An improved cleaning system to reduce microbial contamination of poultry transport crates in the United Kingdom

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Abstract

Aim: Following previous research on improving the cleaning of crates used to transport broiler chickens from the farm to the abattoir, a demonstration project was undertaken to investigate improvements in crate washing on a commercial scale.

Methods and Results: The soak tank of a conventional crate washing system was replaced with a high-performance washer fitted with high-volume, high-pressure nozzles. The wash water could be heated, and a greatly improved filtration system ensured that the nozzles did not lose performance or become blocked. Visual cleanliness scores and microbial counts were determined for naturally contaminated crates which had been randomly assigned to different cleaning protocols.

Conclusions: When a combination of mechanical energy, heat and chemicals (i.e. detergent and disinfectant) was used, the results showed significant improvements to crate cleaning. Reductions of up to 3.6 and 3.8 log₁₀ CFU per crate base were achieved for Campylobacter and Enterobacteriaceae, respectively, along with a marked improvement in visual cleanliness.

Significance and Impact of the Study: Broiler transport crates may become heavily contaminated with faeces and this may contribute to the spread of disease between farms. The results of this trial may be of use in reducing the spread of zoonotic pathogens in the poultry meat supply chain.
At the farm, the modules (containing empty crates) are taken from the truck by forklift, placed inside the poultry shed and filled with birds caught by a dedicated team of catchers. The filled modules are loaded back onto the truck and taken to the processing plant where the modules are placed onto a conveying system. The crates are removed mechanically from the module and the birds are removed manually from the crates. The emptied crates and modules pass through separate washing and sanitizing processes before being combined and reloaded onto trucks.

The impact of cleaning methods on transport crates has been investigated, both in the United States (Bacon et al. 2000; Nachamkin 2002; Berrang and Northcutt 2005; Northcutt and Berrang 2006) and in the United Kingdom (Allen et al. 2008a; Allen et al. 2008b). The major poultry transport systems and practices are different in the two countries and so comparisons should be made with care; however, the results from these studies indicate high variability in the efficacy of cleaning methods. Washing may reduce the bacterial load, but it does not eliminate it on the transport crates or cages. The study by Allen and others led to the draft document, ‘Best practice for cleaning poultry transport crates’, the main findings of which were communicated to the industry in the Food Standards Agency (FSA) Meat Industry Guide (Allen et al. 2008b). These trials found that a reduction in total aerobic counts in the interior base of the crate by 4 log10 units could be achieved by combining the use of hot water containing detergent, vigorous brushing and applying chemical disinfectants to well-cleaned crates.

Poultry transport crates were not originally designed for ease of cleaning, but they are so widely used that it is uneconomic and impractical to redesign and replace them on a large scale. As such, it is appropriate to consider developing a practical solution to crate cleaning rather than redesigning the crates at this stage. The Sinner Circle (Busk Jensen and Friis 2007) states that four factors need to be balanced to achieve satisfactory cleaning: mechanical action, chemical action, temperature and contact time. If one of these factors is reduced, the others will need to be increased to compensate. In addition, an improved washing system needs to maintain near maximum mechanical action throughout the working period, possibly up to 20 h, without undue manual intervention to clean filters and nozzles during operation.

This is a proof of principle study supported by a partnership between the United Kingdom’s FSA and a poultry processor, representing the industry, together with a multidisciplinary team of researchers. The primary objective of this study is to determine the ability of a new poultry transport crate washing system to reduce surface contamination by Campylobacter, Enterobacteriaceae and E. coli bacteriophage under different conditions in a commercial poultry abattoir.

Materials and methods

Study design

A baseline study was undertaken at two similar poultry processing plants within the same company; one was to have the new washing equipment installed (Plant A) while the other plant would continue to run a similar typical crate cleaning system (Plant B). This arrangement effectively gave two controls, one at the modified plant where the control sampling ceased after the new equipment was installed, and the sister plant where control samples were taken continually.

Equipment selection

A schematic diagram showing the original and modified arrangements of the crate and module flow in the processing plants is presented in Fig. 1. The pre-existing commercial crate cleaning system had very little mechanical cleaning action, a low water temperature, poor effective chemical concentration control, a high organic load and limited contact time. Additionally, the wash water was recycled over run-down filters which removed only larger particulate material so that much of the organic debris continued to circulate and accumulate leading to reduced flow and pressure from the spray nozzles. It was not uncommon for flow to stop as nozzles became clogged with debris.

The specifications of the new equipment were based on the ‘Best practice for cleaning poultry transport crates’ developed from previous research by Allen et al. (2008b). Cost, ease of use and reliability also had to be considered, as the equipment was to be used in a commercial plant processing approximately 8500 birds per hour. Undue stoppages were unacceptable, both on commercial and welfare grounds.

The equipment selected was a Numafa RWM 800 Combi Washing System with Belt Filtration and Rotary Fine Filtration Units. The washer combined a high flow stage circulating over 130 m3 h⁻¹ at a pressure of 345 kPa (stage 1) through nozzle bars. This was followed by the high-pressure nozzles operating at 2000 kPa with a flow of 15 m3 h⁻¹ (stage 2). A belt filter took the full return flow filtering down to 400 microns and was cleaned continuously by a rotating brush and an air knife. Filtration for the high-pressure section was via the separate rotary fine filter unit accepting 10 m3 h⁻¹ with a
single drum using 80- and 130-micron cloth in the two stages. This filter was continually cleaned by a small bleed-off from the fully filtered water return. Heating of the water was by thermostatically controlled steam. Interlock emergency stops, steam/aerosol extraction and overall control via a programmable logic controller were also incorporated.

Keeping the original crate inverter simplified crate handling and it easily removed loosely bound organic material. The original washer included a re-inverter and both the original washer and re-inverter were left in place to provide a detergent rinse stage and create handling without compromising the performance of the new washer.

The previous sanitizing applicator and chemical choice formed part of the trials. The existing crate reloader remained unchanged as did the complete module handling and washing system.

Crates selection and interventions

Crates in the control and treatment groups were randomly removed from the line by abattoir staff at intervals over several hours. The selection process could not be formally randomised because workflow and staff availability varied throughout the study. The crate design (open or closed base) and manufacturer (Anglia Autoflow...
or Giodano) were recorded and a photograph taken before visual scoring and microbiological sampling (see below). Thirty-seven samples were taken in each trial, which comprised unwashed crates \((n = 6)\), washed crates \((n = 15)\), modules \((n = 10)\), soak tank \((n = 2)\), tray wash \((n = 2)\) and module run-down filter \((n = 2)\). The following treatment groups were used in Plant A following installation of the new crate washing system: (i) use of a disinfectant spray following crate washing (5% peracetic acid, Holchem Perbac Farm), used at a rate of 0–1 ml l\(^{-1}\); (ii) increasing the temperature of the wash water to 55°C and using peracetic acid disinfectant spray; (iii) increasing the temperature of the wash water to 60°C only; (iv) increasing the temperature of the wash water to 60°C and using peracetic acid disinfectant spray. In addition to the above variations, all trials used a caustic soda detergent (Holchem Caustak, Bury, Lancashire, UK) at a nominal 1% v/v (0.63% w/v NaOH) at the start of washing. The duration of the crate cleaning process was approximately 17 s from start to finish for both the original and modified cleaning systems. The contact time with the chemical disinfectant was approximately 5 min prior to sampling.

A preliminary study was performed by sampling crates at both plants, prior to the modification of Plant A. This was done to determine whether the average and range of microbial counts on washed and unwashed crates were broadly comparable between the two plants. During collection of this preliminary (pilot) data, both plants used a conventional soak tank cleaning system (Fig. 1), with unheated water containing household washing powder and Virkon S disinfectant.

Microbiological sampling

The sampling protocol was based on visual assessment and microbiological examination of samples from the two types of crate currently used (closed and open grid base). Samples from the module top and base were also taken. Sample collection and processing methods follow those used by Allen et al. (2008b).

A sterile sponge of 103 \(\times\) 185 \(\times\) 5–8 mm (cat. no. 95000087, Spongyl 87, Spontex Professionel, Neuilly-sur-Seine, France) was moistened with approximately 10 ml from a 100 ml volume of maximum recovery diluent (MRD, CM 733; Oxoid, Basingstoke, UK). The sponge was then wrung out and the suspension transferred to a sterile 150-ml screw-capped container. For the module samples, a sponge (moistened with MRD as above) was used to swab the entire top surface and another sponge was used to wipe the upper surfaces of the supporting frame at the base of the module. The sponges were processed in an identical manner to the crate swabs (above). Samples of water (approximately 20 ml) from the soak tank (prior to modification) and wash water (after modification) were taken at the start and end of crate sampling. All samples were transported to the laboratory in an insulated box held at approximately 4°C using ice packs and were processed within 4 h of collection.

Microbiological examination

Decimal dilutions of each stomachate or water sample were prepared in MRD. Volumes (100 µl) of each dilution were spread plated onto duplicate plates of Violet Red Bile Glucose Agar (VRBGA; Oxoid CM 0485), Plate Count Agar (PCA; Oxoid CM0325) and modified charcoal cefoperazone deoxycholate agar (mCCDA, Oxoid CM0739, SR0155). These plates were incubated aerobically at either 30°C for 48 h (PCA), 37°C for 24 h (VRBGA) or microaerobically (CampyGen gas packs, CN0035A; Oxoid) at 41-5°C for 48 h (mCCDA) prior to enumeration of typical colonies. All colonies were counted on PCA plates while characteristic red colonies with purple haloes were counted on VRBGA as presumptive Enterobacteriaeae. Standard confirmatory tests were performed on presumptive Campylobacter colonies. These included Gram staining, the oxidase test and failure to grow aerobically at 25°C. In addition, a selection of colonies was confirmed as Campylobacter sp. by a latex agglutination test (Campylobacter Test Kit: Oxoid, DR 0150M).

Enumeration of bacteriophages

A 1-ml sample of each sponge stomachate or water sample was transferred to a sterile microfuge tube and subjected to centrifugation at 13 000 g for 5 min to remove bulk debris. The supernatant was then filtered through a 0.45-µm pore size filter (16533K; Minisart, Sartorius, Gottingen, Germany) and decimally diluted to \(10^{-8}\) in SM buffer (50 mmol l\(^{-1}\) Tris-Cl (pH 7.5), 0.1 mol l\(^{-1}\) NaCl, 0.008 mol l\(^{-1}\) MgSO\(_4\)·7H\(_2\)O, 0.01% gelatine; Sigma, Gillingham, Dorset). Volumes (10 µl) of each dilution were spotted in triplicate onto the surface of a bacterial lawn. Briefly, 0.1 ml of an overnight culture of E. coli K-12 (approx. \(10^8\) CFU per ml) was added to 5 ml of molten overlay agar (nutrient broth, CM0001; 0.5% w/v bacteriological
agar LP0011; Oxoid), gently mixed, then poured on to prewarmed (37°C, 30 min) nutrient agar plates (CM0003; Oxoid). These plates were incubated at 37°C for 24 h before examining for phage plaques.

Visual assessment of crates
A semiquantitative system of visual scoring was devised in order to determine any correlation between visual cleanliness of the crates and their microbial load. Crates were scored visually for the total amount (g) of contaminating material (faeces, litter etc.) on each of three sections of the crate: (i) the interior of the base; (ii) the sides, both inside and out, and (iii) the underside. The organic matter could not be completely removed from the crate to be weighed, so the amount present was estimated on the basis that one heaped 5-ml teaspoonful of debris was found to weigh approximately 2 g. Visual scores were calibrated according to the assessment of at least two trained researchers.

Statistical treatment of data
All microbial counts were log_{10} transformed prior to statistical analysis. The significance of differences between microbial counts, and the quantity of organic matter between unwashed and washed crates was determined using the Mann–Whitney U test.

Results
Visual cleanliness assessment of crates before and after washing
A summary of the visual cleanliness scores and microbial counts of unwashed and washed crates at the test (A) and control (B) processing plants during the pilot study and main study are presented in Tables 1 and 2 respectively. The pilot data showed differences in visible contamination, with crates from Plant B showing a higher median contamination level than those from Plant A, but this difference was not significant. The visible contamination of washed crates from both plants during the pilot trial was almost identical. For the main trial (Table 2), the difference between the visible cleanliness of unwashed crates in the plants A and B was not statistically significant (P = 0.052 before, P = 0.819 after installation).

The majority (75%) of crates washed using the modified system in Plant A were classified as visually clean compared with 5% for the unmodified system. All the crates were classified as visually clean when they were washed using the modified system with detergent in the rinse washer followed by a disinfectant spray. The reduction in faecal contamination on crates washed in the new system was significantly greater than that observed for crates washed prior to modification (P < 0.0001). However, the visual cleanliness scores did not correlate well with microbial counts (Table 2).

Comparison of the microbial counts in the soak tank and washer unit
Samples were taken of water recirculating in the crate soak tank prior to modification of the washing equipment, and from the new spray washer unit after modification. Prior to modification, median microbial counts (log_{10} CFU or PFU per ml) were as follows: aerobic plate count (10–2), Enterobacteriaceae (8–7), Campylobacter (8–5) and E. coli bacteriophage (6–6). The microbial counts in water collected from Plant A following modification were up to 1.4 log_{10} CFU lower than counts in water from Plant B: aerobic plate count (9–6), Enterobacteriaceae (7–9), Campylobacter (7–5) and E. coli bacteriophage (5–2). However, the difference in median microbial counts between the unmodified and modified systems was not statistically significant when both systems used unheated water. There was a slightly greater reduction in microbial counts when the temperature of the water in the modified system was raised to 55°C. However, when the temperature was raised to 60°C there was a significant reduction (P < 0.05) in all median log_{10} CFU or PFU microbial counts: aerobic plate count (7–6), Enterobacteriaceae (<4–4), Campylobacter (<4–4) and E. coli bacteriophage (5–1).

Microbial counts from samples taken from the crate surface
Median reductions in Enterobacteriaceae and Campylobacter sp. counts before and after plant modifications are presented in Table 2. Initially, the modifications made to the Plant A did not result in a significant reduction in microbial counts compared with the unmodified plant. The median reduction for Enterobacteriaceae on washed crates before modification was approximately 1.1 and 1.5 log_{10} CFU per crate base for open and closed base crates respectively, compared with 1.0 and 1.1 log_{10} CFU respectively after modification. For Campylobacter sp., the median reduction on washed crates before modification was 0.6 and 0.8 log_{10} CFU compared with 1.1 and 0.9 log_{10} CFU after modification, for open and closed base crates respectively.

The chemical detergents and disinfectants used at the two plants were nominally the same during the main trial although a different disinfectant had been used at the original plant. During the pilot trials, household washing powder had been used in the soak tank and the disinfectant had been Virkon S. Application of detergent and
Table 1 Results of poultry transport crate cleaning at a pilot trial at plants A and B. Median counts of aerobic microbes (aerobic plate count), Enterobacteriaceae, Campylobacter and coliphage are given along the median absolute deviation. The visible faecal contamination score for each category of crate is given as median grams of faecal contamination per crate base. The open and closed base refers to whether the floor of the crates is based on a grid (open) or solid (closed) design.

| Plant | Crate type and treatment | Number sampled | Median visible contamination score (g) | Microbial population counts (median log_10 CFU per crate base (median absolute deviation)) |
|-------|--------------------------|----------------|----------------------------------------|----------------------------------------------------------------------------------|
| A     | Open base, unwashed      | 9              | 3 (0)                                  | Enterobacteriaceae 8.1 (0.5) Aerobic plate count 9.2 (0.6) Campylobacter 7.5 (0.1) Bacteriophage 5.0 (0.8) |
|       | Open base, washed        | 17             | 1 (0)                                  |                                                                                  |
|       | Closed base, unwashed    | 9              | 4 (0)                                  |                                                                                  |
|       | Closed base, washed      | 28             | 1 (0)                                  |                                                                                  |
| B     | Open base, unwashed      | 10             | 3 (0)                                  |                                                                                  |
|       | Open base, washed        | 25             | 3 (0)                                  |                                                                                  |
|       | Closed base, unwashed    | 8              | 5 (0)                                  |                                                                                  |
|       | Closed base, washed      | 20             | 1 (0)                                  |                                                                                  |

Discussion

Allen et al. (2008b) identified the most effective treatments to reduce Campylobacter as a combination of soaking at 55°C, brushing for 90 s, washing for 15 at 60°C followed by application of detergent (Spectak G, 0.1% (v/v), Johnson Diversey, UK) and disinfectant (Virkon S, 2% v/v). These treatments were applied in a test rig and achieved a 4-log10 CFU reduction in Enterobacteriaceae per crate base using these conditions but were less effective in reducing aerobic plate counts. Similar reductions of 3-9–4-0 log10 CFU have been achieved for Campylobacter and Enterobacteriaceae, respectively, using the modified washing system described in this study, when wash water was heated to 60°C and the crates were treated with a detergent rinse and disinfectant spray. The earlier study by Allen et al. (2008b) and others led to the draft document, ‘Best practice for cleaning poultry transport crates’. The document states the specifications for the new washer used in this study, along with some additional requirements on size, cost, commercial availability and practicality for installation in a commercial poultry processing plant. This study shows that the selected washer met these requirements.

Enhancing existing washing systems with the use of high temperature and chemical treatments would be problematic. The newly installed two-stage crate washer has a water capacity of 1000 l but still required about 224 MJ of heat and around 102 kg of steam, for a startup working temperature of 60°C. A crate washing system based on a soak tank with 43 500 l of water would require about 44 times more heat energy just for startup, even if well insulated. Heat and fog would be produced from a heated soak tank requiring containment and separation from the other areas of the arrival bay and hanging-on area. The enclosed, purpose-designed...
**Table 2** Visible contamination scores and microbial counts from poultry transport crates before and after installation of a modified washing system in Plant A. The top of the table shows results from plants A and B prior to modification of Plant A. The bottom of the table shows the results after modification of Plant A, and contemporaneous results from the unmodified sister plant (Plant B). Median counts of aerobic microbes (aerobic plate count), Enterobacteriaceae, Campylobacter and coliphage are given along with the median absolute deviation. The visible faecal contamination score for each category of crate is given as median grams of faecal contamination per crate base. Significant differences were observed. The visible faecal contamination score (g) indicates where the water used to wash the crates was experimentally increased for the trial.

| Plant | Crate type and treatment | Number sampled | Median visible contamination score (g) | Enterobacteriaceae | Aerobic plate count | Campylobacter | Bacteriophage |
|-------|--------------------------|----------------|----------------------------------------|--------------------|---------------------|---------------|--------------|
| A     | Open base, unwashed      | 12             | 3.5                                    | 8.0 (0.5)          | 9.2 (0.2)           | 6.9 (0.8)     | 4.2 (0.7)    |
|       | Open base, washed        | 18             | 0.5                                    | 6.9 (0.3)          | 9.2 (0.5)           | 6.9 (0.7)     | 4.1 (0.4)    |
|       | Closed base, unwashed    | 12             | 4.0                                    | 8.6 (0.4)          | 9.8 (0.5)           | 7.4 (1.0)     | 4.9 (0.4)    |
|       | Closed base, washed      | 42             | 1.0                                    | 7.1 (0.3)          | 9.3 (0.2)           | 6.6 (0.7)     | 4.7 (0.3)    |
| B     | Open base, unwashed      | 12             | 3.0                                    | 7.4 (0.5)          | 9.2 (0.4)           | 7.4 (0.3)     | 4.2 (0.6)    |
|       | Open base, washed        | 25             | 1.5                                    | 6.7 (0.2)          | 8.5 (0.4)           | 6.4 (0.2)     | 4.4 (0.6)    |
|       | Closed base, unwashed    | 12             | 4.0                                    | 8.2 (0.4)          | 9.7 (0.5)           | 8.1 (0.3)     | 4.8 (0.5)    |
|       | Closed base, washed      | 35             | 1.0                                    | 7.2 (0.3)          | 9.3 (0.2)           | 6.6 (0.2)     | 4.5 (0.3)    |

| Plant | Crate type and condition | Number sampled | Median visible contamination score (g) | Enterobacteriaceae | Aerobic plate count | Campylobacter | Bacteriophage |
|-------|--------------------------|----------------|----------------------------------------|--------------------|---------------------|---------------|--------------|
| A (M) | Open base, unwashed      | 11             | 3                                       | 7.8 (0.2)          | 8.7 (0.2)           | 7.2 (0.2)     | 5.0 (0.4)    |
|       | Open base, washed        | 25             | 0                                       | 6.8 (0.2)          | 8.5 (0.2)           | 6.1 (0.3)     | 4.7 (0.5)    |
|       | Closed base, unwashed    | 13             | 5                                       | 8.4 (0.3)          | 9.4 (0.5)           | 7.5 (0.4)     | 4.8 (0.6)    |
|       | Closed base, washed      | 35             | 0                                       | 7.3 (0.1)          | 9.1 (0.2)           | 6.6 (0.3)     | 4.6 (0.6)    |
| B     | Open base, unwashed      | 9              | 4                                       | 8.1 (0.2)          | 8.6 (0.4)           | 7.5 (0.4)     | 4.9 (0.5)    |
|       | Open base, washed        | 22             | 2                                       | 6.6 (0.4)          | 7.9 (0.4)           | 6.5 (0.5)     | 5.2 (0.3)    |
|       | Closed base, unwashed    | 9              | 5                                       | 8.1 (0.1)          | 9.0 (0.4)           | 7.5 (0.4)     | 5.4 (0.1)    |
|       | Closed base, washed      | 23             | 2                                       | 6.8 (0.2)          | 8.7 (0.4)           | 6.3 (0.5)     | 5.2 (0.3)    |
| A (M, D) | Open base, unwashed | 6             | 4                                       | 8.1 (0.5)          | 9.4 (0.2)           | 7.8 (0.5)     | 5.5 (0.0)    |
|       | Open base, washed        | 12             | 0                                       | 7.2 (0.3)          | 8.6 (0.2)           | 6.9 (0.5)     | 5.0 (0.2)    |
|       | Closed base, unwashed    | 6              | 6                                       | 8.4 (0.2)          | 9.4 (0.1)           | 8.2 (0.5)     | 5.5 (0.0)    |
|       | Closed base, washed      | 18             | 0                                       | 7.2 (0.4)          | 9.1 (0.2)           | 6.6 (0.7)     | 5.2 (0.2)    |
| A (M, D) 55°C | Open base, unwashed | 6             | 6                                       | 7.9 (0.1)          | 8.8 (0.3)           | 7.7 (0.2)     | 5.4 (0.1)    |
|       | Open base, washed        | 12             | 0                                       | 5.5 (0.3)          | 8.6 (0.9)           | 4.7 (1.5)     | 5.1 (0.0)    |
|       | Closed base, unwashed    | 6              | 5.5                                     | 8.2 (0.3)          | 9.6 (0.4)           | 7.4 (0.2)     | 5.4 (0.1)    |
|       | Closed base, washed      | 18             | 0                                       | 6.1 (0.4)          | 8.6 (0.2)           | 2.3 (2.3)     | 5.0 (0.2)    |
| A (M) 60°C | Open base, unwashed | 5             | 4                                       | 7.3 (0.0)          | 8.6 (0.2)           | 7.3 (0.1)     | 5.5 (0.1)    |
|       | Open base, washed        | 10             | 0                                       | 6.5 (0.2)          | 8.6 (0.4)           | 4.8 (0.7)     | 5.2 (0.1)    |
|       | Closed base, unwashed    | 7              | 5                                       | 8.1 (0.2)          | 9.3 (0.1)           | 7.3 (1.1)     | 5.4 (0.0)    |
|       | Closed base, washed      | 20             | 0                                       | 7.2 (0.2)          | 8.6 (0.1)           | 5.9 (0.4)     | 5.1 (0.2)    |
| A (M, D) 60°C | Open base, unwashed | 3             | 5                                       | 8.2 (0.0)          | 8.9 (0.1)           | 7.5 (0.1)     | 5.5 (0.0)    |
|       | Open base, washed        | 5              | 0                                       | 4.7 (0.7)          | 8.0 (0.3)           | 3.6 (0.3)     | 4.4 (0.2)    |
|       | Closed base, unwashed    | 3              | 6                                       | 8.8 (0.0)          | 10.1 (0.1)          | 8.0 (0.1)     | 5.5 (0.1)    |
|       | Closed base, washed      | 10             | 0                                       | 4.8 (1.5)          | 8.1 (0.2)           | 4.8 (0.3)     | 4.7 (0.2)    |

The results of visual assessment of crates did not correlate well with microbial load. Visually clean crates (≤0.5 g per crate base) often had aerobic plate counts exceeding 9.0 log_{10} CFU and Enterobacteriaceae counts exceeding 7.0 log_{10} CFU. Washing the crates and modules using the pre-existing system did not reduce either of these counts significantly, and in some cases increased them.

Prior to the modifications, washing appeared to decrease median Campylobacter sp. counts on crates 0.6–0.8 log_{10}
have been used as surrogates to indicate the survival of Bacteriophages, in general, and coliphages, in particular, recovered from most water and crate surface samples. Disinfectants were used on the modules. After washing, as were found on crates. No detergents or disinfectants were used on the modules.

Bacteriophage capable of infecting E. coli K12, were recovered from most water and crate surface samples. Bacteriophages, in general, and coliphages, in particular, have been used as surrogates to indicate the survival of rotavirus (Arraj et al. 2005), noroviruses (Dawson et al. 2005), polioviruses (Ketratanakul et al. 1991) and adenoviruses (Williams and Hurst 1988), in diverse systems were wastewater is to be reused (Verbyla and Mihelcic 2015). The presence of coliphage does not, in itself, indicate the presence of viruses which can infect animals or humans. However, it does indicate that should any contamination of this kind occur, such viruses may remain viable on the crate surface after cleaning and treatment with disinfectant. The poultry transport chain is probabilistically the most important step in the spread of viruses such as Avian Influenza A H7N9 (Zhang et al. 2018). It is, therefore, very important to determine if the washing of the crates is efficient at reducing the viral as well as the bacterial contamination.

The modification of the test plant improved the percentage of visually clean crates from 5% to 75% which allowed the manual rewashing of crates in the test plant to be halted. However, this modification alone did not lead to a significant reduction in the microbial numbers recovered from the inside base of the crates compared with the control plant. Furthermore, individual measures such as adding detergent or disinfectant or raising the temperature of the wash water did not, by themselves, result in a significant reduction in microbial counts. Recently, other authors have shown that using compressed air foam systems with a cleaner (peracetic acid or chlorinated) may be used to successfully reduce aerobic bacteria in poultry transport crates (Hinojosa et al. 2015, 2018). However, on those studies, the crates were artificially contaminated and the efficacy of the cleaning methods in reducing viral contamination was not addressed.

The results presented here show that raising the temperature of the water used in the main spray washer, followed by a detergent rinse and a final disinfectant spray, resulted in a highly significant reduction in median counts of both Enterobacteriaceae (3·5–4·0) and Campylobacter sp. (3·2–3·9), with all crates appearing visually clean. Under these conditions, the numbers of both these groups of bacteria were below the limit of detection in the recirculating water; reducing the level of cross-contamination.

The results of this study showed that the installation of a new poultry transport crate washing system, in combination with a higher wash water temperature, chemical disinfectants and detergents can significantly reduce the numbers of key bacterial pathogen groups in wash water and on the washed crate surface. In turn, this may reduce the risk bacterial infection of poultry flocks on the farm, particularly with respect to Campylobacter and pathogenic members of the Enterobacteriaceae. The modified crate washing system was more efficient with water and energy use and similar reductions in microbial counts are unlikely to be achieved using conventional crate washing facilities due to cost and practical considerations. These considerations are likely to become more important as issues such as climate change push businesses to use energy and other resources more efficiently.

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Conflict of Interest

The authors declare that no conflict of interest exists.

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