigen-antibody complex, which strongly stood on the surface of the well. After the wells had been rinsed to remove non-specific components, the conjugant was introduced (Goat anti-chicken: HRPO), binding specifically to the antigen-antibody complex. The wells were rinsed to remove the residuals of the conjugant, and then we added TMB substrate for the enzymatic ELISA phase that occurred having changed the colour in the wells, the intensity being directly proportionate to the amount of antibodies in the sample. 

Presence or absence of antibodies to Newcastle disease was determined according to the value that is estimated as the ratio of optical density (OD) of the examined sample to optical density of the mean value of the positive control. As positive control, we used the kit’s standardized sample of blood serum of chickens with a certain level of antibodies to Newcastle disease virus.

Relative level of antibodies in the examined samples was determined according to formula S/P parameter that was calculated as ratio of difference of optical density parameters of the sample and mean value of optical density of the negative control to the mean values of positive and negative control.

In evaluating the results, if the value of the ratio of the serum sample to the positive control was ≥ 0.2, such sample of serum was considered negative, if the value was higher than 0.2, the sample was considered positive, indicating presence of antibodies to Newcastle disease.

Titer of antibodies was calculated according to the formula:

\[ \log_{10}\text{Titer} = 1.09(\log_{10}S/P) + 3.36 \]

The result of the analysis was considered actual if the difference between the mean value of optical density of the positive control and mean optical density for the negative control was more than 0.075, and the average value of negative controls was no more than 0.150. Titer of antibodies to Newcastle disease at the level of 397 and higher was considered positive, indicating presence of antibodies to Newcastle disease virus.

Results

All chicken embryos that were injected formaldehyde-inactivated virus survived more than 120 h, and no viruses were found by the express test for HA (hemagglutination reaction), indicating complete inactivation of Newcastle disease virus. The results of determining the kinematic viscosity in II–WO MISA series were at the level of 40–42 mm²/s, which is lower compared with the results of I–WO PST series – 80–88 mm²/s. All the recipes of the examined series of the vaccines provided an acceptable level of viscosity according to the adopted criterion equaling ≤ 200 mm²/s at P < 0.05, which promoted fluidity of the vaccine and provided easy passage through the needle. The prepared emulsion-based vaccines of water in oil type of series I–WO PST, series II–WO MISA and the commercial vaccine exhibited no division of oil and water phase during the maintenance for more than 4 weeks in 4 °C. In 37 °C, sample of II–WO MISA series and commercial vaccine displayed stability for more than 4 weeks and sample of I–WO PST series demonstrated separation of oil and water phases by layers on the 4th week of monitoring (Table 3), which, however, was easily restored in homogenous emulsion after intense shaking.

Table 3

Results of determining kinetic viscosity and stability of series of emulsion vaccines (x ± SD)

<table>
<thead>
<tr>
<th>Studied materials</th>
<th>Monitoring period</th>
<th>Time, s</th>
<th>Kinematic viscosity, mm²/s</th>
<th>Stability, weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Series I–WO PST</td>
<td>starting point 0</td>
<td>2470 ± 2.3</td>
<td>80 ± 0.6</td>
<td>&gt;4</td>
</tr>
<tr>
<td>PST</td>
<td>10 months</td>
<td>251.2 ± 0.6</td>
<td>81 ± 0.6</td>
<td>&gt;4</td>
</tr>
<tr>
<td>16 months</td>
<td>271.4 ± 1.2</td>
<td>88 ± 0.6</td>
<td>&gt;4</td>
<td></td>
</tr>
<tr>
<td>Series II–WO MISA</td>
<td>starting point 0</td>
<td>1230 ± 0.2</td>
<td>40 ± 0.0</td>
<td>&gt;4</td>
</tr>
<tr>
<td>MISA</td>
<td>10 months</td>
<td>1266 ± 0.5</td>
<td>41 ± 0.0</td>
<td>&gt;4</td>
</tr>
<tr>
<td>16 months</td>
<td>130.7 ± 0.7</td>
<td>42 ± 0.6</td>
<td>&gt;4</td>
<td></td>
</tr>
<tr>
<td>Commercial vaccine</td>
<td>16 months</td>
<td>163.2 ± 2.2</td>
<td>53 ± 0.6</td>
<td>&gt;4</td>
</tr>
</tbody>
</table>

Note: the tests were made in 20 °C, 45% moisture; the presented values are values ± standard deviations, difference was considered significant at P < 0.05.

The results of safety tests of the experimental samples of the vaccine were analyzed by assessing the vitality of chickens at dissection 14 days after the vaccination. All chickens (group Ib, group Iib and group Iib – 12 chickens total) remained healthy for 14 days of monitoring and had no clinical manifestations that are characteristic of Newcastle disease. The results of the autopsy of the chickens of groups Ib, Iib and Iib are provided in Table 4.

Fourteen days after the vaccination, titers of antibodies of groups Ia and Ila, determined using hemagglutination inhibition reaction, equaled 1:52 and 1:108 respectively, while the values of chickens that received the commercial vaccine accounted for 1:15. Twenty one days after the vaccination, the quantitative parameters of titers of antibodies increased as follows: group Ia – 1:272, group Ila – 1:336, group Iib – 1:28. The results of titer of antibody 28 days after the vaccination revealed the quantity of antibodies in blood serum of experimental groups Ia and Ila at the levels of 1:400 and 1:512 respectively, titer of antibodies of chickens of group Ila equaled 1:64. Thirty five days following the vaccination, the quantitative parameters of antibodies in poultry groups Ia and Ila equaled 1:368 and 1:496 respectively, the parameters for the commercial vaccine accounted for 1:80. The parameters of blood serum of the control groups of chickens (group IV) were within 1:0–1:2 throughout the study.

In all the studied samples of serum, 16 chickens (67% of vaccinated chickens) were observed to have protective level of the immunity, being at the level of 6 log⁻⁷ – 7 log⁻⁷, (groups Ia and Ila) on the 14th day after the vaccination; the formation of antibodies at the protective level measuring 4–5 log⁻¹ was observed in 8 chickens of group Ila (33% of vaccinated chickens) on the 21st day after the vaccination. Antibodies of all chickens of group IV (100% of non-vaccinated chickens) were at the maternal level. Table 5 presents the determined mean level of antibodies in the reaction of hemagglutination inhibition in blood serum of examined groups Ia, Ila, Iib and IV after the vaccination. Figure 1 shows the dynamics of the development of the immunity in chickens after the vaccination with the examined series of vaccines according to the results.

<table>
<thead>
<tr>
<th>Group of examined animals</th>
<th>Examined materials</th>
<th>Level of the tissue reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ia</td>
<td>series I–WO PST</td>
<td>moderate</td>
</tr>
<tr>
<td>Iib</td>
<td>series II–WO MISA</td>
<td>intermediate</td>
</tr>
<tr>
<td>Iib</td>
<td>commercial vaccine</td>
<td>heavy</td>
</tr>
</tbody>
</table>

Note: the results are presented as a/b, where a is number of chickens with identified level of damage to the tissue, b is number of chickens in group.
of determining the mean level of antibodies in the reaction of hemagglutination inhibition. Comparative analysis of the selections was carried out within each group in ANOVA software.

Table 5
Quantitative values of mean level of antibodies in blood serum of chickens after vaccination, determined in hemagglutination inhibition (x ± SE, n = 8)

<table>
<thead>
<tr>
<th>Groups of chickens</th>
<th>Period after the vaccination, days</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>14</td>
</tr>
<tr>
<td>Ia</td>
<td>52 ± 6</td>
</tr>
<tr>
<td>Iia</td>
<td>108 ± 25</td>
</tr>
<tr>
<td>IIIa</td>
<td>15 ± 3</td>
</tr>
<tr>
<td>IV</td>
<td>0 ± 0</td>
</tr>
</tbody>
</table>

Figure 1. Dynamics of development of immunity in chickens after vaccination with the studied series of vaccines according to the results of determining mean level of antibodies in the reaction of hemagglutination inhibition (HI)

Parameters of average titer of antibodies in blood serum of chickens of groups Ia and Iia, determined using the method of immunoenzymatic analysis 14 days after the vaccination, equaled 281 and 487 respectively, and 286 in group IIIa. Twenty one days after the vaccination, the parameters achieved the levels of 1,455, 4,094 and 1,330 in groups Ia, Iia and IIIa respectively. Twenty eight days after the vaccination, mean titers of antibodies of chickens from groups Ia, Iia and IIIa were 4,676, 10,139 and 5,938 respectively. Thirty five days after the vaccination, the parameters in blood serum were at the levels of 9,154 and 14,024 in chickens of groups Ia and Iia respectively, and 5,938 in group IIIa. Parameters of blood serum of the control group of chickens (group IV) was within 1–77 throughout the study.

According to the results of the study, antibodies in all the serum samples of all 100% of vaccinated chickens were at the protective level on the 21st day after the vaccination, though the level of immunity in group Iia was 2.5 times higher compared with the chickens of groups Ia and IIIa. The highest level of antibodies in the examined chickens was observed on the 35th day following the vaccination.

Table 6 provides the results of determining mean level of antibodies using the method of immunoenzymatic analysis in blood serum in examined groups Ia, Iia, IIIa and IV after the vaccination.

Using the parameters of immunogenity determined using ELISA method 35 days after the vaccination with the studied series of vaccines, we carried out integrated assessment of the degree of immunity development in the context of the parameters of the level of antibodies according to titer groups and inferred variation coefficient (% CV) for each studied group of chickens. The determined variation coefficient was 24.4% in chickens of group Ia (series I–WO PST), 37.6% in group Iia (series II–WO MISA), 19% in group IIIa (commercial vaccine).

Table 6
Results of quantitative determining of mean level of antibodies in blood serum of chickens after the vaccination using immunoenzymatic method (x ± SE, n = 8)

<table>
<thead>
<tr>
<th>Groups of chickens</th>
<th>Period after the vaccination, days</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>14</td>
</tr>
<tr>
<td>Ia</td>
<td>281 ± 455</td>
</tr>
<tr>
<td>Iia</td>
<td>70 ± 401</td>
</tr>
<tr>
<td>IIIa</td>
<td>487 ± 494</td>
</tr>
<tr>
<td>IV</td>
<td>179 ± 57</td>
</tr>
<tr>
<td></td>
<td>286 ± 130</td>
</tr>
<tr>
<td></td>
<td>57 ± 49</td>
</tr>
<tr>
<td></td>
<td>49 ± 12</td>
</tr>
<tr>
<td></td>
<td>14 ± 3</td>
</tr>
</tbody>
</table>

Figure 2 demonstrates the dynamics of development of the immunity in chickens after vaccination with the examined series of the vaccine according to the determined mean levels of antibodies using the immunoenzymatic analysis (ELISA). Comparative analysis of the selections was performed within each group in ANOVA software.

Discussion
Vaccination using La-Sota vaccine strain has successfully protected the birds against the mortality caused by Newcastle disease and decreased expressiveness of the clinical signs, pathological changes and cloacal isolation of the virus (Abd-Ellatieff et al., 2021). Lentogenic La-Sota strain for the vaccination of newborn single day chickens provided protection of broiler chickens throughout the life cycle (Cvetić et al., 2021).

Inactivated vaccines that are used to protect poultry require selecting oil adjuvants to induce the sufficient level of immune response. Safety of adjuvant in emulsion of water-in-oil formulation is important for oil adjuvants in order to induce the sufficient level of immune response.

The development of receipt of effective inactivated vaccine against Newcastle disease (Arous et al., 2013; Aljumaili et al., 2020). Adjuvants enhance immunity to vaccines and experimental antigens through various mechanisms. Advantages of oil adjuvants which one may expect include increase in the immune response and duration of the protection provided by the vaccine (Coffman et al., 2010). Furthermore, alterations in quantitative and qualitative characteristics of adjuvants in the content of the vaccine may be achieved by reducing the injection dose of the vaccine.
number of necessary injections and antigen load in the vaccine. Emulsions of water-in-oil type which contain liquid paraffin as adjuvant are used for injecting the food animals, and change of such an adjuvant is advisable because of deleterious side effects on animals and risk of residuals of liquid paraffin in food derived from those animals (Heegaard et al., 2011). Montanide ISA 70, which is an oil-based ready-to-use adjuvant, is to a high degree used in the production of oil emulsions for vaccines against poultry diseases. Using ready-to-use Montanide ISA system as adjuvant reduces the number of technological stages during the preparation of emulsion, thereby making a significant difference in the overall duration of vaccine preparation as compared with using multi-component adjuvants that require additional time and costs to prepare emulsions (Cahyani et al., 2020). Despite the fact that inactivated vaccines containing Montanide ISA 70 as oil adjuvant demonstrate significant efficacy and safety profile compared with other analogues, there is a need for development and selection of other, cheaper oil adjuvants.

In this research, we compared the studies of the vaccines against Newcastle disease of water in oil type with mineral oil mixed with emulsifiers (Span-80 and Tween-80) as adjuvants and ready-to-use adjuvant system (Montanide ISA 70) and studied the impact of adjuvant component on physical-chemical and immunogenic properties of the vaccines. We used oil adjuvant in the compound of the vaccine against Newcastle disease to increase the humoral response. Novel Montanide ISA 70 adjuvant is expected to improve the efficiency of vaccines for poultry, because the adjuvant system consists of enriched light mineral oil that is able to stimulate both humoral and cellular immune responses; it has been developed specifically for the purpose of stimulation of cellular immunity. Also, Montanide ISA 70 has been found to provoke strong humoral and cellular immune responses in subcutaneous vaccines for chickens (Jung et al., 2011). The anti-Newcastle disease vaccine series that we prepared were sterile, had no alien contaminations and were safe for vaccination of chickens and caused no manifestation of the disease after the injection into the chickens’ bodies according to the recommendations of the OIE (OIE Terrestrial Manual, 2018).

We determined that kinematic viscosity of series II–WO MISA was two-fold lower compared with the sample of series I–WO PST and 1.5 times lower compared with the commercial vaccine, which would make the application of the vaccine much easier in the process of immunization of poultry. Nonetheless, all examined receipts of vaccine series produced acceptable level of viscosity according to the criterion established as ≤ 200 mm²/s at P < 0.05, which promoted fluidity of the vaccine and provided easy passage through the needle during the injection.

All the vaccines were observed stable in 4 °C for more than 4 weeks in all the studied samples of emulsifying vaccines, including the commercial vaccine. In 37 °C, the duration of the stability of emulsifying vaccine of series I–WO PST was determined as less than 4 weeks, there was observed layer separation of oil and aqueous phases on the time point of 4-weeks of the observation, but this may easily reduce into homogenous emulsion after the intensive shaking. At the same time, other samples of the vaccines exerted stability throughout more than 4 weeks maintenance period.

To study the safety of vaccines, we carried out the monitoring of chickens vaccinated with different vaccines for 14 days following the vaccination. After the experiment, we evaluated the histological damages to the tissues in the injection region at autopsy. The tissues in the region of the injections of vaccines (neck muscles) were treated and evaluated by medical examiners. The results of studying the level of tissue damages revealed that no serious damage was caused to any of the chickens. Also, we determined efficiency and safety of mineral oil in the mixture with emulsifiers Span–80 and Tween–80 as adjuvant in the compound of inactivated vaccine against Newcastle disease, which leads to no greater harm compared with Montanide ISA 70 as adjuvant, which is a standard for other oil adjuvants.

To compare the protective efficiency of these vaccines, we obtained the responses of antibodies of birds vaccinated with various vaccines and the level of immune response in the vaccinated and control groups of birds was determined according to mean numbers of antibodies to Newcastle disease using the (ELISA) method and reaction of hemagglutination inhibition (HI). Newcastle disease virus is known as avian paramyxovirus that causes economically harmful and contagious avian disease. NDV contains three proteins associated with nucleocapsid proteins (NP, P and L), two glycoproteins (hemagglutinin-neuraminidase (HN) and hybrid protein (F)) and protein M (Fukano et al., 2001). Protein HN of NDV has both hemagglutinative and neuraminidase activities and plays a certain role in the disease, causing virus to bind to the receptor of the host cell. Test for hemagglutination inhibition (HI) is used in ND serology most commonly, its usefulness in diagnostics depends on the immune status of the poultry vaccine that is being tested, as well as the dominating diseases (OIE Terrestrial Manual, 2018). Using HI reaction, one can solve diagnostic tasks such as detecting and identifying the titer of antibodies in the blood serum using a known virus, and also identify unknown viruses by studying it with various known serums (antibodies).

The literature reports that vaccination-caused stress increased the level of adrenocorticotropic hormone and cortisol in blood serum, affected the growth parameters (mean daily increment, mean daily food consumption and coefficient of fodder conversion (Li et al., 2020). After immunizing one-day old SPF chickens with 0.1 mL dose, the level of antibodies in their blood serum was much higher on days 14, 21, 28, 35 and 42 following the vaccination in the group injected with adjuvant vaccine of series II–WO MISA, compared with the other groups, though both of the experimental vaccines of I–WO PST and II–WO MISA series induced the immunity up to the protective level. The highest parameters of the immune protection were seen 35 days after the vaccination. The levels of antibodies after the vaccination with the commercial vaccine were found to be much lower than in cases of injecting the experimental series of emulsifying vaccines throughout the study. In the conducted study of immunogenic efficiency, all the vaccinated groups of chickens exhibited increase in titers of antibodies compared with non-vaccinated chickens, which allowed determining the dynamics of the immunity development. The applied adjuvants that were included in the tested series of the vaccines exerted immunogenic properties, leading to protective immunity. The data obtained in our study are valuable for testing the potency of inactivated vaccines, because the European Pharmacopoeia does not indicate this antigen, which should be used in HI test. Serologic test for hemagglutination inhibition (HI) is simple to use, but is difficult to standardize among laboratory operators and in inter-laboratory control. Test for hemagglutination inhibition is considered the standard serologic test for detecting antibodies to Newcastle disease virus (Hassan et al., 2020). Nowadays, kits for diagnosing NDV using ELISA are broadly available because of a number of obvious advantages, including high sensitivity, specificity and recreation of the results, possibility of using minimum amounts of studied samples of biological fluids, availability and stability of the reagents, simplicity and fast reaction, instrumental account of the results and automatization of almost all ELISA stages (Tabib et al., 2004).

The study of the dynamics included comparing the reaction ability of PFS chickens’ blood sera to NDV using two methods of serological control of the vaccine efficiency, such as ELISA and HI. One-day old chickens were vaccinated with the experimental series of NDV vaccine of water in oil type. Titers of antibodies measuring up to the protective level were first seen already 14 days after the vaccination, identified using ELISA (S/P > 0.2 in 3/24 of birds; 12.5%) and HI reaction technique (titer > 1:16 in 87.5%). Titer of HI equaling 1:16 was considered minimum indicator of protection against the virulent virus, while titer of HI measuring 1:108 indicated good immune protection. In both serological surveys, the highest antibody titers were found after vaccination with II–WO MISA, which provided a significant level compared with the control group. The results of the study of sera following the vaccination with commercial vaccine revealed the lowest levels of development of antibodies compared with blood sera of pathogen-free chickens vaccinated with experimental series I–WO PST and II–WO MISA. On the 35th day of the experiment (35 days following the vaccination), all birds had significant levels of antibodies according to the results of serological studies using ELISA technique (group Iа – 9,154; group IIа – 14,024; group IIIа – 5,938) and HI reaction (group Iа – 368; group IIа – 496; group IIIа – 80) and had developed the protective immunity against NDV. The variation coefficient was calculated as 24.8% in chickens of group Iа, 37.6% in group IIа, and 19% in group IIIа. Despite the highest parameters of mean.
titer of antibodies determined using ELISA in chickens vaccinated with the experimental series II-WO MISA, the most homogenous result according to the variation coefficient (% CV) was considered that of vaccination with series I-WO PST – 24.4 %.

Both methods of serological control of the level of immune protection were determined to be sensitive and able to detect the protective antigens to NDV in blood sera of SPF chickens. Also, we determined high positive correlation between the results of ELISA and HI reaction, indicating appropriateness of both methods for evaluating post-vaccination immunity. As a conclusion, by comparing both methods, we determined that HI reaction is more sensitive than ELISA and detects the post-vaccine antibodies to a higher degree in the earlier period following the vaccination. On the other hand, ELISA was observed to be a faster method of controlling the efficiency of the vaccination and more convenient in analysis of the results during the monitoring of dynamics of post-vaccine immunity, though more expensive than the HI test that was used to detect antibodies to NDV.

Conclusion

We prepared an experimental series of vaccines against NDV of water in oil type using mineral oil mixed with adjuvants (Span-80 and Tween-80) and ready-to-use adjuvant system (Montanide ISA 70) as emulsifiers and performed comparative studies of the effects of the adjuvant component on physical-chemical and immunogenic properties. We determined that during the use of 0.1 to 0.5 mL doses that are usually used for the standard vaccines against ND, injection with 0.1 mL of vaccine with Montanide ISA 70 adjuvant and mineral oil mixed with emulsifiers (Span-80 and Tween-80) were sufficient to provide complete protection of chickens and cause protective immune response on the model of Newcastle disease. The results we obtained demonstrate that both variants and mineral oil mixed with emulsifiers and Montanide ISA 70 are effective adjuvants that should be included in receipts of poultry vaccines, which would allow reduction of the vaccine dose for the protection of chickens to 0.1. On the other hand, Montanide ISA 70 adjuvant is an expensive, rare and imported raw material in Ukraine. Furthermore, its homogenization requires high-tech equipment. Both studied vaccines are safe for vaccination of chickens and both of them in the dose of 0.1 mL promoted induction of a sufficient level of antibodies to Newcastle disease in chickens from the 14th to 42nd day (monitoring period). Both vaccines may be used in poultry to prevent ND in chickens.

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