Bacteriophages as Potential Tools for Detection and Control of *Salmonella* spp. in Food Systems

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Abstract: The global problem of antibiotic resistance in bacteria is quickly developing in most antibiotics used in hospitals and livestock. Recently, the infections with multi-drug resistant (MDR) bacteria become a major cause of death worldwide. Current antibiotics are not very effective in treating MDR *Salmonella* infections, which have become a public health threat. Therefore, novel approaches are needed to rapidly detect and effectively control antibiotic-resistant pathogens. Bacteriophages (phages) have seen renewed attention for satisfying those requirements due to their host-specific properties. Therefore, this review aims to discuss the possibility of using phages as a detection tool for recognizing bacterial cell surface receptors and an alternative approach for controlling antibiotic-resistant pathogens in food systems.

Keywords: bacteriophage; phage detection; phage control; *Salmonella*; food system

1. Introduction

*Salmonella*, a Gram-negative rod-shaped bacilli bacterium, is the most common foodborne pathogen and is known as one of the four key global causes of diarrheal diseases, according to the World Health Organization (WHO). As estimated by the Centers for Disease Control and Prevention, 23,000 hospitalizations and 450 deaths have been caused by *Salmonella* infections every year in the United States. Among the 1.2 million illnesses caused by *Salmonella*, contaminated food caused 1 million illnesses [1,2]. Contaminated meat, poultry, eggs, and milk are the main reservoirs for *Salmonella* infections [3]. Some direct contact with infected animals, blood, urine, and feces may also cause the problem to human health [4]. Antibiotic use has been increased for controlling the bacteria in animals or increasing food production, which has accelerated the emergence of antimicrobial-resistant bacteria [5–7]. The antibiotic-resistant bacteria are likely to contaminate in food products throughout the handling or other production stages [8–10]. Fruit and vegetable products are susceptible to cross-contamination during harvest and post-harvest periods [11–13]. Salmonellosis caused by *Salmonella* is one of the serious infections that is difficult to treat due to the reduced antibiotic activities that become less effective [14]. Thus, novel antibiotics or alternative methods are required to control the antibiotic-resistant bacteria.
Bacteriophages (phages) are predominant in nature, defined as viruses that can infect bacteria alone [15,16]. In the 1920s, Frederick Twort first observed the glassy and transparent colonies in micrococci cultures, which could cause an acute infectious disease in 1915, but the term “phage” was neither correctly defined nor clearly understood at this time [17]. Two years later, Félix d’Herelle isolated a microbe that showed an antagonistic effect against *Shiga* bacillus and first described this microbe as an obligate bacteriophage with a high specificity to the host and no pathogenic effects [18].

**Figure 1.** Advantages and disadvantages of using bacteriophages for the treatment of *Salmonella* [19].

**Table 1.** Lytic spectrum of bacteriophages against *Salmonella* and other foodborne pathogens.

| Microorganism                  | Bacteriophage 1 |
|-------------------------------|-----------------|
|                               | 7   | 16 | 18  | 36  | 43  |
| *Salmonella* Typhi ATCC 6539  | +   | 2  | +   | +   | +   |
| *Salmonella* Typhimurium ATCC 14028 |       | +   | +   | +   | +   |
| *Salmonella* Enteritidis ATCC 13076 |       | +   | +   | +   | +   |
| *Salmonella* Gallinarum ATCC 9184 |       | +   | +   | +   | +   |
| *Salmonella* Pullorum ATCC 9120 |       | +   | +   | +   | +   |
| *Salmonella* Abony NCTC 6017 |       | +   | +   | +   | +   |
| *Salmonella* Choleraesuis ATCC 10708 |       | −   | +   | +   | +   |
| *Salmonella* Arizonae ATCC 13314 |       | −   | −   | −   | −   |
| *Escherichia coli* ATCC 11229 |       | −   | +   | +   | −   |
| *Klebsiella pneumoniae* ATCC 10031 |       | −   | −   | −   | −   |
| *Enterobacter aerogenes* ATCC 13048 |       | −   | −   | −   | −   |
| *Campylobacter jejuni* NCTC 12662 |       | −   | −   | −   | −   |
| *Listeria monocytogenes* ATCC 7644 |       | −   | −   | −   | −   |
| *Enterococcus faecalis* ATCC 19433 |       | −   | −   | −   | −   |
| *Staphylococcus aureus* ATCC 6538 |       | −   | −   | −   | −   |
Five phages, phiSE 7, 16, 18, 36, and 43, were isolated from chicken feces, and they belong to the *Podoviridae* family. The phage ability to plaque on different pathogens was evaluated. (-) and (+) indicate the absence of phage plaques and the presence of phage plaques, respectively. (Copyright obtained from [20]).

However, the interest in phages decreased because of the lack of proper quality controls and reproducible results in the western countries [21–23]. Another important reason was the discovery of antibiotics, which were used as the most powerful reagents for controlling bacterial infections. Ironically, the frequent use of antibiotics has resulted in the development of the multidrug-resistance or superbugs [24–26]. Figure 1 shows the advantages and disadvantages of bacteriophage applications. A phage as a biorecognition agent provides many advantages for rapid bacterial sensing [27], including target specificity [28], release of high titer phages, tolerance to environmental stresses [29], safe handling, and effectiveness against live bacteria [30]. The phage-based biosensors include the combination of whole phages or phage-constituents, which can be converted to electrical, colorimetric, fluorescent, or luminescent signals. Phages are thus shown as cheap, fast, sensitive, selective, and specific tools for detecting bacteria [31]. From a therapeutic viewpoint, phage therapy provides many benefits over chemotherapy, since phages are active against antibiotic-resistant bacteria and no side effect occurs during phage treatment [32].

With more scientifically rigorous approaches in the recent years, more researchers have paid attention toward the bacteriophages as a promising tool to treat the pathogens [33]. Bacteriophages also show additional advantages, including a high specificity to the host, an ability to differentiate alive and dead cells, and the most abundant biological entity in nature, which draws renewed attention to the detection and control of antibiotic-resistant pathogens [34–36]. The effectiveness of phage applications in treating pathogenic bacteria is influenced by several factors, such as the multiplicity of infection (MOI), treatment mode, environmental conditions, phage neutralization, and target bacteria. The bacteriophage survival an adverse environment is also a desired characteristic for therapeutic use. Currently, the commercial products based on bacteriophages targeting *Escherichia coli* O157:H7 [37–39], *Listeria monocytogenes* [40–42], *Salmonella* spp. [43,44], and *Shigella* spp. [45–47] are available in the market. Furthermore, application trials in foods are also performed, which would help enhance the food safety. The lytic activities of specific bacteriophages against *Salmonella* and other pathogenic bacteria are compared in Table 1 and 2. In this review, the detection methods and biocontrol applications based on bacteriophages targeting *Salmonella* are summarized and discussed in detail.

**Table 2. Efficacy of phages against *Salmonella* strains and other pathogens.**

| Microorganism                     | Bacteriophage | LPST18 | LPST23 | LPST10 |
|-----------------------------------|---------------|--------|--------|--------|
| *Salmonella* Typhimurium ATCC 14028 | A ¹           | A      | B      |
| *Salmonella* Typhimurium ATCC 13311 | C             | A      | C      |
| *Salmonella* Typhimurium ST-8     | A             | A      | A      |
| *Salmonella* Paratyphi B CMCC 50094 | A             | A      | B      |
| *Salmonella* Enteritidis ATCC 13076 | A             | A      | C      |
| *Salmonella* Enteritidis SJTUf 10978 | E             | C      | A      |
| *Salmonella* Enteritidis SJTUf 10984 | E             | E      | A      |
| *Salmonella* Anatum ATCC 9270     | D             | E      | D      |
| *Salmonella* Choleraesuis ATCC 10708 | E             | E      | D      |
| *Escherichia coli* DH5α           | E             | E      | E      |
| *Escherichia coli* BL21           | E             | E      | E      |
| *Escherichia coli* c83715         | E             | E      | E      |
| *Listeria* monocytogenes ATCC 19114 | E             | E      | E      |
| *Vibrio* parahaemolyticus ATCC 33846 | E             | E      | E      |
| *Staphylococcus aureus* ATCC 29213 | E             | E      | E      |
1 A, B, C, D, and E describe the clearing throughout with a faint hazy background, substantial turbidity throughout the cleared zone, a few individual plaques, and no clearing, respectively. (Copyright obtained from [48].)

2. Phage Plaque Assay as A Traditional Method for Salmonella Detection

The traditional agar overlay method is a very useful technique for studying bacteriophage, including identification, enumeration, purification, and isolation of phage mutants. This method is based on lysis plaques, which are formed on lawns of the host bacteria, immobilized in the top soft agar. After incubation, a series of reaction events, such as phage infection, multiplication, and liberation, occur in the host [49,50]. The soft agar overlay method is a common titer assay, which was introduced by Mark Adams [51]. The plaque assay has been improved based on several modifications, such as the addition of effective supplements to modify growth media and agar composition and the plate spreading method, which can enhance the visibility of the plaques [49,52,53]. However, a long time (more than 24 h) is required for obtaining detection results and it is also labor intensive, which may not meet the demands of rapid pathogen detection. Thus, many researchers devote their efforts to developing reliable and rapid detection methods. Figure 2 shows two different life cycles of bacteriophages and lytic and lysogenic cycles. The active virulence phages can produce progeny phages that burst out of the host cell through the lytic cycle, while the lysogenic cycle involves the integration of the temperate phage genome into the host chromosome, which can remain in an inactive state, known as prophage [54]. The distinct life cycles of bacteriophages are used for designing novel diagnostic tools, including reporter bacteriophages [55] and phage display technologies [56].

![Figure 2. Life cycles of bacteriophages. (Copyright obtained from Kakasis et al., 2019; de Jonge et al., 2019, [57,58].)](image)

3. Rapid Detection Methods Associated with Bacteriophage for Salmonella

With the growing need of food safety, several detection methods for targeting Salmonella were developed by combining bacteriophages, including molecular based real-time PCR [59,60], immunomagnetic separation based on fluorescence immunoassays [61,62], enzyme-linked
immunosorbent assays (ELISAs) [59], matrix-assisted laser desorption/ionization–time-of-flight mass spectrometry (MALDI–TOF MS) [63], and genetically engineered reporter phage [64].

3.1. qPCR-Based Detection

Bacteriophages have been used for the detection of foodborne pathogens based on their specificity towards bacteria and amplification ability, which is like the “enrichment” procedure and shortens the detection time [36]. In this approach, qPCR is used to directly amplify and detect the nucleic acids of progeny bacteriophage after propagation. The bacteriophages coupled with qPCR were used for the detection of *Ralstonia solanacearum*, *Escherichia coli* O157:H7, *Mycobacterium avium*, and *Acinetobacter baumannii* [60,65–67]. The amplification of *Salmonella* phage B_SenS_PVP-SE2 combined with qPCR was then developed for the detection of viable *Salmonella Enteritidis* in chicken samples [68]. The proposed method detected a low concentration level of viable *S. Enteritidis* (8 colony-forming unit (CFU)/g) in chicken samples within 10 h, which saved much time when compared to the culture-based method and also enhanced sensitivity, specificity, and accuracy. Thus, this protocol can be used in the food industry for self-monitoring, which successfully completed a “same-day” detection within 10 h.

3.2. Immunomagnetic-Based Detection.

A novel assay composed of immunomagnetic separation (IMS) and amplification of *Salmonella* bacteriophage SJ2 was developed and optimized for the detection of *Salmonella enterica* serovar *Enteritidis* [62]. In the IMS procedure, Dynabeads® anti-*Salmonella* was used for capturing and concentrating *Salmonella*. Bacteriophage SJ2 was then added, and the mixture was incubated for attachment and amplification. The final sample was detected using fluorescence or optical density measurements. This assay showed a detection limit of less than 10^4 CFU/mL with a short time (4.0–4.5 h). However, the pre-enrichment process was required in food samples. When this technique was applied to contaminated food samples, including skimmed milk, chicken, and beef, at an average of 3 CFU/25 g, *S. Enteritidis* could be detected within 20 h, including a pre-enrichment time of 16 h [62].

3.3. Enzyme-Linked Immunosorbent Assay

The commercial ELISA kits have been applied for detecting *Salmonella* in poultry, seafood, milk, and meat [69–72]. ELISA detects the protein in a liquid form using antibodies against the target samples. Instead of using antibodies, bacteriophages can be used in ELISA for detecting bacteria [73]. The ELISA procedure works by replacing antibodies with bacteriophages and was applied for the detection of *S. enterica* and *E. coli* [59]. The modified ELISA showed a detection limit up to 10^6 cells/mL, which is comparable with other ELISA methods. Thus, bacteriophages in ELISA can be an alternative way to detect pathogenic bacteria without specific antibodies. Since phages are highly abundant in nature, this assay becomes cheap compared with using specific antibodies.

3.4. Matrix-Assisted Laser Desorption/Ionization–Time-of-Flight Mass Spectrometry

MALDI-TOF MS is now becoming a most common method for bacterial identification, differentiating from the advantages of high throughput and rapidity and excepting a high cost of the initial installment [74,75]. MALDI-TOF MS has been applied for screening, identification, and detection of foodborne bacteria, which can enhance food safety. The MALDI-TOF MS-based detection method depends on progeny bacteriophage proteins or peptides. In this method, progeny bacteriophage proteins are applied to the test plate with a UV-absorbing matrix and then ablated by a laser. After 60–120 min of bacteriophage amplification, samples were used for analysis by MALDI-TOF MS. The parameters of MALDI-TOF MS, including matrix preparation, sample preparation, acid added to the matrix, growth medium, and setting parameters, were optimized and a standard protocol was set for the identification of *Salmonella* subspecies, and consequently the classification results were comparable to DNA sequence-based methods [76]. A whole-cell MALDI-TOF MS for rapid prescreening of *S. enterica* subspecies *Enterica*, isolates based on specific biomarker ions, rather
than antigenic determinants that could reduce the sample numbers for subsequent serotyping analysis [77]. The MALDI-TOF MS combined with selective enrichment broth was developed for the identification of Salmonella sp. in clinical stool samples. The discrimination of bacteria species was mainly based on the comparison of peaks of peptides and small proteins with the reference database [78]. Strains of Salmonella and E. coli were simultaneously detected based on the characteristics of proteins by using two phages, MS2 and MPSS-1, respectively, [63]. The simultaneous detection of two bacteria, using MALDI-TOF MS coupled with bacteriophage amplification, provides the possibility of three or more target detections, which may require the specific bacteriophage biomarkers.

3.5. Genetically-Engineered Phages

Recent advances in genetically-engineered bacteriophages have been created as a powerful tool for the monitoring and detecting of bacterial pathogens. This novel technique is useful for detecting bacteria from contaminated foods with high selectivity and sensitivity [64,79]. Reporter bacteriophages are genetically modified bacteriophages that have a reporter gene inserted into their genomes, such as lux, gfp, and lacZ, which are activated by the interaction between bacteriophages and target bacteria [64,80]. The expression of the reporter gene upon infection emits a detectable signal, indicating the presence of target bacteria. The main advantage of using a reporter bacteriophage is the higher specificity for detecting viable host bacteria. To date, most commonly used reporter bacteriophages are associated with the formation of bioluminescence luciferase protein, which emits light in the presence of aldehyde substrates [81]. Several bioluminescent reporter bacteriophage systems have been designed using the lux operon, luxCDABE. The LuxCDE proteins encode a fatty acid reductase complex, including reductase, synthetase, and transferase, responsible for providing the aldehyde as a substrate, and the LuxAB encodes luciferase α- and β-subunits, which feed the bioluminescent reaction [82,83]. Reporter bacteriophages containing the luxAB gene were the first bioluminescent for the detection of Salmonella strains [84]. The luxAB (P22 luxAB) reporter gene without the luxCDE was used to detect S. Enteritidis up to 63 CFU/g in whole eggs [84]. The advantage of the luxAB reporter system is that it can avoid the toxicity and noise signals by emitting a physical signal. However, this system needs the specific substrates for bacterial detections [82]. To avoid this inconvenience, a complete set of luxABCDE operons was constructed for Salmonella Typhimurium detection in different food matrices [83]. The reporter bacteriophage system could detect Salmonella up to 37 CFU/g in sliced pork, 22 CFU/g in iceberg lettuce, and 20 CFU/mL in pure culture. These reporter bacteriophages could be useful for diagnostics and rapid detection of Salmonella spp. in different food samples with no substrates and with the reporter host required.

Apart from the luciferase-based reporter bacteriophage systems, green fluorescent protein (GFP) and β-galactosidase have also been used for the detection of foodborne pathogens. The GFP gene is originated from Aequorea victoria and has many advantages, including high stability and low toxicity [85,86]. The GFP-labeled PP01 bacteriophage (PP01-GFP) system was applied on the surface of E. coli O157:H7, which can emit a fluorescent signal at an MOI of 1000 at 4 °C [87]. Although the specificity and host range are well defined, this system is not widely used in food because of the interference of food components. The lacZ gene encoding β-galactosidase can catalyze the hydrolysis of β-galactosides. The lacZ-based reporter bacteriophage needs various substrates, such as colorimetric, fluorescent, or luminescent substrates, which emit signals to detect bacteria [36,88]. The detection limits of this system were up to 10^3 CFU/100 cm² for the colorimetric method and 10 CFU/100 cm² for luminescence in beef slice samples [88]. The use of additional substrates can be a drawback of this system as it only allows single time point measurements. Although this reporter bacteriophage system can detect viable Salmonella at high specificity and a low detection limit, the construction of new reporter bacteriophages is still difficult. Therefore, further studies are needed for the development of reporter bacteriophage systems, which can detect Salmonella spp. in various food matrices.

4. Bacteriophage-Based Biosensors for Detecting Salmonella
Over the last few decades, biosensors have been developed as a novel analytical platform for pathogen detection [89,90]. A classical biosensor can be defined as an analytical device that measures biological responses by incorporating bioreceptors (antibodies, enzymes, cells, aptamers, bacteriophage, and organelle) with physical transducers and electrochemical (amperometric, impedimetric, and potentiometric), optical (surface plasmon resonance, surface-enhanced resonance spectroscopy, and fluorescence), and mass-based receptors (magnetoelastic and piezoelectric). The continuous efforts have been successfully developed on bacteriophage-based biosensors for the detection of *Salmonella* in food samples. The immobilization of bacteriophage receptors on the sensor surface is crucial to develop bacteriophage-based biosensors. The immobilization steps include physical adsorption, covalent attachment, and genetic modification of receptors [91,92].

Table S1. summarizes different bacteriophage-based biosensors for the detection of *Salmonella*. The first transducers of bacteriophage biosensors for *Salmonella* detection are mass-based transducers and magnetoelastic assays (ME), and Figure 3 shows a schematic illustration for the principle of ME biosensors for detection of target analytes [93].

![Figure 3. Schematic figure illustrating the working principle of ME biosensors.](image)

ME-based detection methods are the most prominent type of biosensors due to their easy and cheap fabrication, composing of amorphous ferromagnetic ribbon that contracts and expands when exposed to the external magnetic field and generates magnetic fluxes by binding targets to the sensor surface. The ME biosensor was employed as a transduction platform in bacteriophage biosensors for the detection of *Salmonella* (Table S1). ME biosensors were developed by using filamentous bacteriophage specific for *S. Typhimurium*. The bacteriophages were immobilized by a physical adsorption method for *S. Typhimurium* detection by the changes in the resonance frequency of the sensor [93]. The numbers of *S. Typhimurium* in fresh tomato surfaces were quantified using the ME biosensor detection method by the immobilization of E2 bacteriophages on the sensor surface [94]. The tomato surfaces contaminated with *S. Typhimurium* were measured using a resonance frequency with a detection limit of $10^3$ CFU/mL. The results show that E2-bacteriophage-based biosensors could detect *Salmonella* directly on the surface of tomatoes. The same principle for detection of *S. Typhimurium* in spinach leaves showed a similar detection limit as low as $10^2$ CFU/mL [94].

Other bacteriophage-based biosensor detection systems have been developed using an acoustic wave piezoelectric biosensor combined with filamentous bacteriophages [95]. The detection limit was $10^2$ CFU/mL for *S. Typhimurium* by measuring the changes in resonance frequency as a consequence of binding bacteria to the bacteriophage. In addition, the recombinant prophage coupled with a flow cytometer and specific fluorescence filter was used for sensitive and specific detection of *Salmonella*...
with a detection limit of 10 CFU/mL [86]. A surface enhanced Raman scattering (SERS) by conjugating bacteriophage tail spike proteins to silica-encapsulated Raman reporter-embedded nanoprobes could detect single Salmonella cells [96]. Therefore, the use of bacteriophage as a bioreceptor in biosensors can contribute to the development of desirable detection tools for Salmonella in food samples. The stability, low cost, environment-friendly production, and genetic modification provide benefits for biosensor development. For the successful development of biosensors, the immobilization of phage onto the biosensor surface plays an important role. The genetically modified phages provide effective immobilization by introducing the functional ligands on their heads. In addition, the ability to manipulate the genetic material provides the possibility of creating novel recognition systems for biosensor applications, such as expanding the host range of phages by manipulating the receptor-binding protein [27]. However, further work should focus on detecting Salmonella in complex food matrices for extending the range of application of bacteriophage-based diagnostic tools from the laboratory to clinical diagnosis, environmental monitoring, and further food analysis in the near future.

5. Bacteriophage-Based Tool for Salmonella Control

Bacteriophages have been used for controlling bacterial infections based on their specificity to the host bacteria [35,97–103]. Bacteriophages kept stable in thermal conditions from 30 to 60 °C and pH ranges from 3 to 13 can suggest the possibility of using bacteriophages in variable conditions. Recently, bacteriophages as a biocontrol tool have gained great attention and are recognized as an alternative for antibiotics [104–106]. Listeria bacteriophages were approved by the Food and Drug Administration (FDA) and the United States Department of Agriculture (USDA) in all food products, which were granted as generally recognized as safe (GRAS) [107]. Table S2 summarizes the applications of bacteriophage or bacteriophage-based treatments as biocontrol tools for Salmonella.

Bacteriophage control technique has been applied for Salmonella in vivo and food samples. When lytic bacteriophages was applied to the chicken skin contaminated with S. enterica serovar Enteritidis, less than one log reduction was obtained at the MOI of 1 and no viable bacteria were observed at the MOI of 104 [108]. A new virulent bacteriophage, F01-E2, was isolated for controlling S. Typhimurium [109]. F01 belongs to Myoviridae with a double-stranded deoxyribonucleic acid dsDNA genome of 86.2 kb and a broad host range [110,111].

Five log reductions were obtained for turkey deli meat and chocolate milk at 15 °C, and three log reductions were observed for hot dogs and seafood, implying that bacteriophage immobilized on the food surfaces were affected by the structure and chemical composition of the foods [112]. Salmonella Enteritidis bacteriophage SE07 showed a potential against S. Enteritidis in both solid and liquid food [113]. The isolated SE07 belongs to Podoviridae and is stable from 28 °C to 65 °C and pH 4 to 11. As shown in Table 3, two log reductions were obtained for the different food matrices after 48 h incubation at 4 °C. Additionally, the bacteriophage ΦCJ07 was applied for controlling S. Enteritidis in chicken [114].

Because Salmonella in contaminated, chickens can survive under the acidic conditions in the digestion system. Bacteriophage ΦCJ07 was added as a feed additive, which was effective against Salmonella by protection from other ingested feed constituents [115]. The bacteriophage ΦCJ07 isolated from the sewage effluent showed a lytic activity against most Salmonella spp., including S. Enteritidis, S. Typhimurium, Salmonella Gallinarum, Salmonella Pullorum, Salmonella Choleraesuis, and Salmonella Derby. Further evaluations in vivo also demonstrated the good performance of phage ΦCJ07 in reducing both S. Enteritidis colonization and environment contamination levels. This provides a promising alternative of bacteriophage for preventing and controlling S. Enteritidis infections and reducing the incidence of Salmonella food poisoning.

Table 3. Efficacy of the bacteriophage cocktail in the reduction of Salmonella Enteritidis in raw salmon fillets and smoked salmon slices.
Incubation Phage Food Sample Reduction (log CFU/g)^1 Phage cocktail (log PFU/g) \(^2\)  
| Incubation (day) | Cocktail Addition | 18 °C | 4 °C | 18 °C | 4 °C  | 18 °C | 4 °C |
|------------------|-------------------|-------|-------|-------|-------|-------|-------|
| 3                | –                  | 7.51 ± 0.16 | 4.76 ± 0.20 | 6.76 ± 1.20 | 1.64 ± 0.36 | 0.75 | 3.12 | 6.57 ± 0.24 | 9.32 ± 0.23 |
|                  | +                 | 6.70 ± 0.60 | 5.07 ± 0.17 | 4.13 ± 0.95 | 2.24 ± 0.45 | 2.57 | 2.83 | 7.32 ± 0.27 | 9.04 ± 1.82 |
| 6                | –                  | 5.90 ± 0.49 | 3.12 ± 0.45 | 2.71 ± 0.98 | 0.30 ± 0.43 | 3.19 | 2.82 | 7.80 ± 0.40 | 9.68 ± 0.39 |
|                  | +                 | 6.54 ± 0.28 | 3.34 ± 0.18 | 1.69 | 0.5 | 7.30 ± 0.37 | 9.32 ± 0.23 |
| 10               | –                  | 8.23 ± 0.13 | 3.84 ± 0.08 | 6.96 ± 0.42 | 2.28 ± 0.24 | 5.0 ± 0.48 | 1.12 ± 0.32 | 1.96 | 1.16 | 6.27 ± 0.19 | 9.66 ± 0.33 |
|                  | +                 | 5.32 ± 0.37 | 3.38 ± 0.19 | 1.02 | 0.35 | 6.61 ± 0.36 | 8.80 ± 0.07 |
\* The bacterial inoculums were 3.2 and 4.2 log colony-forming unit (CFU)/g, respectively, for 18 °C and 4 °C. \(^2\) The phage titers were 7 and 8 log10 plaque-forming unit (PFU)/g, respectively, for 18 °C and 4 °C. \(^3\) (-) indicates the control samples without phage and (+) denotes the samples treated with the phage cocktail. [116].

5.1. Phage Cocktails

Despite the advantages of bacteriophages, bacteria can become resistance to bacteriophages through surface modification, superinfection exclusion, restriction modification, abortive infection, and clustered regularly interspaced short palindromic repeats (CRISPR) systems [117,118]. Therefore, phage cocktails with different host specificities have been of great interest and are more practical for expanding the bacteriophage application, since the combined bacteriophage cocktails can reduce the development of bacteriophage-resistant mutants.

A mixture of two bacteriophages was used for controlling *Salmonella* in sprout seeds [119]. Bacteriophage A belongs to the *Myoviridae* family, while bacteriophage B is a member of the *Siphoviridae* family. The reductions of *S. Typhimurium*, *S. Enteritidis*, and *Salmonella* Montevideo were noticeable at the bacteriophage mixture of A and B in broccoli seeds compared to single bacteriophage treatment. The isolated bacteriophages effectively reduced the numbers of *S. Typhimurium* and *S. Enteritidis* in chickens [120]. The mixture of three phages, UAB_Phi20, Phi78, and Phi87, showed higher lytic activity than that obtained by any of the three phages alone, while the phage cocktail lysed *Salmonella* Virchow, *Salmonella* Hadar, *Salmonella* Infantis, *S. Typhimurium*, and *S. Enteritidis*, showing a broad spectrum lytic capability. The bacteriophage cocktail was applied in different food systems [121]. Significant reductions of *S. Typhimurium* and *S. Enteritidis* were observed for different food matrices, including pig skin, chicken breasts, and lettuce. Recently, a phage cocktail (BSPM4, BSP101, and BSP22A) based on targeting different cell surface receptors, including flagella, O-antigen, and BtuB, has been developed for the inhibition of *Salmonella* Typhimurium from fresh produce foods [122]. The multiple receptor-targeting bacteriophage cocktail can reduce *Salmonella* by up to 4.7–5.5 log CFU/cm\(^2\) in iceberg lettuce and 4.8–5.8 log CFU/cm\(^2\) in cucumber after 12 h incubation at 25 °C, without the development of bacteriophage resistance [122]. At present, the commercial bacteriophage cocktail has been applied for controlling *Salmonella* in poultry products [123].

5.2. Phage Endolysins

Bacteriophage endolysins have been used as a novel biocontrol agent and natural food preservatives over the past decades. The endolysins are peptidoglycan hydrolases that can lyse host cells after phage replication and propagation. The endolysins are mainly active against Gram-positive
bacteria, which do not contain an outer membrane [36,124]. The outer membrane of Gram-negative bacteria can prevent contact between free endolysins and peptidoglycan. However, some *Salmonella* bacteriophage endolysins can bypass the outer membrane barriers when combined with different outer membrane permeabilizers, such as ethylene diamine tetra-acetic acid (EDTA), citrate, and malate [114,125,126]. The bactericidal activity of a *Salmonella* phage endolysin (Lys68) combined with organic acids was increased against Gram-negative bacteria [127]. A *Salmonella* bacteriophage endolysin, Gp110, has currently proved to show enzymatic activity [128]. In addition, bacteriophage endolysins have also been engineered to increase the bactericidal effect against Gram-negative bacteria. The modified endolysin combined with lipopolysaccharide (LPS)-destabilizing peptides showed promising results against *Pseudomonas aeruginosa*, showing more than 5 log CFU/mL reduction. However, there are still some limited effects against *Salmonella Typhimurium* (<1 log CFU/mL reduction) [129]. Although many bacteriophage endolysins have been introduced and characterized, further optimization is still needed to increase the host specificity and lytic activity. The genetic engineering endolysin can be one of the useful approaches for satisfying these requirements.

5.3. Phage Control Combined with Other Preservatives

The hurdle concept (or barrier technology) is applied to foods to enhance the microbiological safety and quality. Many preservative methods are employed, together with other barriers to effectively control microbial contamination in food [130]. Many studies have demonstrated bacteriophages as alternative antimicrobials to control bacteria. Several *Salmonella* bacteriophages, such as Salomonex™, SalmoFresh™, and SalmoPro™, have been approved as GRAS by the United States Food and Drug Administration (US FDA) and the US Department of Agriculture’s Food Safety and Inspection Service (USDA-FSIS) [131,132]. The combinations of bacteriophages and antimicrobials or sequential applications showed an effective biocontrol ability against the target bacteria [38,133]. SalmoFresh™ bacteriophages combined with cetylpyridinium chloride (CPC) or lauric arginate (LAE) showed more than 5 log reductions against *Salmonella* spp. in chicken products [133–136]. However, an in vivo test on chicken breast fillets showed that a lower number of *Salmonella* (0.5 to 1.3 log CFU/g) was reduced by the combinations of bacteriophages with CPC or LAE, which may be attributed to the complex matrix of the meat components [137]. Sequential treatment of chlorine, CPC, LAE, or peracetic acid (PAA) with concentrations of 50 and 400 ppm, respectively, followed by phage spray, were carried out to evaluate the hurdle effect of *Salmonella* on chicken skin. The high reductions of 1.7 to 2.2 and 2.2 to 2.5 log CFU/cm² were obtained with an immersion in 50 and 400 ppm of PAA, followed by phage spray, which may be used in industries for the reduction of *Salmonella* contamination in cut meat. With growing interest of the combinations of bacteriophages and antimicrobials, further studies are needed to evaluate the inhibitory effect of antimicrobials combined with bacteriophages, the potential synergistic effect of the combination, and the mode of phage application, such as immersion and spraying [38,138–140].

6. Conclusions

Notably, research related to bacteriophages and their promising applications has increased in recent decades due to frequent outbreaks and the emergence of antibiotic-resistant bacteria. The effective detection and biocontrol of *Salmonella*, based on the potential bacteriophages, are of importance to reduce the incidence of *Salmonella* and ensure the food safety. Since many studies have been performed in the laboratory with well-controlled conditions, bacteriophages showed a significant effect on the inhibition of bacteria both in vivo and in vitro. Novel hurdle technology-coupled phages with antimicrobials, UV, or antagonistic bacteria are of interest to find synergistic effects against pathogens, which provide potential effective ways to be used in industries for control pathogens and alleviate the risk of pathogen contaminations in foods.
**Supplementary Materials:** The following are available online at www.mdpi.com/2076-2607/7/11/570/s1, Table S1: Bacteriophage based sensors for detection of *Salmonella*, Table S2: Applications of bacteriophage or bacteriophage-based treatments for biocontrol of *Salmonella*.

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**References**

1. Scallan, E.; Hoekstra, R.M.; Angulo, F.J.; Tauxe, R.V.; Widdowson, M.A.; Roy, S.L.; Jones, J.L.; Griffin, P.M. Foodborne illness acquired in the United States-Major pathogens. *Emerg. Infect. Dis.* 2011, 17, 7–15.
2. CDC. *Salmonella*. 2019. Available online: https://www.cdc.gov/salmonella/general/index.html#two (accessed on 1 October 2019).
3. WHO. *Foodborne Diseases, Salmonella*. Available online: https://www.who.int/foodsafety/areas_work/foodborne-diseases/salmonella/en/ (accessed on 1 October 2019).
4. Chang, Q.; Wang, W.; Regev-Yochay, G.; Lipsitch, M.; Hanage, W.P. Antibiotics in agriculture and the risk to human health: How worried should we be? *Evol. Appl.* 2015, 8, 240–247.
5. Agyare, C.; Boamah, V.E.; Zumbi, C.N.; Osei, F.B. Antibiotic use in poultry production and its effects on bacterial resistance. In *Antibiotic Resistance-A Global Threat*; Kumar, Y., Ed.; IntechOpen: London, UK, 2019.
6. Medeiros, M.A.N.; de Oliveira, D.C.N.; dos Prazeres Rodrigues, D.; de Freitas, D.R.C. Prevalence and antimicrobial resistance of *Salmonella* in chicken carcasses at retail in 15 Brazilian cities. *Rev. Panam. Salud Publica* 2011, 30, 555–560.
7. Khachatourians, G.G. Agricultural use of antibiotics and the evolution and transfer of antibiotic-resistant bacteria. *Can. Med. Assoc. J.* 1998, 159, 1129–1136.
8. Liu, Y.-Y.; Wang, Y.; Walsh, T.R.; Yi, L.-X.; Zhang, R.; Spencer, J.; Doi, Y.; Tian, G.; Dong, B.; Huang, X.; et al. Emergence of plasmid-mediated colistin resistance mechanism MCR-1 in animals and human beings in China: A microbiological and molecular biological study. *Lancet Infect. Dis.* 2016, 16, 161–168.
9. Marshall, B.M.; Levy, S.B. Food animals and antimicrobials: Impacts on human health. *Clin. Microbiol. Rev.* 2011, 24, 718–733.
10. Founou, L.L.; Founou, R.C.; Essack, S.Y. Antibiotic resistance in the food chain: A developing country-Perspective. *Front. Microbiol.* 2016, 7, 1881.
11. Campos, J.; Mourão, J.; Pestana, N.; Peixe, L.; Novais, C.; Antunes, P. Microbiological quality of ready-to-eat salads: An underestimated vehicle of bacteria and clinically relevant antibiotic resistance genes. *Int. J. Food Microbiol.* 2013, 166, 464–470.
12. Schwaiger, K.; Helmke, K.; Hölzle, C.S.; Bauer, J. Antibiotic resistance in bacteria isolated from vegetables with regards to the marketing stage (farm vs. supermarket). *Int. J. Food Microbiol.* 2011, 148, 191–196.
13. Berger, C.N.; Sodha, S.V.; Shaw, R.K.; Griffin, P.M.; Pink, D.; Hand, P.; Frankel, G. Fresh fruit and vegetables as vehicles for the transmission of human pathogens. *Environ. Microbiol.* 2010, 12, 2385–2397.
14. WHO. Antibiotic Resistance. Available online: https://www.who.int/news-room/fact-sheets/detail/antibiotic-resistance (accessed on 22 September 2019).
15. Doss, J.; Culbertson, K.; Hahn, D.; Camacho, J.; Barekzi, N. A review of phage therapy against bacterial pathogens of aquatic and terrestrial organisms. *Viruses* 2017, 9, 50.
16. Salmond, G.P.; Fineran, P.C. A century of the phage: Past, present and future. *Nat. Rev. Microbiol.* 2015, 13, 777–786.
17. Twort, F.W. An investigation on the nature of ultramicroscopic viruses. *Lancet* 1915, 186, 1241–1243.
18. D’Herelle, F. On an invisible microbe antagonistic toward dysenteric bacilli. *Res. Microbiol.* 2007, 158, 553–554.
19. Torres-Barceló, C. Phage therapy faces evolutionary challenges. *Viruses* 2018, 10, 323.
20. Hungaro, H.M.; Mendonça, R.C.S.; Gouvêa, D.M.; Vanetti, M.C.D.; Pinto, C.L.D.O. Use of bacteriophages to reduce *Salmonella* in chicken skin in comparison with chemical agents. *Food Res. Int.* 2013, 52, 75–81.

21. Sulakvelidze, A.; Alavidze, Z.; Morris, J.G. Bacteriophage therapy. *Antimicrob. Agent Chemother.* 2001, 45, 649–659.

22. Summers, W.C. Bacteriophage therapy. *Ann. Rev. Microbiol.* 2001, 55, 437–451.

23. Haq, I.; Chaudhry, W.; Akhtar, M.; Andleeb, S.; Qadri, I. Bacteriophages and their implications on future biotechnology: A review. *Virol. J.* 2012, 9, 9.

24. Fischbach, M.A.; Walsh, C.T. Antibiotics for emerging pathogens. *Science* 2009, 325, 1089–1093.

25. Alainis, A.J. Resistance to antibiotics: Are we in the post-antibiotic era? *Arch. Med. Res.* 2005, 36, 697–705.

26. Clark, J.R.; March, J.B. Bacteriophages and biotechnology: Vaccines, gene therapy and antibacterials. *Trends Biotechnol.* 2006, 24, 212–218.

27. Alcaine, S.D.; Law, K.; Ho, S.; Kinchla, A.J.; Sela, D.A.; Nugen, S.R. Bioengineering bacteriophages to enhance the sensitivity of phage amplification-based paper fluidic detection of bacteria. * Biosens. Bioelectron.* 2016, 82, 14–19.

28. Balasubramanian, S.; Sorokulova, I.B.; Vodyanoy, V.J.; Simonian, A.L. Lytic phage as a specific and selective probe for detection of *Staphylococcus aureus*—A surface plasmon resonance spectroscopic study. *Biosens. Bioelectron.* 2007, 22, 948–955.

29. Bárdy, P.; Pantucék, R.; Benešík, M.; Doškař, J. Genetically modified bacteriophages in applied microbiology. *J. Appl. Microbiol.* 2012, 121, 618–633.

30. Altintas, Z.; Pocock, J.; Thompson, K.-A.; Tothill, I.E. Comparative investigations for adenovirus recognition and quantification: Plastic or natural antibodies? *Biosens. Bioelectron.* 2015, 74, 996–1004.

31. Wang, F.; Horikawa, S.; Hu, J.; Wikle, H.C.; Chen, I.H.; Du, S.; Liu, Y.; Chin, B.A. Detection of *Salmonella* Typhimurium on spinach using phage-based magnetoelastic biosensors. *Sensors* 2017, 17, 386.

32. Sommer, J.; Trautner, C.; Witte, A.K.; Fister, S.; Schoder, D.; Rossmanith, P.; Mester, P.-J. Don’t shut the stable door after the phage has bolted-The importance of bacteriophage inactivation in food environments. *Viruses* 2019, 11, 468.

33. Wittebole, X.; De Roock, S.; Opal, S.M. A historical overview of bacteriophage therapy as an alternative to antibiotics for the treatment of bacterial pathogens. *Virulence* 2014, 5, 226–235.

34. Stewart, G.S.; Jassim, S.A.; Denyer, S.P.; Newby, P.; Linley, K.; Dhir, V.K. The specific and sensitive detection of bacterial pathogens within 4 h using bacteriophage amplification. *J. Appl. Microbiol.* 1998, 84, 777–783.

35. Hagens, S.; Loensner, M.J. Application of bacteriophages for detection and control of foodborne pathogens. *Appl. Microbiol. Biotechnol.* 2007, 76, 513–519.

36. Schmelcher, M.; Loensner, M.J. Application of bacteriophages for detection of foodborne pathogens. *Bacteriophage* 2014, 4, e28137.

37. Boyacioglu, O.; Sharma, M.; Sulakvelidze, A.; Goktepe, I. Biocontrol of *Escherichia coli* O157: H7 on fresh-cut leafy greens. *Bacteriophage* 2013, 3, e24620.

38. Ferguson, S.; Roberts, C.; Handy, E.; Sharma, M. Lytic bacteriophages reduce *Escherichia coli* O157: H7 on fresh cut lettuce introduced through cross-contamination. *Bacteriophage* 2013, 3, e24323.

39. Wang, L.; Ku, Q.; Li, X.; Cao, Z.; Wang, X.; Li, Z.; Song, Y.; Xu, Y. Use of bacteriophages to control *Escherichia coli* O157:H7 in domestic ruminants, meat products, and fruits and vegetables. *Foodborne Pathog. Dis.* 2017, 14, 483–493.

40. Perera, M.N.; Abuladze, T.; Li, M.; Woolston, J.; Sulakvelidze, A. Bacteriophage cocktail significantly reduces or eliminates *Listeria monocytogenes* contamination on lettuce, apples, cheese, smoked salmon and frozen foods. *Food Microbiol.* 2015, 52, 42–48.

41. Baños, A.; García-López, J.D.; Núñez, C.; Martínez-Bueno, M.; Maqueda, M.; Valdivia, E. Biocontrol of *Listeria monocytogenes* in fish by enterocin AS-48 and *Listeria* lytic bacteriophage P100. *LWT-Food Sci. Technol.* 2016, 66, 672–677.

42. Gutiérrez, D.; Rodríguez-Rubio, L.; Fernández, L.; Martínez, B.; Rodriguez, A.; Garcia, P. Applicability of commercial phage-based products against *Listeria monocytogenes* for improvement of food safety in Spanish dry-cured ham and food contact surfaces. *Food Control* 2017, 73, 1474–1482.

43. Grant, A.Q.; Parveen, S.; Schwarz, J.; Hashem, F.; Vimin, B. Reduction of *Salmonella* in ground chicken using a bacteriophage. *Poult. Sci.* 2017, 96, 2845–2852.
44. Moye, Z.D.; Woolston, J.; Sulakvelidze, A. Bacteriophage applications for food production and processing. *Viruses* 2018, 10, 205.
45. Soffer, N.; Woolston, J.; Li, M.; Das, C.; Sulakvelidze, A. Bacteriophage preparation lytic for *Shigella* significantly reduces *Shigella sonnei* contamination in various foods. *PLoS ONE* 2017, 12, e0175256.
46. Shahin, K.; Bouzari, M. Bacteriophage application for biocontrolling *Shigella flexneri* in contaminated foods. *J. Food Sci. Technol.* 2018, 55, 550–559.
47. Bernasconi, O.J.; Dona, V.; Tinguely, R.; Endimiani, A. In vitro activity of 3 commercial bacteriophage cocktails against *Salmonella* and *Shigella* spp. isolates of human origin. *Pathog. Immun.* 2018, 3, 72–81.
48. Huang, C.; Shi, J.; Ma, W.; Li, Z.; Wang, J.; Li, J.; Wang, X. Isolation, characterization, and application of a novel specific *Salmonella* bacteriophages in different food matrices. *Food Res. Int.* 2018, 111, 631–641.
49. Lillehaug, D. An improved plaque assay for poor plaque-producing temperate lactococcal bacteriophages. *J. Appl. Microbiol.* 1997, 83, 85–90.
50. Kropinski, A. Measurement of the rate of attachment of bacteriophage to cells. In *Bacteriophages*; Clokie, M.J., Kropinski, A., Eds.; Humana Press: Totowa, NJ, USA, 2009; Volume 501, pp. 151–155.
51. Adams, M.H. *Bacteriophages*; Interscience Publishers Inc.: New York, NY, USA, 1959; pp. 14–15.
52. Cormier, J.; Janes, M. A double layer plaque assay using spread plate technique for enumeration of bacteriophage MS2. *J. Virol. Methods* 2014, 196, 86–92.
53. Cormax, R.; Moriiigo, M.A.; Paez, I.G.; Muñoz, M.A.; Borrego, J.J. Application of direct plaque assay for detection and enumeration of bacteriophages of *Bacteroides fragilis* from contaminated-water samples. *Appl. Environ. Microbiol.* 1990, 56, 3170–3173.
54. Brown-Jaqué, M.; Muniesa, M.; Navarro, F. Bacteriophages in clinical samples can interfere with microbiological diagnostic tests. *Sci. Rep.* 2016, 6, 33000.
55. Burnham, S.; Hu, J.; Anany, H.; Brovko, L.; Deiss, F.; Derda, R.; Griffiths, M.W. Towards rapid on-site phage-mediated detection of generic *Escherichia coli* in water using luminescent and visual readout. *Anal. Bioanal. Chem.* 2014, 406, 5685–5693.
56. Petrenko, V.A.; Jayanna, P.K. Phage protein-targeted cancer nanomedicines. *FEBS Lett.* 2014, 588, 341–349.
57. Kakasis, A.; Panitsa, G. Bacteriophage therapy as an alternative treatment for human infections. A comprehensive review. *Int. J. Antimicrob. Agents* 2019, 53, 16–21.
58. de Jonge, P.A.; Nobrega, F.L.; Brouns, S.J.J.; Dutilh, B.E. Molecular and evolutionary determinants of bacteriophage host range. *Trends Microbiol.* 2019, 27, 51–63.
59. Galikowska, E.; Kunikowska, D.; Tokarska-Pietrzak, E.; Dzidziuszko, H.; Los, J.M.; Golec, P.; Wegrzyn, G.; Los, M. Specific detection of *Salmonella enterica* and *Escherichia coli* strains by using ELISA with bacteriophages as recognition agents. *Eur. J. Clin. Microbiol. Infect. Dis.* 2011, 30, 1067–1073.
60. Botsaris, G.; Liapi, M.; Kakogiannis, C.; Dodd, C.E.R.; Rees, C.E.D. Detection of *Mycobacterium avium* subsp. *paratuberculosis* in bulk tank milk by combined phage-PCR assay: Evidence that plaque number is a good predictor of MAP. *Int. J. Food Microbiol.* 2013, 164, 76–80.
61. Bennett, A.R.; Davids, F.G.C.; Vlahodimou, S.; Banks, J.G.; Betts, R.P. The use of bacteriophage-based systems for the separation and concentration of *Salmonella*. *J. Appl. Microbiol.* 1997, 83, 259–265.
62. Favrin, S.J.; Jassim, S.A.; Griffiths, M.W. Development and optimization of a novel immunomagnetic separation-bacteriophage assay for detection of *Salmonella enterica* serovar enteritidis in broth. *Appl. Environ. Microbiol.* 2001, 67, 217–224.
63. Rees, J.C.; Voorhees, K.J. Simultaneous detection of two bacterial pathogens using bacteriophage amplification coupled with matrix-assisted laser desorption/ionization time-of-flight mass spectrometry. *Rapid Commun. Mass Spectrom.* 2005, 19, 2757–2761.
64. Smartt, A.E.; Xu, T.; Jegier, P.; Carswell, J.J.; Blount, S.A.; Sayler, G.S.; Ripp, S. Pathogen detection using engineered bacteriophages. *Anal. Bioanal. Chem.* 2012, 402, 3127–3146.
65. Kutin, R.K.; Alvarez, A.; Jenkins, D.M. Detection of *Ralstonia solanacearum* in natural substrates using phage amplification integrated with real-time PCR assay. *J. Microbiol. Methods* 2009, 76, 241–246.
66. Luo, J.; Jiang, M.; Xiong, J.; Li, J.; Zhang, X.; Wei, H.; Yu, J. Exploring a phage-based real-time PCR assay for diagnosing *Acinetobacter baumannii* bloodstream infections with high sensitivity. *Anal. Chim. Acta* 2018, 1044, 147–153.
67. Wang, Z.; Wang, D.; Kinchla, A.J.; Sela, D.A.; Nugen, S.R. Rapid screening of waterborne pathogens using phage-mediated separation coupled with real-time PCR detection. *Anal. Bioanal. Chem.* 2016, 408, 4169–4178.
68. Garrido-Maestu, A.; Fuciños, P.; Azinheiro, S.; Carvalho, C.; Carvalho, J.; Prado, M. Specific detection of viable Salmonella Enteritidis by phage amplification combined with qPCR (PAA-qPCR) in spiked chicken meat samples. Food Control 2019, 99, 79–83.

69. Kumar, R.; Surendran, P.K.; Thampuran, N. Evaluation of culture, ELISA and PCR assays for the detection of Salmonella in seafood. Lett. Appl. Microbiol. 2008, 46, 221–226.

70. Schneid, A.D.S.; Rodrigues, K.L.; Chemello, D.; Tondo, E.C.; Ayub, M.A.Z.; Aleixo, J.A.G. Evaluation of an indirect ELISA for the detection of Salmonella in chicken meat. Braz. J. Microbiol. 2006, 37, 350–355.

71. Perelle, S.; Dilasser, F.; Malorny, B.; Grout, J.; Hoorfar, J.; Fach, P. Comparison of PCR-ELISA and LightCycler real-time PCR assays for detecting Salmonella spp. in milk and meat samples. Mol. Cell. Probes 2004, 18, 409–420.

72. Croci, L.; Delibato, E.; Volpe, G.; Palleschi, G. A rapid electrochemical ELISA for the detection of Salmonella in meat samples. Anal. Lett. 2001, 34, 2597–2607.

73. Hu, Y.-F.; Zhao, D.; Yu, X.-L.; Hu, Y.-L.; Li, R.-C.; Ge, M.; Xu, T.-Q.; Liu, X.-B.; Liao, H.-Y. Identification of bacterial surface antigens by screening peptide phage libraries using whole bacteria cell-purified antisera. Front. Microbiol. 2017, 8, 82.

74. Singhal, N.; Kumar, M.; Kanaujia, P.K.; Virdi, J.S. MALDI-TOF mass spectrometry: An emerging technology for microbial identification and diagnosis. Front. Microbiol. 2015, 6, 791.

75. Bell, R.L.; Jarvis, K.G.; Ottesen, A.R.; McFarland, M.A.; Brown, E.W. Recent and emerging innovations in Salmonella detection: A food and environmental perspective. Microb. Biotechnol. 2016, 9, 279–292.

76. Dieckmann, R.; Helmuth, R.; Erhard, M.; Malorny, B. Rapid classification and identification of Salmonella at the species and subspecies levels by whole-cell matrix-assisted laser desorption ionization-time of flight mass spectrometry. Appl. Microbiol. 2008, 74, 7767–7778.

77. Dieckmann, R.; Malorny, B. Rapid screening of epidemiologically important Salmonella enterica subsp. enterica serovars by whole-cell matrix-assisted laser desorption ionization-time of flight mass spectrometry. Appl. Environ. Microbiol. 2011, 77, 4136–4146.

78. Sparbier, K.; Weller, U.; Boogen, C.; Kosztrewa, M. Rapid detection of Salmonella spp. by means of a combination of selective enrichment broth and MALDI-TOF MS. Eur. J. Clin. Microbiol. Infect. Dis. 2012, 31, 767–773.

79. Pires, D.P.; Cleto, S.; Sillankorva, S.; Azeredo, J.; Lu, T.K. Genetically engineered phages: A Review of advances over the last decade. Microbiol. Mol. Biol. Rev. 2016, 80, 523–543.

80. Chen, J.; Alcaine, S.D.; Jiang, Z.; Rotello, V.M.; Nugen, S.R. Detection of Escherichia coli in drinking water using T7 bacteriophage-conjugated magnetic probe. Anal. Chem. 2015, 87, 8977–8984.

81. Kim, J.; Kim, M.; Kim, S.; Ryu, S. Sensitive detection of viable Escherichia coli O157:H7 from foods using a luciferase-reporter phage pHyV10lux. Int. J. Food Microbiol. 2017, 254, 11–17.

82. Franche, N.; Vinay, M.; Ansaldo, M. Substrate-independent luminescent phage-based biosensor to specifically detect enteric bacteria such as E. coli. Environ. Sci. Pollut. Res. 2017, 24, 42–51.

83. Kim, S.; Kim, M.; Ryu, S. Development of an engineered bioluminescent reporter phage for the sensitive detection of viable Salmonella Typhimurium. Anal. Chem. 2014, 86, 5858–5864.

84. Chen, J.; Griffiths, M.W. Salmonella detection in eggs using LuX+ bacteriophages. J. Food Prot. 1996, 59, 908–914.

85. Tanji, Y.; Furukawa, C.; Na, S.-H.; Hijiakata, T.; Miyanaga, K.; Unno, H. Escherichia coli detection by GFP-labeled lysozyme-inactivated T4 bacteriophage. J. Biotechnol. 2004, 114, 11–20.

86. Vinay, M.; Franche, N.; Grégori, G.; Fantino, J.-R.; Pouillot, F.; Ansaldo, M. Phage-based fluorescent biosensor prototypes to specifically detect enteric bacteria such as E. coli and Salmonella enterica Typhimurium. PLoS ONE 2015, 10, e0131466.

87. Oda, M.; Morita, M.; Unno, H.; Tanji, Y. Rapid detection of Escherichia coli O157:H7 by using green fluorescent protein-labeled PP01 bacteriophage. Appl. Environ. Microbiol. 2004, 70, 527–534.

88. Goodridge, L.D.; Willford, J. An integrated assay for rapid detection of Escherichia coli O157:H7 on beef samples. Food Prot. Trends 2008, 28, 468–472.

89. Rubab, M.; Shahbaz, H.M.; Olaimat, A.N.; Oh, D.-H. Biosensors for rapid and sensitive detection of Staphylococcus aureus in food. Biosens. Bioelectron. 2018, 105, 49–57.

90. Hameed, S.; Xie, L.; Ying, Y. Conventional and emerging detection techniques for pathogenic bacteria in food science: A review. Trends Food Sci. Technol. 2018, 81, 61–73.
91. Singh, A.; Arutyunov, D.; Szymanski, C.M.; Evoy, S. Bacteriophage based probes for pathogen detection. *Analyst* **2012**, *137*, 3405–3421.

92. Tawil, N.; Sacher, E.; Mandeville, R.; Meunier, M. Bacteriophages: Biosensing tools for multi-drug resistant pathogens. *Analyst* **2014**, *139*, 1224–1236.

93. Lakshmanan, R.S.; Guntupalli, R.; Hu, J.; Petrenko, V.A.; Barbaree, J.M.; Chin, B.A. Detection of *Salmonella typhimurium* in fat free milk using a phage immobilized magnetoelastic sensor. *Sens. Actuators B Chem.* **2007**, *126*, 544–550.

94. Park, M.-K.; Li, S.; Chin, B.A. Detection of *Salmonella typhimurium* grown directly on tomato surface using phage-based magnetoelastic biosensors. *Food Bioprocess Technol.* **2013**, *6*, 682–689.

95. Olsen, E.V.; Sorokulova, I.B.; Petrenko, V.A.; Chen, I.H.; Barbaree, J.M.; Vodyanoy, V.J. Affinity-selected filamentous bacteriophage as a probe for acoustic wave biodetectors of *Salmonella typhimurium*. *Biosens. Bioelectron.* **2006**, *21*, 1434–1442.

96. Tay, L.-L.; Huang, P.-J.; Tanha, J.; Ryan, S.; Wu, X.; Hulse, J.; Chau, L.-K. Silica encapsulated SERS nanoprobe conjugated to the bacteriophage tailspike protein for targeted detection of *Salmonella*. *Chem. Commun.* **2012**, *48*, 1024–1026.

97. Park, S.C.; Nakai, T. Bacteriophage control of *Pseudomonas plecoglossicida* infection in ayu *Plecoglossus altivelis*. *Dis. Aquat. Org.* **2003**, *53*, 33–39.

98. Karunasagar, I.; Shivu, M.M.; Girisha, S.K.; Krohne, G.; Karunasagar, I. Biocontrol of pathogens in shrimp hatcheries using bacteriophages. *Aquaculture* **2007**, *268*, 288–292.

99. Hooton, S.P.T.; Atterbury, R.J.; Connerton, I.F. Application of a bacteriophage cocktail to reduce *Salmonella Typhimurium U288* contamination on pig skin. *Int. J. Food Microbiol.* **2011**, *151*, 157–163.

100. Silva, Y.J.; Moreirinha, C.; Pereira, C.; Costa, L.; Rocha, R.J.M.; Cunha, A.; Gomes, N.C.M.; Calado, R.; Almeida, A. Biological control of *Aeromonas salmonicida* infection in juvenile *Senegalese sole* (*Solea senegalensis*) with phage AS-A. *Aquaculture* **2016**, *450*, 225–233.

101. Pereira, C.; Silva, Y.J.; Santos, A.L.; Cunha, A.; Gomes, N.C.M.; Almeida, A. Bacteriophages with potential for inactivation of fish pathogenic bacteria: Survival, host specificity and effect on bacterial community structure. *Mar. Drugs* **2011**, *9*, 2236–2255.

102. Costa, P.; Pereira, C.; Gomes, A.T.P.C.; Almeida, A. Efficiency of single phage suspensions and phage cocktail in the inactivation of *Escherichia coli* and *Salmonella Typhimurium*: An in vitro preliminary study. *Microorganisms* **2019**, *7*, 94.

103. Chen, L.; Yuan, S.; Liu, Q.; Mai, G.; Yang, J.; Deng, D.; Zhang, B.; Liu, C.; Ma, Y. In vitro design and evaluation of phage cocktails against *Aeromonas salmonicida*. *Front. Microbiol.* **2018**, *9*, 1476–1476.

104. Bao, H.; Zhang, P.; Zhang, H.; Zhou, Y.; Zhang, L.; Wang, R. Bio-control of *Salmonella Enteritidis* in foods using bacteriophages. *Viruses* **2015**, *7*, 2847.

105. Kim, J.; Jo, A.; Ding, T.; Lee, H.-Y.; Ahn, J. Assessment of altered binding specificity of bacteriophage for ciprofloxacin-induced antibiotic-resistant *Salmonella Typhimurium*. *Arch. Microbiol.* **2016**, *198*, 521–529.

106. Phongtang, W.; Choi, G.-P.; Chukeatirote, E.; Ahn, J. Bacteriophage control of *Salmonella Typhimurium* in milk. *Food Sci. Biotechnol.* **2019**, *28*, 297–301.

107. Hagens, S.; Loessner, M.J. Phages of *Listeria* offer novel tools for diagnostics and biocontrol. *Front. Microbiol.* **2014**, *5*, 159.

108. Goede, D.; Allen, V.M.; Barrow, P.A. Reduction of experimental *Salmonella* and *Campylobacter* contamination of chicken skin by application of lytic bacteriophages. *Appl. Environ. Microbiol.* **2003**, *69*, 5032–5036.

109. Guenther, S.; Herzig, O.; Fieseler, L.; Klumpp, J.; Loessner, M.J. Biocontrol of *Salmonella Typhimurium* in RTE foods with the virulent bacteriophage FOI-E2. *Int. J. Food Microbiol.* **2012**, *154*, 66–72.

110. Whichard, J.M.; Weigt, L.A.; Borris, D.J.; Li, L.L.; Zhang, Q.; Kapur, V.; Pierson, F.W.; Lingohr, E.J.; She, Y.-M.; Kropinski, A.M.; et al. Complete genomic sequence of bacteriophage felix O1. *Viruses* **2010**, *2*, 710–730.

111. Cherry, W.B.; Davis, B.R.; Edwards, P.R.; Hogan, R.B. A simple procedure for the identification of the genus *Salmonella* by means of a specific bacteriophage. *J. Lab. Clin. Med.* **1954**, *44*, 51–55.

112. Guenther, S.; Huwyler, D.; Richard, S.; Loessner, M.J. Virulent bacteriophage for efficient biocontrol of *Listeria monocytogenes* in ready-to-eat foods. *Appl. Environ. Microbiol.* **2009**, *75*, 93–100.

113. Thung, T.Y.; Jayarukshi, K.; Premarathne, K.; Mudiyanselage, J.; San Chang, W.; Loo, Y.Y.; Chin, Y.Z.; Kuan, C.H.; Tan, C.W.; Basri, D.F.; et al. Use of a lytic bacteriophage to control *Salmonella Enteritidis* in retail food. *IWT-Food Sci. Technol.* **2017**, *78*, 222–225.
114. Lim, J.A.; Shin, H.; Kang, D.H.; Ryu, S. Characterization of endolysin from a *Salmonella* Typhimurium-infecting bacteriophage SPN15. *Res. Microbiol.* 2012, 163, 233–241.

115. Ma, Y.; Pacan, J.C.; Wang, Q.; Xu, Y.; Huang, X.; Korenensky, A.; Sabour, P.M. Microencapsulation of bacteriophage felix O1 into chitosan-alginate microspheres for oral delivery. *Appl. Environ. Microbiol.* 2008, 74, 4799–4805.

116. Galacce, N.E.; Bravo, J.L.; Robeson, J.P.; Borie, C.F. Bacteriophage cocktail reduces *Salmonella enterica* serovar Enteritidis counts in raw and smoked salmon tissues. *Rev. Argent. Microbiol.* 2014, 46, 333–337.

117. Gill, J.J.; Hyman, P. Phage choice, isolation, and preparation for phage therapy. *Curr. Pharm. Biotechnol.* 2010, 11, 2–14.

118. Van Houte, S.; Buckling, A.; Westra, E.R. Evolutionary ecology of prokaryotic immune mechanisms. *Microbiol. Mol. Biol. Rev.* 2016, 80, 745–763.

119. Pao, S.; Rolph, S.; Westbrook, E.; Shen, H. Use of bacteriophages to control *Salmonella* in experimentally contaminated sprout seeds. *J. Food Sci.* 2004, 69, M127–M130.

120. Bardina, C.; Spricigo, D.A.; Cortes, P.; Llagostera, M. Significance of the bacteriophage treatment schedule in reducing *Salmonella* colonization of poultry. *Appl. Environ. Microbiol.* 2012, 78, 6600–6607.

121. Spricigo, D.A.; Bardina, C.; Cortés, P.; Llagostera, M. Use of a bacteriophage cocktail to control *Salmonella* in food and the food industry. *Int. J. Food Microbiol.* 2013, 165, 169–174.

122. Bai, J.; Jean, B.; Ryu, S. Effective inhibition of *Salmonella* Typhimurium in fresh produce by a phage cocktail targeting multiple host receptors. *Food Microbiol.* 2019, 77, 52–60.

123. Clavijo, V.; Baquero, D.; Hernandez, S.; Farfan, J.C.; Arias, J.; Arevalo, A.; Donado-Godoy, P.; Vives-Flores, M. Phage cocktail SalmoFREE(R) reduces *Salmonella* on a commercial broiler farm. *Poult. Sci.* 2019, 1, 1–10.

124. Bai, J.; Kim, Y.T.; Ryu, S.; Lee, J.H. Biocontrol and rapid detection of food-borne pathogens using bacteriophages and endolysins. *Front. Microbiol.* 2016, 7, 474.

125. Legotsky, S.; Vlasova, K.; Priyma, A.; Shneider, M.; Pugachev, V.; Totmenina, O.; Kabanov, A.; Miroshnikov, K.; Klyachko, N. Peptidoglycan degrading activity of the broad-range *Salmonella* bacteriophage S-394 recombinant endolysin. *Biochimie* 2014, 107, 293–299.

126. Walmagh, M.; Boczkowska, B.; Grymonprez, B.; Briers, Y.; Drulis-Kawa, Z.; Lavigne, R. Characterization of five novel endolysins from Gram-negative infecting bacteriophages. *Appl. Microbiol. Biotechnol.* 2013, 97, 4369–4375.

127. Oliveira, H.; Thiagarajan, V.; Walmagh, M.; Sillankorva, S.; Lavigne, R.; Neves-Petersen, M.T.; Kluskens, L.D.; Azepend, J. A thermostable *Salmonella* phage endolysin Lys68, with broad bactericidal properties against Gram-negative pathogens in presence of weak acids. *PLoS ONE* 2014, 9, e108376.

128. Rodriguez-Rubio, I.; Gerstmans, H.; Thorpe, S.; Mesnage, S.; Lavigne, R.; Briers, Y. DUF3380 domain from a *Salmonella* phage endolysin shows potent N-acetylmuramidase activity. *Appl. Environ. Microbiol.* 2016, 82, 4975–4981.

129. Briers, Y.; Walmagh, M.; Van Puyenbroeck, V.; Cornelissen, A.; Cenens, W.; Aertsens, A.; Oliveira, H.; Azepend, J.; Verweeu, G.; Pirnay, J.-P.; et al. Engineered endolysin-based “Artielysins” to combat multidrug-resistant Gram-negative pathogens. *mBio* 2014, 5, e01379–e01314.

130. Leistner, L. Basic aspects of food preservation by hurdle technology. *Int. J. Food Microbiol.* 2000, 55, 181–186.

131. FDA. GARS Notice (GRN) No.603. 2015. Available online: https://www.fda.gov/media/95017/download (accessed on 7 August 2019).

132. USDA-FSIS. FSIS Directive 7120.1-Safe and Suitable Ingredients Used in the Production of Meat, Poultry, and Egg Products. 2013. Available online: https://www.fsis.usda.gov/wps/wcm/connect/7f981741–468c-b61d-b428c971152d/7120_68.pdf?MOD=AJPRES (accessed on 21 August 2019).

133. Sukumaran, A.T.; Nannapaneni, R.; Kiess, A.; Sharma, C.S. Reduction of *Salmonella* on chicken meat and chicken skin by combined or sequential application of lytic bacteriophage with chemical antimicrobials. *Int. J. Food Microbiol.* 2014, 207, 8–15.

134. Kim, J.-W.; Slavik, M.F. Cetylpyridinium chloride (CPC) treatment on poultry skin to reduce attached *Salmonella*. *J. Food Prot.* 1996, 59, 322–326.

135. Rodriguez, E.; Seguer, J.; Rocabayera, X.; Manresa, A. Cellular effects of monohydrochloride of l-arginine, N,lauroyl ethylester (LAE) on exposure to *Salmonella typhimurium* and *Staphylococcus aureus*. *J. Appl. Microbiol.* 2004, 96, 903–912.

136. Sharma, C.S.; Ates, A.; Joseph, P.; Nannapaneni, R.; Kiess, A. Reduction of *Salmonella* in skinless chicken breast fillets by lauric arginate surface application. *Poult. Sci.* 2013, 92, 1419–1424.
137. Burt, S. Essential oils: Their antibacterial properties and potential applications in foods—a review. *Int. J. Food Microbiol.* 2004, 94, 223–253.

138. Pimchan, T.; Cooper, C.J.; Eumkeb, G.; Nilsson, A.S. In vitro activity of a combination of bacteriophages and antimicrobial plant extracts. *Lett. Appl. Microbiol.* 2018, 66, 182–187.

139. Chaudhry, W.N.; Concepcion-Acevedo, J.; Park, T.; Andleeb, S.; Bull, J.J.; Levin, B.R. Synergy and order effects of antibiotics and phages in killing *Pseudomonas aeruginosa* biofilms. *PLoS ONE* 2017, 12, e0168615.

140. Oechslin, F.; Piccardi, P.; Mancini, S.; Gabard, J.; Moreillon, P.; Entenza, J.M.; Resch, G.; Que, Y.-A. Synergistic interaction between phage therapy and antibiotics clears *Pseudomonas aeruginosa* infection in endocarditis and reduces virulence. *J. Infect. Dis.* 2017, 215, 703–712.

141. Li, S.; Li, Y.; Chen, H.; Horikawa, S.; Shen, W.; Simonian, A.; Chin, B.A. Direct detection of *Salmonella typhimurium* on fresh produce using phage-based magnetoelastic biosensors. *Biosens. Bioelectron.* 2010, 26, 1313–1319.

142. Huang, S.; Yang, H.; Lakshmanan, R.S.; Johnson, M.L.; Wan, J.; Chen, I.H.; Wikle, H.C.; Petrenko, V.A.; Barbaree, J.M.; Chin, B.A. Sequential detection of *Salmonella typhimurium* and *Bacillus anthracis* spores using magnetoelastic biosensors. *Biosens. Bioelectron.* 2009, 24, 1730–1736.

143. Chen, I.H.; Horikawa, S.; Bryant, K.; Riggs, R.; Chin, B.A.; Barbaree, J.M. Bacterial assessment of phage magnetoelastic sensors for *Salmonella enterica* Typhimurium detection in chicken meat. *Food Control* 2017, 71, 273–278.

144. Chai, Y.; Horikawa, S.; Li, S.; Wikle, H.C.; Chin, B.A. A surface-scanning coil detector for real-time, in-situ detection of bacteria on fresh food surfaces. *Biosens. Bioelectron.* 2013, 50, 311–317.

145. Park, M.-K.; Chin, B.A. Novel approach of a phage-based magnetoelastic biosensor for the detection of *Salmonella enterica* serovar Typhimurium in soil. *J. Microbiol. Biotechnol.* 2016, 26, 2051–2059.

146. Mack, J.D.; Yehualaeshet, T.; Park, M.-K.; Tameru, B.; Samuel, T.; Chin, B.A. Phage-based biosensor and optimization of surface blocking agents to detect *Salmonella enterica* Typhimurium on romaine lettuce. *J. Food Saf.* 2017, 37, e12299.

147. Lakshmanan, R.S.; Guntupalli, R.; Hu, J.; Kim, D.J.; Petrenko, V.A.; Barbaree, J.M.; Chin, B.A. Phage immobilized magnetoelastic sensor for the detection of *Salmonella typhimurium*. *J. Microbiol. Methods* 2007, 71, 55–60.

148. Park, M.-K.; Wikle, H.C.; Chai, Y.; Horikawa, S.; Shen, W.; Chin, B.A. The effect of incubation time for *Salmonella Typhimurium* binding to phage-based magnetoelastic biosensors. *Food Control* 2012, 26, 539–545.

149. Agrawal, S.; Kulabhushan, P.K.; Joshi, M.; Bodas, D.; Paknikar, K.M. A high affinity phage-displayed peptide as a recognition probe for the detection of *Salmonella Typhimurium*. *J. Bacteriol.* 2016, 231, 40–45.

150. Karoonuthaisiri, N.; Charlermroj, R.; Morton, M.J.; Oplatowska-Stachowiak, M.; Grant, I.R.; Elliott, C.T. Development of a M13 bacteriophage-based SPR detection using *Salmonella* as a case study. *Sens. Actuators B Chem.* 2014, 190, 214–220.

151. Wang, J.; Morton, M.J.; Elliott, C.T.; Karoonuthaisiri, N.; Segatori, L.; Biswal, S.L. Rapid detection of pathogenic bacteria and screening of phage-derived peptides using microcantilevers. *Anal. Chem.* 2014, 86, 1671–1678.

152. Horikawa, S.; Chai, Y.; Wikle, H.C.; Suh, S.-J.; Barbaree, J.M.; Chin, B.A. Direct detection of *Salmonella* on fresh produce. *ECS Trans.* 2015, 69, 25–31.

153. Singh, A.; Arya, S.K.; Glass, N.; Hanifi-Moghadam, P.; Naidoo, R.; Szymanski, C.M.; Tanha, J.; Evoy, S. Bacteriophage tailspike proteins as molecular probes for sensitive and selective bacterial detection. *Biosens. Bioelectron.* 2010, 26, 131–138.

154. Blasco, R.; Murphy, M.J.; Sanders, M.F.; Squirrell, D.J. Specific assays for bacteria using phage mediated release of adenylate kinase. *J. Appl. Microbiol.* 1998, 84, 661–666.

155. Wu, Y.; Brovko, L.; Griffiths, M.W. Influence of phage population on the phage-mediated bioluminescent adenylate kinase (AK) assay for detection of bacteria. *Lett. Appl. Microbiol.* 2001, 33, 311–315.

156. Park, M.-K.; Park, J.W.; Wikle, H.C.; Chin, B.A. Evaluation of phage-based magnetoelastic biosensors for direct detection of *Salmonella Typhimurium* on spinach leaves. *Sens. Actuators B Chem.* 2013, 176, 1134–1140.

157. Chai, Y.; Li, S.; Horikawa, S.; Park, M.-K.; Vodyanoy, V.; Chin, B.A. Rapid and sensitive detection of *Salmonella Typhimurium* on eggsheels by using wireless biosensors. *J. Food Prot.* 2012, 75, 631–636.

158. Pereira, C.; Moreirinha, C.; Lewicka, M.; Almeida, P.; Clemente, C.; Cunha, A.; Delgadoillo, I.; Romalde, J.L.; Nunes, M.L.; Almeida, A. Bacteriophages with potential to inactivate *Salmonella Typhimurium*: Use of single phage suspensions and phage cocktails. *Virus Res.* 2016, 220, 179–192.
159. Sharma, M.; Dashiell, G.; Handy, E.T.; East, C.; Reynnells, R.; White, C.; Nyarko, E.; Micallef, S.; Hashem, F.; Millner, P.D. Survival of Salmonella Newport on whole and fresh-cut cucumbers treated with lytic bacteriophages. J. Food Prot. 2017, 80, 668–673.

160. Yeh, Y.; Purushothaman, P.; Gupta, N.; Ragnone, M.; Verma, S.C.; de Mello, A.S. Bacteriophage application on red meats and poultry: Effects on Salmonella population in final ground products. Meat Sci. 2017, 127, 30–34.

161. El-Dougdoug, N.K.; Cucic, S.; Abdelhamid, A.G.; Brovko, L.; Kropinski, A.M.; Griffiths, M.W.; Anany, H. Control of Salmonella Newport on cherry tomato using a cocktail of lytic bacteriophages. Int. J. Food Microbiol. 2019, 293, 60–71.

162. Zhang, X.; Niu, Y.D.; Nan, Y.; Stanford, K.; Holley, R.; McAllister, T.; Narvaez-Bravo, C. SalmoFresh effectiveness in controlling Salmonella on romaine lettuce, mung bean sprouts and seeds. Int. J. Food Microbiol. 2019, 305, 108250.

163. Ye, J.; Kostrzynska, M.; Dunfield, K.; Warriner, K. Control of Salmonella on sprouting mung bean and alfalfa seeds by using a biocontrol preparation based on antagonistic bacteria and lytic bacteriophages. J. Food Prot. 2010, 73, 9–17.

164. Yeh, Y.; de Moura, F.H.; Van Den Broek, K.; de Mello, A.S. Effect of ultraviolet light, organic acids, and bacteriophage on Salmonella populations in ground beef. Meat Sci. 2018, 139, 44–48.