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In vivo efficacy of phage therapy against S*almonella typhimurium* infection in chicken

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Abstract

Salmonella enterica serovar Typhimurium is a major pathogen associated with poultry. This study evaluates the efficacy of a bacteriophage cocktail, comprising SEPL01 (Siphovirus) and SEPL13 and SEPL20 (Myoviruses), in controlling *Salmonella typhimurium* infection in poultry. For current study, 168, day-old indigenous chicks were selected and divided into five groups: negative control, positive control, prophylactic, 3-days, delayed post challenge and 6-hr post-challenge groups. For experiment, birds were orally dosed with 1.00×10^5 colony-forming unit mL^{-1} of *S. typhimurium* on day four of trial. Test groups were administered a bacteriophage cocktail (1.00×10^7 PFU mL^{-1} [plaque-forming unit *per* mL]) orally, intra-nasally, or through drinkers. Quantitative assessment of bacteria loads was done by performing dilution plate counts using xylose lysine deoxycholate agar and the log reduction determined. The positive group showed a natural progression of bacterial infection with bacterial counts increasing from $\log_{10}$ 4.82 at 3rd day post challenge to $\log_{10}$ 5.45 (7th day), and $\log_{10}$ 5.20 (14th day). The prophylactic group recorded the greatest level of the bacterial decrease; the $\log_{10}$ reduction were 1.94 (3rd day), 1.73 (7th day) and 1.22 (14th day) after the oral gavage. For drinking water administration, values were 1.84, 1.66 and 1.12 for log reduction, whereas, for nasal spray, the values were 1.17, 0.88 and 0.41 on 3rd, 7th and 14th day, respectively. 6-hr post-challenge group had a moderate reduction, (1.63, 1.37, 1.22 through oral gavage) while the 3-day post-challenge group possessed slightly less reduction (1.56, 1.24, 0.92). The lowest bacterial loads were recorded when bacteriophages were given via oral gavage and drinking water.

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Introduction

Salmonella enterica serovar Typhimurium is responsible for causing salmonellosis in poultry, causing losses for the worldwide poultry industry. Clinical signs in young birds include poor appetite, diarrhea, dehydration, weight loss, emaciation and lower growth when infected with this pathogen.[1] Under extreme conditions, sepsis can lead to a disease throughout the body that affects main organs like the liver, spleen and digestive system and usually results in a high death rate during the first two weeks of an chick's life. Apart from making poultry sick, *Salmonella typhimurium,* being a zoonotic pathogen, also endangers humans by being a frequent cause of food poisoning from products contaminated with poultry.[2]

Globally, *S. typhimurium* is found widely on poultry farms due to high stock density, weak protection against infections and the ability of the bacteria to last outside the body for long time. As a result of its persistent appearance, diseases frequently spread and challenge the efforts to control them.[3] Antibiotics have long been used as the main way to manage diseases like *Salmonella* in poultry. Still, using antibiotics irrationally and uncontrolled has sped up the appearance of multidrug-resistant *Salmonella* strains.[4] Resistant strains make traditional medicines less effective and they can bring up worries about drug residues in our food and resistance genes reaching disease-causing bacteria. For this reason, it is urgent to look for new and sustainable ways to prevent *Salmonella* infections in poultry.[5]

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As an alternative to antibiotics, phytochemicals in plants like *Curcuma longa* (turmeric) and *Syzygium aromaticum* (clove) are useful for their ability to fight bacteria, reduce inflammation and affect the immune system.[6] Such natural substances have been a good alternative to halt the growth of many bacteria such as *Salmonella* and may be used as a helpful extra treatment alongside traditional medicine. Bacteriophage therapy has become a powerful choice to combat bacterial infections that are hard to control with antibiotics.[7]

Bacteriophages are useful because they can only attack bacteria, cause few changes to the microbiota and create a low chance for bacteria to resist them. This research aimed to assess *in vivo* the ability of phage therapy to treat *S. typhimurium,* in chickens using controlled infection models and specific phage administration to measure the effects of phage treatment on *Salmonella* levels and poultry health, and help develop novel methods for managing these infections in poultry operations.

Materials and Methods

Experimental site. The study was conducted at the Post Graduate Research Institute for Poultry Diseases, Rawalpindi, Pakistan. Ethical approval for this study was exempted from the Institutional Review Committee, (DR/61-2022) University of Veterinary and Animal Sciences, Lahore, Pakistan.

Preparation of shed. Poultry house was thoroughly cleaned and disinfected using quaternary ammonium compound and fumigation was carried out with 40.00% formalin added with potassium permanganate. Post fumigation the shed was sealed for 48 hr. Overcrowding and cross contamination were prevented by installing separate partitions. Temperature, humidity and light intensity were maintained at: 32.00 - 35.00˚C, 60.00% and 30.00 - 35.00 lux, respectively. On the first 10 days, the paper lining was used to collect fecal build up and then move to rice husk litter.[8]

Experimental birds: A total number of 168, day-old indigenous chicks (40.00 - 45.00 g), were sourced from *Salmonella*-free flocks. Vitamin and mineral supplementation were withheld from birds and reared under standard management conditions. Housing temperature and humidity were regulated within recommendations of Hy-Line W-36 guidelines. Feed and water were tested to be free of *Salmonella*. Slide agglutination was used to confirm birds negative for *Salmonella* antibodies and the birds were housed in biosafety-controlled conditions.[9]

Bacterial strains. For *in vivo* assessment of phage lytic activity, confirmed isolates of serotype of *S. typhimurium*, was procured from stock cultures developed in PARB funded project (P-680) at Central Lab Complex, University of Veterinary and Animal Sciences Ravi Campus, Pattoki, Pakistan. For challenge inoculation, bacterial suspensions were prepared in Luria-Bertani broth (Sigma-Aldrich, St. Louis, USA), the optical density 625 adjusted to 0.08 - 0.10 (about 105 colony-forming unit mL^{-1}) and to achieve appropriate bacterial concentrations it was serially diluted in phosphate buffered saline (PBS). A stock bacterial suspension was prepared in LB broth and adjusted to an optical density 625 of 0.08 - 0.10, corresponding to a concentration of approximately 1.00×10^5 colony-forming unit mL^{-1} by serial dilution using PBS.[10]

Bacteriophages. The purified and confirmed bacteriophage cocktail, comprising SEPL01 (Siphovirus) and SEPL13 and SEPL20 (Myoviruses), was collected from PARB Research Project 680 at the Central Lab Complex, University of Veterinary and Animal Sciences Ravi Campus. The phage cocktail, consisting of three bacteriophages, was isolated and characterized from sewage samples collected from commercial poultry.[11]

Experimental design. For the *in vivo* evaluation, chicks were randomly divided into five experimental groups and monitored for a period of 14 days, as detailed in Table 1. The study baseline was established with the negative control group, which received neither a bacterial challenge nor a phage treatment. The positive control group (PCG) was challenged with *S. typhimurium* on day four to serve as pathogenic control, but no phage therapy was given. The remaining three groups received phage cocktail treatment at different intervals relative to the bacterial challenge. The Prophylactic group was challenged with *S. typhimurium* on day seven but was treated with the phage cocktail from days four through six, prior to the challenge. The delayed post-challenge group received the bacterial challenge on day four, with phage treatment administered 2 days later on day six. Finally, the 6-hr post-challenge group was treated with the phage cocktail just 6 hr after being challenged with the bacterial pathogen on day four. Throughout the 14-day study, all birds were closely monitored daily for morbidity and mortality.[12]

Sample collection and bacterial enumeration. Three birds in each group were slaughtered at 3-, 7- and 14-days following infection. The ileum and caecum were aseptically harvested, and 1.00 g of each tissue was weighed and homogenised in 9.00 mL of sterile PBS (pH 7.20) to yield a 1.00×10^{-1} (1:10 w/v) initial suspension. Ten-fold serial dilutions were then prepared by transferring 1.00 mL of homogenate into 9.00 mL of sterile PBS through to 1.00×10^{-6}. From each dilution, 100 µL was spread-plated in duplicate onto xylose lysine deoxycholate agar (Neogen Corp., Lansing, USA) and incubated at 37.00 ˚C for 24 hr. Bacterial load reduction was assessed by counting the *Salmonella* colonies on the petri dishes.[13]

Statistical analysis. The results of all experiments were subjected to statistical analysis through one-way ANOVA by SPSS Software (version 20.0; IBM Corp., Armonk, USA). The significant difference among treatments was considered at p-value < 0.05.[14]

Table 1. Experimental design. All groups were sampled at days 3, 7 and 14.

Groups	No. of birds	Route	Bacteria (10^5 CFU mL^{-1})	Bacteriophage (10^7 PFU mL^{-1})
Negative control	18	-	No	No
Positive control	15	Oral gavage	4^{th} day of age	No
Prophylactic group	15 + 15 + 15	Nasal spray + Drinking water + Oral gavage	7^{th} day of age	4^{th}, 5^{th} and 6^{th}
Delayed post challenge	15 + 15 + 15		4^{th} day of age	6^{th} day of age
Six hours post challenge therapy	15 + 15 + 15		4^{th} day of age	6 hr of post challenge

CFU: colony-forming unit; PFU: plaque-forming unit.

Results

There were no unusual markers and no abnormalities in the organs of the negative control. Depression, lack of appetite, an inability to stand, diarrhea and vent pasting were present in the PCG. In those infected groups given treatment on the 3^{rd} day, depression and diarrhea appeared 2 days following the infection. Toward the end of 3 days after having the challenge, we found bleeding around the heart, watery droppings and congestion of the liver. Birds in the PCG were in good condition with minor symptoms during the entire trial, no birds died. The number of bacteria recorded in the gut (cecum/ileum) was $\log_{10}$ 4.82 after 72 hr of challenge. On the 7^{th} and 14^{th} days following inoculation, the bacterial counts were recorded as $\log_{10}$ 5.45 and 5.20, respectively. On days three, seven and 14, the number of bacteria was compared in the treatment and PCGs as demonstrated in Figures 1- 3.

Throughout the 14-day trial, birds in the negative control group remained clinically healthy with no gross pathological lesions observed in their organs. In stark contrast, birds in the PCG showed significant clinical signs of salmonellosis, including depression, anorexia, lethargy and severe diarrhea with vent pasting. Gross necropsy of these birds revealed pericardial hemorrhage and hepatic congestion, although no mortality was recorded. The phage-treated groups displayed only mild and transient clinical signs that were resolved shortly after infection. For the PCG, the bacterial load in the cecum was $\log_{10}$ 4.82 on day three post-challenge, which increased to $\log_{10}$ 5.45 by day seven before persisting at $\log_{10}$ 5.20 on day 14. A detailed comparison of the bacterial loads between the treatment and PCGs at each sampling point is presented in Figures 1- 3.

A combination of bacteriophages was given to the prophylactic group via nasal spray, drinking water and

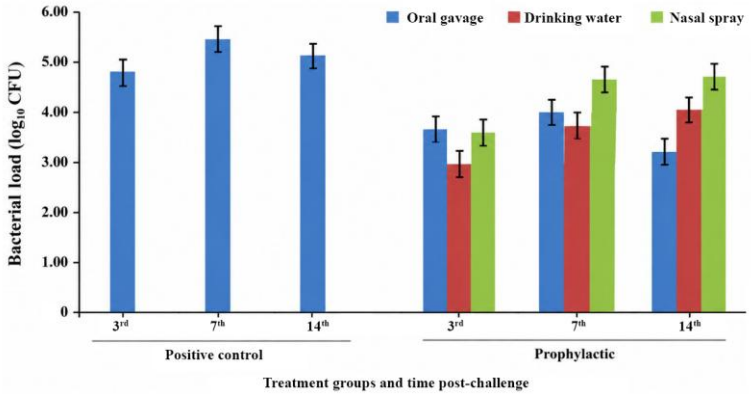


Fig. 1. Comparison between log reductions of prophylactic and positive control groups. CFU: colony-forming unit.

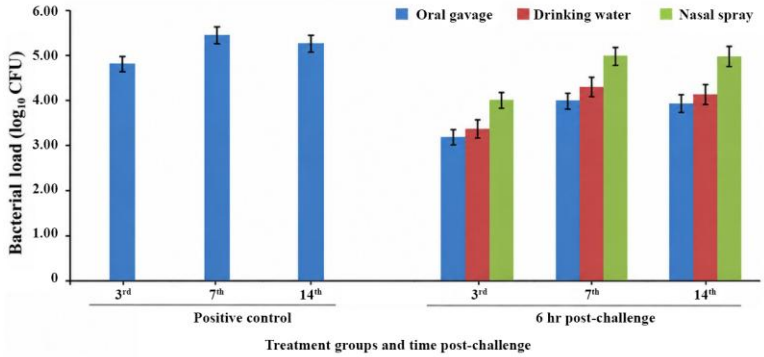


Fig. 2. Comparison between 6 hr post challenge therapy and positive control groups. CFU: colony-forming unit.

oral gavage for 3 days before the administration of the bacterial challenge. Three days after the challenge, the intestinal content of *S. typhimurium* had a mean $\log_{10}$ 4.88, a substantial $\log_{10}$ decrease ($p \leq 0.05$) when compared to the untreated PCG. A significant pairwise comparison was found with every delivery route and every day ($p < 0.05$). When the bacteriophage cocktail was administered on 3rd day via drinking water and oral gavage, respectively, a decrease of $\log_{10}$ 1.94 and $\log_{10}$ 1.84 was observed. A lower reduction of $\log_{10}$ 1.17 was seen with the nasal route. On the 7th day after the challenge, oral gavage and drinking water showed a reduction of $\log_{10}$ 1.73 and $\log_{10}$ 1.66 in *S. typhimurium,* respectively, while nasal spray showed a smaller decrease of $\log_{10}$ 0.88. On the 14th day after the challenge, bacteriophages given via drinking water and oral gavage showed a $\log_{10}$ 1.12 and $\log_{10}$ 1.22 reduction, respectively. Additionally, when the cocktail was delivered by nasal spray, a non-significant decrease of $\log_{10}$ 0.41 was seen.

Six hours following the bacterial challenge, all birds received post-challenge therapy using a mix of bacteriophages. The intestinal content bacterial count was then determined three, seven, and 14 days after the challenge. With a mean $\log_{10}$ of 4.88, a significant log reduction ($p < 0.05$) was seen in comparison with the PCG. When bacteriophages were administered by oral gavage on the 3rd, 7th, and 14th days after the challenge, respectively, a significant log decrease ($p \leq 0.05$) of $\log_{10}$ 1.63, $\log_{10}$ 1.37, and $\log_{10}$ 1.22 was seen in pairwise comparison. On the third and 7th days after the challenge, there was a substantial log reduction ($p \leq 0.05$) of $\log_{10}$ 1.43 and $\log_{10}$ 1.15 when a cocktail of bacteriophages was used *via* drinking water. On the 14th day after the challenge, a non-significant log reduction ($p > 0.05$) of $\log_{10}$ 0.94 was observed. On the 3rd, 7th, and 14th days after the challenge, respectively, a non-significant log reduction of $\log_{10}$ 0.46, $\log_{10}$ 0.15, and $\log_{10}$ 0.12 was seen through the nasal route ($p > 0.05$). Administration of the phage cocktail via the nasal route resulted in non-significant reductions ($p > 0.05$) of 0.46, 0.15, and 0.12 $\log_{10}$ at days 3, 7, and 14 post-challenge, respectively.

The bacteriophages were administered 48 hr after the bacterial challenge in delayed post-challenge therapy, and the intestine *S. typhimurium* count was determined three, seven-, and 14-days post administration of bacteriophages. At day seven and 10 after the challenge, respectively, a substantial log reduction ($p \leq 0.05$) of $\log_{10}$ 1.56 and $\log_{10}$ 1.24 was seen after oral gavage. On the 14th day after the challenge, a non-significant log reduction ($p > 0.05$) of $\log_{10}$ 0.92 was observed. The 3rd day after the challenge showed a significant log reduction ($p \leq 0.05$) of $\log_{10}$ 1.25 through drinking water, while the seventh and 14 days after the challenge showed non-significant log reductions ($p > 0.05$) of $\log_{10}$ 0.90 and $\log_{10}$ 0.79, respectively. On the third, seventh, and 14th days after the challenge, respectively, a non-significant log reduction ($p > 0.05$) of $\log_{10}$ 0.42, $\log_{10}$ 0.13, and $\log_{10}$ 0.10 was seen through the nasal route.

Discussion

The present study evaluated bacteriophage cocktails against *S. typhimurium* in broiler chickens indicating that phage therapy could serve as a beneficial alternative to conventional antibiotic treatment. The bacterial load analysis results provided information on the treatment and prophylactic effects of phage application through a variety of routes. The bird robust health was demonstrated by the absence of clinical signs and lesions in all negative controls. Rather, the PCG displayed depressive, anorexic, diarrhea and postmortem evidence of cardiac hemorrhage, which were characteristic symptoms of salmonellosis. The results were consistent with the established findings that *S. typhimurium* caused sickness and digestive issues in chicken.[15]

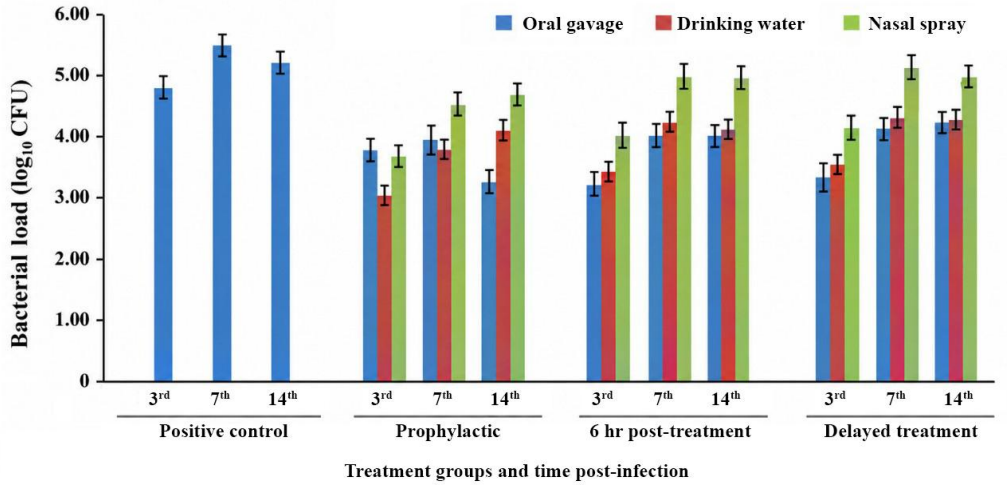


Fig. 3. Comparison among log reductions of prophylactic, 6 hr post challenge therapy and delayed post challenge therapy groups. CFU: colony-forming unit.

High bacterial counts dominated the intestinal content of the PCG during the study period, as evidenced by $\log_{10}$ value of 4.80 at the end of the 3rd day and higher $\log_{10}$ 5.45 at the end of the 7th day following the challenge which showed that *S. typhimurium* was difficult to eradicate from the chicken stomach due to its prolonged survival, which was crucial for both food safety and poultry health.[16] Phage therapy was found to be bactericidal, as counts of *Salmonella* were lower in all treatment groups than in the positive control.[17]

Prophylactic administration of the phage cocktail caused the largest reductions, with reductions of about $\log_{10}$ 1.90 detected through both oral gavage and drinking water on day three. It seems that having pre-exposure to phages can stop at least some bacteria from starting to grow by killing them long before they have the chance to multiply in the body.[18] The nasal spray intervention, although it did lower bacteria, was less efficient at killing the infection, perhaps because phages did not travel well to the infection site or helped bacteria less than the pure administered phage in the stomach.[19] While the nasal spray administration reduced the bacterial load, it was significantly less effective than the oral routes. A likely explanation for this reduced efficacy is the inefficient translocation of bacteriophages from the upper respiratory tract to the primary site of infection in the gastrointestinal tract. After initiating therapy 6 hr after infection with phages, big drops in bacterial counts occurred, mainly when phages were administered by oral route. Continued decline in bacteria found on days three, seven and 14 after treatment showed that early intervention could prevent infection from worsening and lower the burden of pathogens. But the results from drinking or breathing in phages only lasted for a short time, indicating that parameters such as phage stability, the dosage used and route of administration might limit long-term protection.[20]

When administered orally or through drinking water for the phages, treatment started 48 hr after infection showed some efficacy on days three and seven. Since biofilms or cell persistence could stop many phages from attacking, stronger resistance on day 14 indicated that treating chronic infections would be difficult.[21] The nasal route produced the least effective results out of all the treatments, demonstrating that the right route selection was essential for the best possible therapeutic outcomes. Nasal spray does not seem to be a good choice for fighting enteric pathogens because of its limited success. It is clear from the findings that both the time of phage application and how they are applied affect the outcomes against *S. typhimurium.*[22]

The highest levels of bacterial reduction were observed after oral gavage, partly because the bacteria ended up directly in the gastrointestinal tract. Managing drinking water also provides benefits, with practical applications for large poultry enterprises. The findings support the idea that using bacteriophages is a promising choice for controlling *Salmonella* in poultry, given the increase in antimicrobial resistance. The improvements without causing negative outcomes prove that phages are both specific and safe. Moreover, using phages prophylactically may help cut down on *Salmonella* in poultry farms.[23]

One limitation of the study was that phage titers in the gastrointestinal tract were not enumerated prior to challenge, and persistence at the time of challenge was therefore not directly confirmed. The observed reduction in *Salmonella* colonization in the prophylactic group was consistent with residual phage activity at challenge. Future work should incorporate serial phage enumeration by plaque assay to characterize gut persistence kinetics. Another limitation of the present study was the absence of a phage-only control group, *i.e.,* unchallenged birds receiving the phage cocktail alone. Such a group would have permitted direct assessment of any independent effect of the phage preparation on host health, growth performance and gut microbial composition, independent of *Salmonella* infection. Although no adverse clinical signs or phage-attributable mortality were observed in any of the treated groups, the absence of this control means that potential effects of the phage cocktail on the commensal microbiota or host immune response cannot be excluded.

Salmonella typhimurium infection in poultry can be significantly lowered with bacteriophage therapy, most effectively if given either before or shortly after infection. The lowest levels of bacteria were found when microbes were given via oral gavage and drinking water, pointing out that time and route of administration of the agent matters. As the issue of antibiotic resistance grows, phage therapy looks like an effective and sustainable way to fight salmonellosis in poultry, therefore, it should be advanced for practical use.

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Conflict of interest

All the authors declare no conflict of interest.

References

1. Raza A, Ahmad S, Ahmad M, et al. Zoonotic diseases: emerging threats to public health and livestock production. In: Zoonosis. Faisalabad, Pakistan: Unique Scientific Publishers 2023; 74-88.

2. Saleem G, Farooq U, Javed MT, et al. Pathobiological and immunohistochemical findings in broiler chickens naturally infected with *Salmonella enterica* serotype Gallinarum biotype Gallinarum. Pak Vet J 2022; 42(1): 88-94.
3. Shakir MZ, Rizvi F, Masoud F, et al. Seroprevalence, molecular confirmation and application of bacteriophage as a potential prophylactic therapy against fowl typhoid disease in commercial poultry birds. Pak Vet J 2024; 44(4): 1185-1192.
4. Durrani RH, Sheikh AA, Humza M, et al. Evaluation of antibiotic resistance profile and multiple antibiotic resistance index in avian adapted *Salmonella enterica* serovar Gallinarum isolates. Pak Vet J 2024; 44(4): 1349-1352.
5. Mahmood S, Rasool MH, Khurshid M, et al. Genetic outlook of colistin resistant *Salmonella enterica* serovar Typhimurium recovered from poultry-environment interface: a One Health standpoint. Pak Vet J 2025; 45(1): 246-256.
6. Zeshan MQ, Ashraf M, Omer MO, et al. Safety profile and toxicological evaluation of essential oils of *Curcuma longa* and *Syzygium aromaticum*. J Popul Ther Clin Pharmacol 2024; 31(6): 1099-1108.
7. Golkar Z, Bagasra O, Pace DG. Bacteriophage therapy: a potential solution for the antibiotic resistance crisis. J Infect Dev Ctries 2014; 8(2): 129-136.
8. Amin MT, Usman M, Ishaq HM, et al. Comparative evaluation of management practices among large-scale broiler farms of Punjab, Pakistan. Heliyon 2025; 11(1): e42381. doi: 10.1016/j.heliyon.2025.e42381.
9. Shakir MZ, Rizvi F, Javed MT, et al. Seroprevalence and pathological studies of *Salmonella* infection in commercial white layer birds. Microb Pathog 2021; 159: 105146. doi: 10.1016/j.micpath.2021.105146.
10. Kokab A, Sheikh A, Rabbani M, et al. Post-harvest biocontrol of *Salmonella* Enteritidis on chicken breast meat and shell eggs using multiphage cocktail. Vet Ital 2023; 59(3): doi: 10.12834/VetIt. 2975.19320.1.
11. Kokab A, Sheikh AA, Rabbani M, et al. Physiological profiling of lytic bacteriophages and their efficiency against *Salmonella* Enteritidis on chicken breast cuts. Pak J Zool 2024; 56(1): 375-383.
12. Costa MJ, Pastrana LM, Teixeira JA, et al. Bacteriophage delivery systems for food applications: opportunities and perspectives. Viruses 2023; 15(6): 1271. doi: 10.3390/v15061271.
13. Miller RG, Tate CR, Mallinson ET, et al. Xylose-lysine-tergitol 4: an improved selective agar medium for the isolation of *Salmonella*. Poult Sci 1991; 70(12): 2429-2432.
14. Singh V, Rana RK, Singhal R. Analysis of repeated measurement data in the clinical trials. J Ayurveda Integr Med 2013; 4(2): 77-81.
15. Ullah A, Anjum AA, Rabbani M, et al. Phytochemical composition and *in-vitro* activity of ethanolic extract of *Eucalyptus globulus* leaves against multidrug resistant poultry pathogens. Cell Mol Biol (Noisy-le-grand) 2021; 67(1): 159-164.
16. Chambers JR, Gong J. The intestinal microbiota and its modulation for *Salmonella* control in chickens. Food Res Int 2011; 44(10): 3149-3159.
17. Nikkhahi F, Soltan Dallal MM, Alimohammadi M, et al. Phage therapy: assessment of the efficacy of a bacteriophage isolated in the treatment of salmonellosis induced by *Salmonella* Enteritidis in mice. Gastroenterol Hepatol Bed Bench 2017; 10(2): 131-136.
18. Atterbury RJ, Van Bergen MA, Ortiz F, et al. Bacteriophage therapy to reduce *Salmonella* colonization of broiler chickens. Appl Environ Microbiol 2007; 73(14): 4543-4549.
19. Oliveira A, Sereno R, Nicolau A, et al. The influence of the mode of administration in the dissemination of three coliphages in chickens. Poult Sci 2009; 88(4): 728-733.
20. Ryan EM, Gorman SP, Donnelly RF, et al. Recent advances in bacteriophage therapy: how delivery routes, formulation, concentration and timing influence the success of phage therapy. J Pharm Pharmacol 2011; 63(10): 1253-1264.
21. Liu S, Lu H, Zhang S, et al. Phages against pathogenic bacterial biofilms and biofilm-based infections: a review. Pharmaceutics 2022; 14(2): 427. doi: 10.3390/pharmaceutics14020427.
22. Ahmadi M, Karimi Torshizi MA, Rahimi S, et al. Prophylactic bacteriophage administration more effective than post-infection administration in reducing *Salmonella enterica* serovar Enteritidis shedding in quail. Front Microbiol 2016; 7: 1253. doi: 10.3389/ fmicb.2016.01253.
23. Bardina C, Spricigo DA, Cortés P, et al. Significance of the bacteriophage treatment schedule in reducing *Salmonella* colonization of poultry. Appl Environ Microbiol 2012; 78(18): 6600-6607.