Table 3: A summary of direct phage application onto a variety of foods (from the year 2010 to the present) The studies from the year 2001-2009 have been reviewed elsewhere (Hagens and Loessner 2010).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Reference** | **Food items** | **Targeted pathogen** | **Phages/product** | **Results** |
| Soni and Nannapaneni, 2010 | Raw salmon fillets | *L. monocytogenes* | PhageGuard Listex™ | Reduction of 1.8-3.5 logs bacterial counts after the application of phage at ∼108 PFU/g concentration on the surface of contaminated raw salmon fillets stored at 4/ 22°C. |
| Soni et al., 2010 | Raw catfish fillets | *L. monocytogenes* | PhageGuard Listex™ | Decreased microbial count by 1.4-2.0 logs at 4°C, 1.7-2.1 logs bacterial count at 10°C, and 1.6-2.3 logs bacterial count at 22°C.  |
| Ye et al., 2010 | Sprouting mung beans & alfalfa seeds | *Salmonella* spp. | F01, P01, P102, P700, P800, and FL 41(Caudovirales) | Reduction of the bacteria count by ∼3-6 logs on sprouting mung beans  |
| Bigot et al., 2011 | Chicken | *L. monocytogenes* | FWLLm1*(Myoviridae*) | Decreased *Listeria* counts 1-2 logs on the surface of contaminated food stored at 4°C or 30°C. But, subsequently, bacteria regrew at 30°C.  |
| Guenther and Loessner, 2011 | soft cheese | *L. monocytogenes* | A511*(Myoviridae)* | Reduction of *Listeria* count by 2 logs and the natural microbial community of cheese was not affected. |
| Viazis et al., 2011  | Leafy green vegetables | *E. coli O157:H7* | BEC8*(Myoviridae)* | Bacterial count decreased by ~2-4 logs after the treatment with phage cocktail at 4, 8, 23, & 37°C, and the addition of essential oil enhanced this effect.  |
| Bandara et al., 2012 | Fermented soya bean paste | *B. cereus* | BCP1-1 & BCP8-2 *(Myoviridae)* | Decreased bacterial count, the presence of divalent cations enhanced the phage adsorption resulting in eradication of the bacterial load.  |
| Bueno et al., 2012 | Cheese | *S. aureus* | vB\_SauS-phi-IPLA35 and vB\_SauS-phi-SauS-IPLA88(*Siphoviridae)* | In the cheese prepared from phage-treated milk, counts of *S. aureus* were decreased significantly as compared to the cheese prepared from untreated milk with no effect on the microbiota of milk.  |
| Carter et al., 2012 | Beef and lettuce | *E. coli* O157:H7 | EcoShield™ | Reduction of the bacterial load by ≥ 94% in beef and ∼87% in lettuce. |
| Guenther et al., 2012  | Hot dogs, sliced turkey breast, chocolate milk, egg yolk, and mixed seafood | *Salmonella* spp. | FO1-E2*(Myoviridae)* | Reduced *Salmonella* count to an undetectable level in various foods within 24-48 hours at 15°C and regrowth occurred after a few days, while in chocolate milk and mixed seafood, the treatment with phage at 8°C reduced bacterial counts below detection level within 24 hours with no regrowth. In egg yolk and assorted seafood initial reduction in *Salmonella* count was observed after phage addition but after a few days regrowth matched to that of control. |
| Soni et al., 2012 | Qeso fresco cheese | *L. monocytogenes* | PhageGuard Listex™ | Reduction in *Listeria* count by ∼3 logs on the surface of experimentally contaminated queso fresco cheese, but regrowth of *Listeria* was observed. |
| Boyacioglu et al., 2013 | Leafy green spinach and lettuce | *E. coli O157:H7* | EcoShield™ | Counts of *E.coli* were decreased by > 2 logs after phage application at both 4 and 10°C. |
| Chibeu et al., 2013 | Roasted beef and turkey | *L. monocytogenes* | PhageGuard Listex™ | *Listeria* counts on contaminated ready-to-eat roasted beef and turkey reduced more effectively with phage treatment at 4°C or 10°C, compared to chemical antimicrobial and subsequent regrowth was observed at both temperatures. Combined treatments with phage and chemical antimicrobials showed similar results. |
| Endersen et al., 2013 | Milk  | *Mycobacterium smegmatis* | Six phages(*Siphoviridae*) | Bacterial counts were reduced by 9 logs in experimentally contaminated milk after 96 hours at 37°C. |
| Ferguson et al., 2013 | Lettuce  | *E. coli O157:H7* | EcoShield™ | Application of phage cocktail on the surface of lettuce by spraying led to a sizeable initial reduction (~0.8-1.3 logs) in *E. coli* O157:H7 counts. While their application by dipping did not reduce bacterial count significantly. |
| Hudson et al., 2013 | Beef  | *E. coli* | FAHEc1*(Myoviridae)* | *E. coli* counts were reduced by 2-4 logs at various temperatures on the raw and cooked beef surface after phage application in a concentration-dependent manner but regrowth was observed at a higher temperature. |
| Hungaro et al., 2013 | Chicken skin | *Salmonella* spp. | Five phage cocktail(*Podoviridae*) | Reduced *Salmonella* count by ~1 log on chicken skin. The results were comparable with 200ppm dichloroisocyanurate, 10 ppm peroxyacetic acid and 2 % lactic acid. |
| Kang et al., 2013 | Chicken skin  | *S.* Enteritidis*, S.* Typhimurium | wksl3(*Siphoviridae)* | Phage treatment reduced *Salmonella* spp. counts by ∼3 logs on chicken skin at 8°C. To test for safety phage cocktails (SS3e, vB\_SenS-Ent1, SE2, SETP3, and wksl3) were also administered to mice orally and mice displayed no adverse effects. |
| McLean et al., 2013 | Milk  | *E. coli* | EC6 (*Siphoviridae*), EC9 *(Myoviridae)*, EC11 (*Podoviridae*) | At 5-9°C and 25°C, phage treatment eradicated *E. coli* from raw and ultrahigh temperature processed (UHT) milk but regrowth was observed in raw milk. |
| Magnone et al., 2013 | Broccoli, cantaloupe, and strawberries | *E. coli, Salmonella* spp.*, Shigella* | EcoShield™, SalmoFresh™, ShigActive™ | Reduction of the pathogenic bacteria more effectively than chlorine, while their combined treatment showed better results. |
| Spricigo et al., 2013 | Fresh eggsLettuce | *Salmonella* spp | UAB\_Phi 20, & UAB\_Phi78 (*Pdoviridae*), UAB\_Phi87 *(Myoviridae)* | Reduction in *Salmonella* counts by ∼1 log on fresh eggs after 60 mins, 2-4 logs on lettuce after 60 mins, 1-2 logs on chicken breasts at 4°C and 2-4 logs on pig skin at 33°C after 6 hours. |
| Zhang et al., 2013 | Spiced chicken  | *Shigella* spp | SD-11, SF-A2, SS-92 *(Myoviridae)* | Reduction of *Shigella* spp. count by ∼1-4 logs at 4°C. |
| Galarce et al., 2014 | Salmon fillets | *S. Enteritidis* | Five phages cocktails | Phage cocktail treatment in raw salmon fillets reduced the bacterial count by 2.8- 3.2 logs and in smoked salmon fillets 1.2-1.9 logs after 10 days of storage at 4°C and 18°C, respectively. |
| Oliveira et al., 2014 | Melon, pear and apple slices | *L. monocytogenes* | PhageGuard Listex™ | Phage treatment reduced the *Listeria* count on experimentally contaminated melon and pear slices at 10°C in a dose-dependent manner, but *Listeria* levels in apple slices remained unaffected.  |
| Silva et al., 2014 | Soft cheese | *L. monocytogenes* | P100 | Phage treatment initially reduced the *Listeria* count, but after storage for 7 days at 10°C on experimentally contaminated soft cheese, regrowth was observed. |
| Zinno et al., 2014 | Chicken samples, apple juice, liquid egg, energy drink, and skimmed milk | *Salmonella* spp. | P22 (Caudovirales) | *Salmonella* count decreased by 0.5-2 logs, ~3 logs, ~3 logs, ~2 logs, and below the detection limit on the experimentally contaminated chicken samples, apple juice, liquid egg, energy drink, and skimmed milk, respectively, after the treatment with phage and storage at 4°C. |
| Perera et al., 2015 | Cheese, lettuce, smoked salmon, frozen entrèes and apple slice | *L. monocytogenes* | ListShield™ | Reduction in *Listeria* count by 1.1 log, 0.7 logs, 1.0 log, and 2.2 logs on the surface of experimentally contaminated lettuce, cheese, smoked salmon, and frozen entrèes, respectively. Application of phage alone or in combination with an antioxidant/anti-browning solution reduced bacterial count by 1.1 logs on apple slice after 24 hours at 4 °C. |
| Sukumaran et al., 2015 | Chicken breast fillets | *Salmonella* spp. | SalmoFresh™ | Combined treatment with chlorine or PAA and phage to experimentally contaminated chicken breast reduced *Salmonella* count more effectively than alone. |
| Hong et al., 2016 | Ground pork and eggs | *Salmonella* spp. | SJ2 (*Siphoviridae*) | *Salmonella* counts reduced significantly in experimentally contaminated ground pork and eggs after phage treatment. More phage-resistant *Salmonella* colonies were recovered from the egg.  |
| Soffer et al., 2016 | Raw pet foods | *Salmonella* spp. | SalmoLyse® | *Salmonella* counts decreased by 60 to 92%. |
| Sukumaran et al., 2016 | Chicken breast fillets | *Salmonella* spp. | SalmoFresh™ | After phage treatment by dipping or surface application to the chicken breast fillet and storage at 4°C significant reductions in *Salmonella*, counts were observed by up to 0.9 logs; storing the meat in modified atmospheric packaging after phage application decreased bacterial count up to 1.2 logs. |
| Figueiredo and Almeida, 2017 | Sliced pork ham | *L. monocytogenes* | PhageGuard Listex™ |  Reduction in *Listeria* count to an undetectable level after 72 hours.  |
| Grant et al., 2017 | Boneless chicken thighs and legs | *Salmonella* spp. | PhageGuard S™ | Treatment with phage solution prepared with tap water to the experimentally contaminated boneless chicken thighs and legs resulted in a more significant reduction of *Salmonella* count compared to that prepared using filtered water. |
| Soffer et al., 2017 | Lettuce, melon, smoked salmon, corned beef, & pre-cooked chicken | *Shigella* spp. | ShigaShield™ | In various ready-to-eat (RTE) foods, a 90% reduction in *Shigella* counts was observed after phage addition. |
| Hagens et al., 2018 | Skinless and skin-on poultry products | *Salmonella* spp. | PhageGuard S™ | *Salmonella* counts were reduced by more than 1 log on various poultry products. |
| Yeh et al., 2018 | Ground beef | *Salmonella* spp. | PhageGuard S™ | *Salmonella* count reduced by ~1 log on experimentally contaminated ground beef trim after treatment with phage or irradiation individually. However, combined therapy with phage and irradiation reduced bacterial count by ~2 logs. |
| Bai et al., 2019 | Lettuce and cucumber | *Salmonella* spp. | BSPM4 (*Siphoviridae)*, BSP101 *(Myoviridae)*, BSP22A (*Siphoviridae*) | Reduction of *Salmonella* count by 4.7-5.8 logs. |
| Islam et al., 2019 | Chicken breast and milk | *Salmonella* spp. | LPSTLL *(Siphoviridae)*, LPST94 (*Ackermannviridae*), LPST153 (*Podoviridae*) | Reduction of *Salmonella* count below the detection limit on various foods while phage cocktail reduced bacterial count by 5.23 logs on microtiter plates and steel chips, showing their effectivity against *Salmonella* formed biofilms over food processing surfaces. |
| Zhang et al., 2019 | Lettuce and sprouts | *Salmonella* spp. | SalmoFresh™ | *Salmonella* count was reduced by 2-3 logs with phage treatment and by 2.7-3.8 logs using combined treatment with chlorine and phage. |
| Shebs-Maurine et al., 2020 | Beef | *E. coli O157:H7* | MS (Caudovirales) | A 0.7 to 1.3 log reduction of *E. coli* was observed on ground beef. |
| Vikram et al., 2020 | Beef chuck roast, ground beef, chicken breast, cooked chicken, salmon, cheese, cantaloupe, and romaine lettuce | *E. coli O157:H7* | EcoShield PX™ | Bacterial counts decreased by 97% on various food products after the treatment with phage cocktail at two different concentrations (5 × 106, or 1 × 107 PFU/g).  |

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Response to Q17- References for Supplementary material

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