Final Report on FSA Project FS121014A (M01058)

Efficacy, practicality, and costs of using currently available intervention methods to reduce *Campylobacter* contamination in slaughterhouses

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SUMMARY

This report considers the efficacy of the following interventions in reducing *Campylobacter* on poultry: hot water, steam, electrolysed water, chlorine/chlorine dioxide, steam, electro-oxidation of scald water, ultra-violet (UV) radiation. The report includes published data, industry data, and the results of trials within this FSA-funded project. Apart from the use of UV, all trials were carried out at poultry processing sites using carcasses at pre-chill. The conclusions for each intervention are outlined below.

Hot Water - Reductions in *Campylobacter* around 1-log have been reported in the literature but all studies, including evidence presented from two trials in this project, show changes in the appearance and elasticity of the carcasses after treatment.

Steam - Published data on carcasses that have not been inoculated show around a 0.5-log reduction in *Campylobacter*. Several processors have tried using steam to achieve microbial reductions but they have all experienced unacceptable changes to the appearance and elasticity of treated carcasses.

Changes to the appearance/elasticity of poultry due to heat treatment using hot water or steam are not unsurprising. Data in the literature show that proteins in chicken meat and collagen in the skin denature at around 55ºC and 66ºC, respectively.

Electrolysed Water - No published data show evidence of a significant reduction in *Campylobacter* on poultry carcasses that have not been inoculated. Four trials were carried out spraying plain water or electrolysed solutions of sodium chloride or sodium carbonate. The highest free chlorine concentration used in any of the solutions was 18 ppm. None of the treatments produced greater than a 0.3-log reduction in the numbers of *Campylobacter* on carcasses when tested one or seven days after kill and treatment.

Chlorine/Chlorine Dioxide - Many poultry processors use chlorine dioxide to treat bore hole water and use a free chlorine concentration of around 0.5 ppm. Published data indicate that, even at 50 ppm free chlorine, there is little effect of chlorine, when delivered as hypochlorite, on *Campylobacter* counts on carcasses. In the trial carried out in this project, chlorine dioxide at 1 ppm in water was applied to birds and then the chlorine dioxide application was stopped. However, the concentration in the water did not fall over the next hour and consequently it was not possible to test the effect of the chlorine dioxide.

Electro-Oxidation of Scald Tank Water - One published paper reports that *Campylobacter* counts were reduced by up to 1.4-log in the water in a chiller by the use of electro-oxidation but counts on carcasses were not assessed. That research is not directly relevant to the UK where all birds are air chilled. One poultry processor reported that they had trialled the technology on scald tank water and found no reductions in microbial counts on carcasses and bad off-odours from the water. No trials were carried out with this technology within this FSA-funded project.

Ultra-Violet Radiation - Large reductions in *Campylobacter*, 6 to 7-log, have been reported on agar plates and in liquid treated with ultra-violet radiation. However, much smaller reductions, 0.4 to 0.8-log, have been reported on chicken breast meat and skin inoculated with *Campylobacter*. No data have been published on the effect of UV radiation on *Campylobacter* on carcasses that have not been inoculated. Concerns were expressed by industry that the use of UV might be restricted due to the difficulty of transmitting the UV to all parts of the carcass. Also, suppliers of UV systems advised keeping the UV lamps away from water such as splashing or sprays. A trial in this project found no evidence of an effect of UV treatment on the *Campylobacter* numbers on naturally contaminated skin-on breast portions.

None of the treatments described above produced large reductions in *Campylobacter* when applied under practical conditions to naturally contaminated carcasses or portions. For that reason, the costs of the implementing the systems were not examined. Additional work, within a sister project considering other interventions, and by the industry, examined the effects of rapid surface cooling of carcass surfaces. That work, which produced reductions in *Campylobacter* over 1-log, has been described in two other reports.

CONTENTS

1. INTRODUCTION

Campylobacter is the most common cause of food poisoning in the UK and is found mainly in poultry (BBSRC, FSA, defra, 2010). Prevalence of *Campylobacter* on poultry in the UK has been reported as 86% (EFSA, 2010). Reducing this cause of food poisoning requires interventions at the farm through to the consumer. This project (M01058) assessed the efficacy, practicality and costs of using interventions that are currently allowed by EU regulations to reduce *Campylobacter* numbers on chicken at the slaughterhouse. This report brings together published data on the effectiveness of those interventions and the results of trials carried out within the project to assess the efficacy of those interventions.

This report considers the following interventions: hot water, steam, electrolysed water, chlorine/chlorine dioxide, electro-oxidation of the scald water, and ultra-violet radiation. Most of these trials were carried out at working poultry plants either at-line or on-line and, in most cases, 36 control and 36 treated carcasses were tested. The following sections consider the various interventions.

In addition to the trials described in this report, another intervention based on the rapid cooling of the surfaces of chicken carcasses was investigated. This included trials with a batch system with liquid nitrogen sprays, a continuous system with liquid nitrogen sprays, immersion in liquid nitrogen, and the use of very low temperature air. The results of those trials have been provided in two further reports to the Food Standards Agency. These reports are not published as they include commercially sensitive material and are covered by a confidentiality statement (Burfoot et al., 2013b,c).

2. HOT WATER

2.1 Published Data and Industry Data - Hot Water

Table 1 shows the data gathered from the literature on the use of hot water. The methods of application have been immersion or spraying with most studies being carried out on cold or warm carcasses on pilot rigs remote from the production plant. Water temperatures varied from 20 to 97ºC with application times from 10 to 360s. Removal of *Campylobacter* from inoculated samples is easier than removal from naturally contaminated carcasses. Li, Yang, and Swem (2002) found a 0.5 to 1.4-log reduction in *Campylobacter* on inoculated samples treated with water at 20 to 60ºC for 12 s. Whyte, McGill and Collins (2003) found reductions of 0.9 to 1.0-log of *Campylobacter* on inoculated samples when treated with water at 75 to 85ºC for 10 s. Interestingly, Northcutt et al. (2005) found no reduction in *Campylobacter*

achieved by spraying water relative to the naturally contaminated control but the treatment did remove the artificially applied contamination i.e. the water removed the artificial contamination and not the natural contamination. Zhang et al. (2013) came to a similar conclusion after using a hot water spray at 71ºC for 1 minute. They found that the spray did not reduce the prevalence of *Campylobacter* except for loosely attached cells. They also concluded that hot water exposure produced a partially cooked appearance on both broiler skin and skinless breast surfaces.

Other studies with hot water have been carried out with FSA funding by Corry et al. (2007 and unknown date) and James et al. (2007). Using immersion, they found *Campylobacter* reductions on artificially contaminated carcasses ranging from 1 to 2.9-log when using temperatures from 70 to 80ºC. Reductions in naturally contaminated carcasses varied from 0.2 to 2.0-log after immersion in water at 80ºC for 20s. Their studies concluded that the latter were the most suitable conditions because more severe treatments caused more significant changes in appearance. Such changes are the reason why this intervention has not been adopted. Problems with carcasses splitting when trussed, or having a wrinkled appearance, were reported after applying some treatments. Immersion in water at 80ºC for 20s produced an appearance that was acceptable to the researchers but a retailer suggested that there were differences between control and treated samples and any difference was not acceptable. The EFSA (2011) scientific opinion on the control options for *Campylobacter* in broiler meat production concluded that hot water treatment of carcasses may result in a 0.27 to 1.5-log reduction in *Campylobacter* counts, but the report also notes that deterioration of the physical appearance may also occur.

Several poultry processors said that they had investigated the use of hot water for reducing microbial counts on poultry and all of them had found changes in appearance. They also had concerns over the use of water immersion systems and the potential for cross-contamination.

Two trials with hot water were carried out within this project. The first trial examined the effect of hot water immersion, or a gentle hot water spray, on the appearance of turkeys. The second trial examined the effect of a hot water spray.

2.2 Hot Water Trial 1

This trial was carried out at-line in a turkey processing plant because a hot water tank and spray system were available next to the production line.

2.2.1 Methods - Hot Water Trial 1

Immediately prior to the test, a water sample was taken and the pH and oxidation-reduction potential (Metrohm 825 meter, Metrohm AG, Herisau, Switzerland), and chlorine concentration (Lovibond 2000, Tintometer, Salisbury, UK) were measured and found to be pH = 7.9 and ORP= 458 mV, and chlorine concentration = 0.2 ppm. An electrically heated knife steriliser (approximately 1.5 m long x 1 m high x 0.5 m wide) was used to maintain the water at the required temperature. This was connected to a tank (approximately 1.2 long m x 1.2 m wide x 1.0 m high) that had a spray nozzle in each corner directed towards the centre of the tank. Water was transferred from the steriliser to the nozzles using a pump (EBARA, Matrix 5-47/0.9M, 3-130 l/min, 1.28 kW, max head = 46 m, min head = 17 m).

A stag or hen bird was taken off the production line, weighed, the temperature directly under the skin was measured, and the carcass was then photographed and either suspended from a shackle and hung in the centre of the spray tank or immersed by hand in the hot water in the steriliser tank. The treatment time was recorded and in some cases the temperature under the skin was recorded and the carcass photographed. In most cases, the bird temperature was not measured but the bird was immediately dipped in an ice bath for up to 30 s and the carcass then photographed. Comments on the appearance and "feel" of the skin were made by two of the technical team of the production facility and recorded. The carcass was then put on a support in the air chiller and the time noted. The next day (Day K+1) all of the carcasses were photographed and further comments made by the two technical staff. The birds were then transported in insulated boxes with ice packs to another site, approximately 4 hours away, where they were held in a chiller at 4ºC and photographed, and comments from research staff recorded, on Days K+2, K+3, and K+7.

2.2.2 Results - Hot Water Trial 1

Tables 2 and 3 show photographs of control and treated stag and hen carcasses along with records of the comments, weights and temperatures. Temperature measurements are subject to variability due to the difficulty of locating the measurement tip at the same location on the breast and at the same depth on each carcass. Stags 1 and 8 and Hen 1 were sprayed with water at 85ºC. No adverse effect on appearance was noted as the water in the spray most likely cooled between leaving the nozzle and reaching the bird. Measurements on Stag 1 indicated that the temperature just beneath the skin increased from 41.4 to 43ºC due to the treatment of water spray at 85ºC for 20 s. More nozzles, placed closer to the carcass would be required to achieve a more aggressive treatment.

Immersion in water at 85ºC for 10 s increased the temperature of Stag 2 from 41.7 to 42.4ºC just beneath the skin but there was a very adverse effect on the carcass which appeared blown (enlarged), with skin that was stretched and easily torn. This treatment was clearly too aggressive. Cooling a carcass in an ice bath after dipping in water at 85ºC for 10s negated some of the adverse action of the hot water but still the skin was easily torn and there was a "cooked" appearance of any exposed flesh (eg Stag 3). Dipping in hot water at 80ºC for 12 s also showed some denaturing of exposed flesh and some slight swelling of the skin (Stag 4). Reducing the time to 10 s appeared to reduce the swelling but there was still some slight denaturing of exposed flesh (Stag 5). The difference in appearance of Stags 4 and 5 might be associated with any differences in the birds rather than the 2 s difference in heating times. Stags 6 and 7 were also treated by dipping in water at 80ºC for 10 s followed by immersion in the ice bath and these also showed slight denaturing of exposed flesh. Exposed flesh was usually sited at the neck and around the area where the tail had been removed. Results with the hens were very similar although in one case (Hen 2) a large split in the skin between the leg and breast occurred as the bird was lifted out of the hot water tank. This might indicate difficulties in using a hot water treatment on a high speed line.

2.2.3 Conclusions - Hot Water Trial 1

Extensive tests with hot water spraying did not prove to be possible due to failure of a pipe and the nozzles not being close enough and sufficient in number. However, the observations with the carcasses after immersion in hot water agree with earlier work by others that 80ºC for 10s does lead to some adverse effect on the appearance. Trimming of the carcass would be required.

Spraying with hot water is expected to lead to similar problems of denaturing of exposed flesh. However, another practical problem could arise. Earlier work by others indicated that a treatment of 80ºC/10s could lead to a reduction of 0.3-log in *Campylobacter* (Whyte et al., 2003) and a treatment of 85ºC/20s would give a 1 to 1.5-log reduction. Achieving similar thermal treatments on the surface of the birds would require high water spray temperatures and many nozzles close to the birds and using steam may be a better option to achieve those temperatures. However, companies that had carried out tests using steam, and research papers, reported adverse effects on appearance and skin texture. Consequently, a further trial using a hot water spray was carried out as described below.

2.3 Hot Water Trial 2

Spraying showed no adverse effect on appearance in the trial described above most likely because the spray nozzles were located about one metre from the bird and the water (initially at 85ºC) would have cooled substantially before impacting on the bird. The purpose of this trial was to examine the reduction in *Campylobacter* that would be achieved by spraying with hot water with the nozzle located within 4 centimetres of the surface of the skin. The trials were carried out close to a production line to prevent much cooling of the birds prior to treatment.

2.3.1 Methods - Hot Water Trial 2

Hot water was obtained from the poultry plant's boiler water pre-heater. This vessel, with a capacity of over 5000 litres, maintained the water at a steady 90ºC. A pump delivered water from the vessel along a 12 mm i.d. flexible pipe to a nozzle. The pipe was approximately 30 m long to deliver the water from the tank to the location of the turkey carcasses. 42 carcasses were removed from the production line in batches of 6 carcasses. 12 of the carcases were weighed to provide an assessment of the size of the birds. 21 of the carcasses were placed on the hooks used in the chilling room: these were the untreated control carcasses. The other 21 carcasses were each sprayed with the hot water over a 1 minute period. The nozzle was held within 4 centimetres of the surface of the carcass. The temperature of the water was measured by placing a thermocouple (within a 0.5 mm o.d. steel sheath) so that it was almost touching the surface of the carcass whilst the carcass was being sprayed. The water temperature was measured 4 times. The flow rate of the water over a one minute period was measured 4 times using a bucket and stopwatch. The temperature of some birds were measured before or after treatment with the hot water.

After treatment, the carcasses were hung on hooks within a chiller and aligned to restrict cross contamination. Five hours later, a section of the left side breast skin was removed aseptically from each carcass and put into sterile bags. The breast skins were left in the chill room over night and the next day transported by refrigerated van (2ºC) on a one hour journey to the microbiology laboratory of the poultry processing company. Part of each skin sample was tested for aerobic plate count and *Campylobacter* on that day (K+1) and most of the samples (30 out of 42) were tested for *Campylobacter* at Day K+7. One untreated control bird and one treated bird were stored at 4ºC and photographed on Days K+1, K+3, and K+7.

2.3.2 Results - Hot Water Trial 2

The average weight of the carcasses was 15.3 kg (s.d.=0.7 kg), the water temperature near to the surface of the carcasses was 66.6ºC (s.d.=1.3ºC) and the water flow rate was 2.23kg per minute (s.d.=0.06 kg/min). The temperature of the birds before treatment was 32.9ºC (s.d.=0.9ºC, n=6) and the temperature after treatment was 36.6ºC (s.d.=1.9ºC, n=4).

Photographs of the carcasses are shown in Table 4. At the time of treatment, the researchers and the Group Technical Director noted that the treated carcasses were noticeably darker in appearance compared to the control carcasses. At Days K+1, K+3 , and K+7, the treated birds exhibited a beige/brown colour compared to the fresh pink hue of the untreated bird.

Tables 5a and 5b show the aerobic plate counts and *Campylobacter* counts on the control and treated carcasses. The tables show that there was no evidence of an effect of the treatment on APC, *Campylobacter* counts, or the prevalence of *Campylobacter*.

2.3.3 Conclusions - Hot Water Trial 2

Although the water temperature at the surface of the skin was below the temperature (80ºC) used in the previous tests, there was still an effect on the appearance of the birds. Although the researchers considered the difference to be acceptable, the Group Technical Director commented that any change due to a treatment is unacceptable as consumers would be able to distinguish between treated and control carcasses and consequently may regard treated carcasses as somehow inferior. Notwithstanding the changes in appearance, the hot water treatment applied over 1 minute did not show any effect on the microbiological counts.

2.4 Conclusions on the Use of Hot Water

The greatest drawback to the use of hot water is the change in appearance that it causes. Those changes are considered unacceptable to the industry. Reasons for the changes in appearance are discussed later when reviewing the evidence associated with the use of steam and the effects of thermal treatments.

3. STEAM

3.1 Published Data and Industry Data - Steam

The use of hot water could be expected to have an effect on the numbers of *Campylobacter* due to the temperature change and washing action. The advantage of steam over hot water is that it provides a much greater rate of heat transfer and has a greater ability to move into cavities and pores on the carcasses. The use of steam at sub-atmospheric pressure (<1 atm (101kPa), <100ºC) has not been considered here as it requires the use of vacuum chambers that are expensive and probably impractical for use at the high throughputs of poultry production. Table 6 shows two features of using steam: the reduction in *Campylobacter* of 0.4 to 3.3-log, and the effect on appearance. All references refer to differences in appearance between control and treated carcasses and these include yellowing of the skin, skin shrinkage, skin wrinkling, or a boiled appearance. A report for the FSA by Corry et al. (no date) found quality changes at times as short as 5 s. When speaking with some researchers, they suggest that the differences in appearance may reduce during storage. The EFSA (2011) scientific opinion on *Campylobacter* control concluded that steam treatment may cause a reduction of around 0.5-log: studies indicating higher reductions used inoculated carcasses.

The SonoSteam system uses steam and high power ultrasound. Boysen and Rosenquist (2009) report on adverse quality changes with a 5 s application to the inside of carcasses and a 10s application to the outside. Mousavian et al. (2013, abstract) found a reduction in *Campylobacter* numbers of 0.9-log after treatment and report that a sensory panel concluded that treated carcasses were acceptable for purchase. No details are given in the abstract of the treatment time or temperatures of the carcass surfaces after treatment. However, in a presentation of the work (CHRO 2013, Aberdeen, September, 2013), the treatment time was reported as 1.5s and treatment temperatures were between 90 and 94ºC. Andersen et al. (2011) also report on the use of the SonoSteam system and carried out biophysical measurements and sensory assessments on skin samples taken from untreated control chicken carcasses and those that had been treated with SonoSteam for up to 2s at 90ºC. They concluded that heat treatment for only 0.3s created a change in the collagen in the skin and that “even during very short treatment times, the changes in collagen I integrity were pronounced”. Sensory assessment did not reveal any changes in appearance of the skin quality but sensory evaluation revealed statistically significant change in the elasticity of skin due to treatment. Differential scanning calorimetry revealed changes in the collagen which affects the elasticity of skin. The changes occurred at 55 to 65ºC.

Several poultry processors reported that that they had carried out tests to examine the potential for using steam to reduce microbial counts. In all cases they reported unacceptable changes to the appearance of treated carcasses.

3.2 Trial with Steam

The use of superheated steam, created by injecting fine water droplets into hot air above 100°C, might be beneficial because higher temperatures and shorter treatment times could be used. This trial used superheated steam at a commercial chicken processing plant. The study consisted of two parts: first to determine the most severe conditions that did not affect the appearance of the carcasses and second to assess the effect on the numbers of *Campylobacter*.

3.2.1 Methods - Steam Trial

Figure 1 shows the chamber used to create the superheated steam environment (Carbolite, Hope Valley, UK S33 6RB, Oven Technical Specification SPLO 13775). Air is heated by electrical elements and is dispersed in the chamber by a fan. Fine water droplets are sprayed into the air at the back of the chamber. The small door at the front of the chamber can be pulled outwards and samples put onto a rack and the door quickly closed. Earlier trials had shown that the air temperature dropped by no more 2°C when the door was opened and closed whilst inserting a sample.

In the first part of the study to define the most severe treatment conditions that did not affect the appearance of the birds, eight large birds were taken from a production line just before the chiller. These were treated individually under various conditions, either as halves or whole birds, and then 10 small birds were removed from a production line, again pre-chill, and treated individually, halved or whole, in the superheated steam chamber. Table 7 shows the range of conditions used in these tests. A thermal image and photograph of the bird, halved or whole, was taken after treatment and, in some cases, before treatment. Once the “best” treatment conditions had been defined, ten birds were removed from the production line and each one split in half. One half was treated individually in the chamber for the defined temperature/time treatment and the other half used as a control. Breast skin samples were removed cleanly from the control half and from the other half after treatment. The skin samples were placed into individual sterile bags and put into a cool box with ice packs surrounded by bubble wrap. After 20 minutes another ten birds were removed from the line and treated in the same way. Using two groups of birds from the same batch reduced the cooling of the birds between removal from the line and being placed in the

treatment chamber. The birds came from a flock expected to be campylobacter positive based on recent hot weather conditions and history of the source farm. The batch of birds was processed over an approximately 20 minute period and that is why the second group of birds had to be removed after about 20 minutes to ensure that all birds came from the same batch. Treating the first group of birds took about 30 minutes and treating all twenty birds took 65 minutes. The skin samples were taken to a microbiology laboratory in the cool box and tested the next day for aerobic plate counts and campylobacter (limit of detection of 5 cfu per g).

3.2.2 Results - Steam Trial

During the first part of the study, to assess the effect of the treatment on appearance, the presence or absence of skin on the flesh was found to be important. Figures 2a and 2b show the appearance of a bird before and after a treatment, in this case 150°C for 1 minute. Part of the skin had been removed prior to treatment to demonstrate the effect of the treatment on exposed flesh. The photographs show that the exposed flesh became denatured during the treatment. Photographs later in the report show that denaturation of exposed flesh was common when using the more severe treatments. The skin was removed from the breast region as it was easy to view and this area is prone to skin tears on the processing line.

During the trial, larger birds were found to be resistant to harsher treatments than smaller birds and consequently tests were carried out with both large and small birds. However, the decision on which treatment to use for the birds for microbiological testing was based on the tests with smaller birds (i.e. the worst case).

Figure 3 shows photographs of the chicken samples before and after the superheated steam treatments and Figure 4 shows the thermal images and other photographs of the samples. These photographs clearly show the denaturation of exposed flesh that occurs with the more severe treatments. The most severe treatment that did not cause changes to the appearance of the chicken samples was 115°C for 30 seconds. Photographs of chicken samples before and after this treatment are shown in Figure 3 as Chicken 18a to 19c. Table 7 shows the surface temperatures measured on the birds by thermal imaging. The average surface temperature prior to treatment was around 36°C. Not surprisingly, the maximum temperatures measured soon after treatment increased with treatment temperature and time. A treatment of 150°C for 1 minute produced a maximum surface temperature of 56°C. The mildest treatment, 115°C for 30 seconds, produced maximum temperatures of 44 and 48°C.

Table 8 shows that treating the chicken halves with superheated steam at 115°C for 30s provided no evidence of a statistically significant effect of the treatment on the average aerobic plate count (p=0.649) or average campylobacter count (p=0.799).

3.3 Discussion and Conclusions on Use of Steam

Treatments with temperatures above 115°C had an effect on the appearance of the carcasses as seen by changes to any areas of exposed flesh. When using 115°C for 30s, the appearance was not affected and the surface temperature was 48°C or less. A treatment of 1 minute at that temperature was not acceptable and surface temperatures up to 56°C were reported. The surface of the carcass does not rise quickly to the steam temperature because of the boundary layer at the surface of the carcass.

The change in exposed flesh was not surprising based on reported denaturation temperatures for chicken meat. Murphy, Marks and Marcy (1998) reported finding three endothermic transitions of chicken breast meat at 53, 70 and 79°C. These corresponded to the denaturation of myofibrillar (53°C) and sacroplasmic (70 and 79°C) proteins. Kijowski and Mast (1988) had previously found similar results with the first transition beginning around 50°C and peaking at 57°C. They also found a major endothermic peak for chicken skin at 66°C which corresponds to the denaturation of skin collagen. This indicates why the exposed flesh changed during many of the tests but the skin did not. Andersen et al. (2011) report changes in the endotherms of chicken skin samples at slightly lower temperatures (55 to 65ºC) and suggest that a 50% reduction in collagen occurs over each 0.85s of treatment over the range of their testing with differential scanning calorimetry.

When chickens are processed some exposed flesh is inevitable and consequently the surface temperature must be kept below 53°C. However, the D-value for *Campylobacter* at 55°C, the time taken to produce a 1-log reduction, has been reported as approximately 1 minute in milk (Doyle and Roman, 1981) and 2.5 to 6.6 depending on heating rate in heart infusion broth (Nguyen, H.T.T., Corry, J.E.L., Miles, C.A., 2006). This suggests that no practical heat treatment can produce satisfactory reductions in the numbers of *Campylobacter* without affecting the appearance of exposed flesh. The lack of an unacceptable change in the appearance of birds heated to greater than 53ºC in some studies might come from liquid diffusing to the surface of the flesh or skin during storage of the carcass after treatment. That liquid might then replace moisture lost during the treatment. This is only speculation and would require testing.

4. ELECTROLYSED WATER (also known as Electro-Oxidised (EO) Water)

4.1 Published Data and Industry Data - Electrolysed Water

Electrolysed water is produced by electrolysis of a dilute solution of sodium chloride or other salts. The anode and cathode of the electrolysis system are separated by a membrane which causes an acidic solution to be captured on the anode side. This acid solution has low pH, high oxidation-reduction potential (ORP, aka redox potential) and presence of hypochlorous acid (Park et al., 2002). The properties of the electrolysed water can be modified by altering the electrical current during electrolysis (Kim et al, 2000). The mechanism of inactivation of microorganisms by electrolysed water is not clear but is thought to result from the action of the hypochlorous acid and high ORP (Park et al., 2002). The modes of action of the hypocholorous acid that have been considered include: oxidation of cell surface sulfhydryl compounds, inactivation of enzymes involved in respiration, inhibition of ATP generation, and retardation of active transport mechanisms (Park et al., 2002).

Although concerned only with E. coli 0157:H7 in suspension, Kim, Hung and Brackett (2000) present an interesting study examining the relative contributions of pH, ORP, and chlorine to the antimicrobial activity of liquids that had been produced by chemically modifying de-ionized water or through electrolysis. Iron was added to the modified chemical waters and EO water to reduce the chlorine or redox potential. The addition of iron reduced the redox potential of the water from the JAW system (type of equipment from a specific manufacturer) from 1123 to 322 mV, whereas it only reduced the ORP of the water from the ROX system (another type of system) from 1160 to 1122 mV over two hours; however, after 10 hours, it had dropped to 300-400 mV. Kim, Hing and Brackett do not suggest reasons for this difference. The redox potential of chemically modified water was also reduced and they proposed that this may be due to chemical reactions of chlorine and the iron. The study concluded that redox potential of the solutions may be the primary factor affecting microbial inactivation and several other papers are quoted supporting this conclusion.

Park et al. (2002) found a greater antimicrobial effect of electrolysed water on *Campylobacter* in a solution compared to chlorinated water (Table 9). They suggest that this may relate to its lower pH and higher ORP. However, they conclude that "further investigation is required to define the characteristic components in EO water responsible for its inhibitory effects on pathogens".

No published information was found on the effect of electrolysed water on carcasses naturally contaminated with *Campylobacter*. Hinton et al. (2007) found a 0.5 to 3.0-log reduction in psychrotrophs compared to the reduction found using a water spray.

Reductions of *Campylobacter* on artificially contaminated carcasses ranged from 1.9 to 3-log. A significant point to note in Table 9 is that the chlorine concentration in all of the reported studies was greater than 20 ppm at the time of application. The EFSA (2011) scientific opinion on control of *Campylobacter* on poultry concluded that no published reports convincingly demonstrate that electrolysed water would significantly reduce *Campylobacter* numbers on chicken carcasses.

No data have been found on the use of electrolysed solutions of salts other than sodium chloride. In one of the trials reported here, an electrolysed solution of sodium carbonate was tested.

Data were provided by the industry on the use of electrolysed water but that has not been included in this report because either it did not relate to *Campylobacter*, or there were insufficient data for a statistical analysis, or the data were unsuitable for analysis because treated and untreated birds did not come from the same batches of birds.

Four trials were carried out with electrolysed waters in this project. These trials included the use of plain water, electrolysed sodium chloride (NaCl) solution at various concentrations of free chlorine, and the use of electrolysed sodium carbonate (Na_2CO_3) solution.

4.2 Electrolysed Water Trial 1 (Plain Water, Electrolysed NaCl, Electrolysed Na_2CO_3 tested at-line)

In this trial, carcasses from the same batch were left unsprayed (controls) or sprayed with plain water, an electrolysed NaCl solution, or an electrolysed $NaCO_3$ solution. The effect on *Campylobacter* counts on the carcasses was then tested.

4.2.1 Methods - Electrolysed Water Trial 1

The electrolysed waters were produced using a unit (Diapod 4c2mm) provided and operated by YORECO (Leyburn, North Yorks, UK DL8 4PD, www.yoreco.co.uk). The unit, measuring around 300 mm x 150 mm x 150 mm, consisted of four electrolytic cells with current applied across boron doped electrodes. The unit was operated at 150V and 10 A. Two hundred litres of water were circulated through the cells and an intermediate bulk container (IBC) at the rate of 15 l/s for 30 minutes. In producing the electrolysed solutions, 4 g of NaCl was used for one solution and 5.35g of $NaCO_3$ in the other solution. Forty litres of electrolysed sodium chloride solution and 40 litres of electrolysed sodium carbonate solution were produced for the trial. The electrolysed solutions were held in 50 litres capacity plastic containers and used within 1.5 hours of being produced.

The study was carried out at a chicken plant processing around 75 000 000 birds per year. Carcasses were removed from the production line after the inside-outside washer, and before the chiller, in batches of 10. Each carcass was tagged with a cable-tie and twenty of the carcasses were returned to the production line without any treatment (controls). Twenty carcasses were treated with plain water from a tap (plain water). Each bird was suspended singly on a shackle and the water supplied using one of two sprayers (Model 36381-000, Hozelock KillaSpray Plus-7 litre, Hozelock, Midpoint Park, Birmingham B76 1AB, UK, www.hozelock.com) which had been set up to deliver around 750 g of liquid each minute. The flow rates were measured using a bucket and stop watch. One sprayer delivered 786 g/min and the other 765 g/min (based on five flow rate measurements). Two sprayers were used so that two birds could be sprayed simultaneously. Liquid was applied to each bird over a 1 minute period. The same procedure was used to treat 20 birds with electrolysed NaCl solution or electrolysed $NaCO_3$ solution. The birds were removed from the production line as they left the chiller (around 90 minutes chill time) and they were then weighed and bagged individually. They were then transported in a chilled van (4ºC) to a microbiology laboratory where they were held in a chiller (4ºC) overnight. The left side breast skin was tested for aerobic plate counts and *Campylobacter* (enumeration and confirmation) on Day K+1 and the right side breast skin was tested at Day K+7.

Whilst the first and last birds of each test batch (control, plain water, NaCl, $NaCO_3$) were being treated, the room temperature, bird temperature just under the skin before and after treatment, and the temperature, pH, redox potential and chlorine concentration of the solution being applied was measured. The pH and redox potential of the liquid were measured using a Metrohm 825 meter (Metrohm AG, Herisau, Switzerland); the chlorine concentration was measured using a Lovibond 2000 (Tintometer, Salisbury, UK). Liquid samples were also taken into sample pots and the chlorine concentration tested again at a laboratory using a Palintest 1000 (Palintest Ltd, Tyne and Wear, NE11 0NS, UK)

4.2.2 Results - Electrolysed Water Trial 1

The average weights of the control, plain water, NaCl, and $NaCO_3$, treated birds were 1226g (s.d.=174g), 1205g (s.d.=173g), 1203g (s.d.=153g), and 1248g (s.d.=137g), respectively. The average room temperature whilst treating each group of birds was 13.4, 12.8, 13.3, and 13.3ºC, for the control, plain water, NaCl, and $NaCO_3$, treated birds, respectively. The average temperatures of the birds before treatment were 31.5, 35.6, 33.5, and 32.4ºC, for the control, plain water, NaCl, and $NaCO_3$, treated birds, respectively.

The temperature of the plain water whilst treating the first and last bird was 13.5 and 13.4ºC. Corresponding temperatures for the electrolysed NaCl were 16.3 and 14.7ºC, and for the electrolysed $NaCO_3$ were 16.2 and 14.8ºC. These temperatures were measured at the time of application.

The average pH, redox potential, and chlorine concentrations were pH7.8, 523 mV, 0.1 ppm free chlorine, and 0.3 ppm total chlorine for the plain water; pH8.5, 790 mV, 0.2 ppm free Cl, and 1.6 ppm total chlorine for the NaCl electrolysed water; and pH11.3, 15 mV, and 0.2 ppm free chlorine and 0.2 ppm total chlorine for the $NaCO_3$ electrolysed water.

Tables 10a to 10d show the aerobic plate counts and *Campylobacter* counts for each treatment at Days K+1 and K+7.

Considering the APC first, and including data for all days, there is little indication of an effect of treating the birds ($p<0.052$), however, the effect of treatment varies with the day of testing i.e. there is an interaction between treatment and day of testing ($p<0.001$). Considering the APC on Day K+1 alone, the data show strong evidence of a difference between APC on control and plain water treated birds ($p<0.005$), between control and electrolysed NaCl treatment ($p<0.005$), and between control and electrolysed $NaCO_3$ treatment ($p<0.005$). However, the differences in APC on treated and control birds are always small at around 0.5-log. The results indicate that spraying with plain water is as effective as using the electrolysed waters. By Day K+7, there is no evidence that spraying with the electrolysed waters has any effect on the APC ($p=1.00$) compared to not treating the carcasses.

Considering the counts of *Campylobacter*, 50% of the untreated samples showed *Campylobacter* counts below the limit of detection (10 cfu per g) at Day K+1. The log (*Campylobacter* counts below the limit of detection) were replaced with values of $\log(10/\sqrt{2})$ when calculating the means counts for each treatment (following Hornung and Reed, 1990). Due to the high number of samples with counts below the LOD, comparison of the effects of the treatment was based on the prevalence of *Campylobacter* (Fisher Exact test) rather than comparison of the means. There is no evidence of a difference between the counts on control and plain water treated birds ($p=0.333$), or a difference between control and electrolysed NaCl treated birds ($p=1.000$), and only very weak evidence of any effect of the electrolysed Na_2CO_3 solution ($P=0.041$) compared to not treating the carcasses. By Day K+7, most of the samples showed *Campylobacter* counts below the limit of detection and there was no evidence of a significant effect of any treatments compared to the controls.

4.2.3 Conclusions - Electrolysed Water Trial 1

Although the electrolysed waters reduced the APC on chicken carcasses, the effect was small (~0.5-log) and there was no evidence that the effect was greater than that produced by plain water. No evidence was found that the use of electrolysed water reduces the counts of *Campylobacter* on chicken carcasses.

The lack of any statistically significant differences between the effects of the electrolysed waters and the plain water is not surprising considering that the electrolysed NaCl solution did not contain a high concentration of chlorine. The pH of the solution was also above the pH of the plain water so there was no beneficial effect of using an acidic solution (chlorine solutions are generally more effective at pH below 7). The chlorine level in this study (0.2 ppm free chlorine) was far lower than that used in published studies (generally greater than 20 ppm) and is probably the reason that no effect of the electrolysed NaCl water on APC was found compared to the plain water. Further trials with a higher concentration of chlorine were carried out as described below.

The electrolysed Na_2CO_3 solution was no more effective than plain water in reducing APC. The pH of the solution was very alkaline and this could have helped in removing the microorganisms but no effect was found using the spray system in this work.

4.3 Electrolysed Water Trial 2 (Electrolysed NaCl tested on-line)

The aim of this trial was to obtain data on the efficacy of electrolysed NaCl solution as an intervention against *Campylobacter* when applied on an operating process line. The electrolysed water was applied twice to each bird and the concentration of chlorine in the water was far higher than used in the previous trial.

4.3.1 Methods - Electrolysed Water Trial 2

The site where the trial was carried out already had spray units located post-pluck and pre-chill. Their units were connected to an electrolysed water generator at the time of the trial. The generator was supplied by Cordon. The spray heads in the first spray unit consisted of a shower head, conventional spray nozzles and an open ended pipe. A sample of water collected at the time of the trial showed a free chlorine concentration of 16.7 ppm, pH of 7.3 and redox potential of 792 mV (temperature of 13.3ºC at time of testing). The second sprayer was fitted with conventional spray nozzles and a water sample showed free chlorine at 18.4 ppm, pH at 7.3 and redox potential at 825 mV (11.9ºC at time of testing). Redox

potential and pH were measured using a Metrohm 825 meter (Metrohm AG, Herisau, Switzerland) and the chlorine concentrations were measured using a Palintest 1000 (Palintest, Tyne and Wear, NE11 0NS, UK). It was not possible to measure the flow rates of the solutions and any measurement might have had little value due to the range of "nozzles" used. Between the two electrolysed water sprayers, a further spray of chlorine dioxide was applied to the birds. A plant technician reported that the chlorine concentration of that solution was 0.5 ppm or below.

Whilst the electrolysed water system was operating, 40 carcasses were removed from the production line post-chiller: these were the treated birds. Thirty six of the carcasses were to be used for microbiological testing and the other four were kept to examine any changes in appearance or odour. The carcasses were tagged, weighed, and bagged individually. Whilst the same batch of carcasses was being processed, the electrolysed water supply was cut-off so that the birds were no longer sprayed post-pluck or pre-chill. Forty birds that had not been sprayed were then removed from the process line post-chiller and handled in the same way as the birds that had been treated with electrolysed water. The mean weights of the treated and untreated birds were 1640 g (s.d. =145 g) and 1581 (s.d.=226g), respectively. All of the birds were then put into transport crates and sent by the processor's usual distribution system to a supply depot. The birds were then taken by further refrigerated transport to the microbiology laboratory. The left side breast skin of each carcass was tested for aerobic plate counts (APC) and *Campylobacter* (enumeration and confirmation) at Day K+2 and the right side breast skin was similarly tested at Day K+7.

4.3.2 Results - Electrolysed Water Trial 2

Tables 11a and 11b show the aerobic plate counts and *Campylobacter* counts for each treatment at Days K+1 and K+7. Analysis of variance using the statistical package MINITAB, showed there was no evidence of a reduction in APC due to the use of the electrolysed water when carcasses were tested at Day K+2 (p=0.728). There was some evidence of an effect of the treatment at Day K+7 (p=0.018) but the difference was only 0.6-log. When considering *Campylobacter*, many samples showed counts below the limit of detection (10 per g) and the logs of these values were replaced with log(10/√2) (=0.85) in the tables. The *Campylobacter* data were also analysed, using a Fisher Exact test, to look for evidence of an effect of the treatment on the prevalence of the organisms. There was no statistically significant evidence of an effect at Day K+2 but there was weak evidence of an effect at Day K+7 (p=0.032).

4.3.3 Conclusions from Electrolysed Water Trial 2

The only evidence of effects of the electrolysed water were found at Day K+7 when APC were reduced by around 0.6-log and the prevalence of *Campylobacter* positive samples was reduced from 58% to 31%. The pH of the solution was slightly greater than the desired value of 7 but this is unlikely to have caused a large reduction in effectiveness of the free chlorine. Also, the birds may have become re-contaminated as they passed through the chiller and this would also mask any effect of the electrolysed water treatment.

4.4 Electrolysed Water Trial 3 (Electrolysed NaCl tested on-line on turkeys)

This trial was carried out on turkeys using a chlorine concentration between the low level used in Trial 1 and the high level used in Trial 2.

4.4.1 Methods - Electrolysed Water Trial 3

The site where the trial was carried out already had a spray unit located at the point before which the feet of the turkeys were removed. The spray unit was connected to an electrolysed water generator at the time of the trial. The generator was supplied by Cordon. A sample of water collected at the time of the trial showed a free chlorine concentration of 7.0 ppm and pH of 7.0. Chlorine concentration was measured using a Palintest 1000 (Palintest, Tymne and Wear, NE11 0NS, UK) and pH was measured using a Metrohm 825 meter (Metrohm AG, Herisau, Switzerland). The flow rate of the electrolysed water could not be measured due to the location of the equipment.

Thirty-eight carcasses were removed from the production line just after the water spray unit that was applying the electrolysed water. These were the treated birds. At this point the feet had not been removed from the birds. The carcasses were carefully placed into wheeled bins whilst trying to avoid contamination transferring from the feet to the breasts. The birds were removed at this point otherwise they would have subsequently passed through the foot removal operation and down a chute into the chiller. These operations might have caused cross-contamination of the birds. The water supply to the spray unit was turned off and another thirty-eight carcasses were then removed from the production line just after the water sprayer that had been switched off. Those carcasses were carefully placed into mobile bins and all of the bins containing the carcasses were wheeled into the chiller. The carcasses were then tagged with numbered cable ties, weighed, and hung on hooks in such an arrangement that the birds were not touching each other and any drip would not transfer from one bird to another. The average weights of the treated and untreated carcasses were 3680 g (s.d.=413g) and 3646 (s.d.=466g), respectively.

The next day (K+1), the carcasses were removed from the hooks, the feet removed, and the carcasses bagged individually and put into trays that went into the processor's distribution system to the storage depot. The birds were then transported in another chilled distribution vehicle to the microbiology laboratory. Thirty-six of the treated carcasses and thirty-six untreated carcasses were to be used for microbiological testing and the remaining two treated and untreated carcasses were to be stored to assess changes in appearance and smell during storage.

The left side breast skin of each carcass was tested for APC on Day K+2 and for *Campylobacter* (enumeration and confirmation) on Days K+2 or K+3. The right side breast skins were tested for APC on Day K+7 and for *Campylobacter* on Day K+8.

4.4.2 Results - Electrolysed Water Trial 3

Tables 12a and 12b shows the aerobic plate counts and *Campylobacter* counts for each treatment at Days K+2 and K+7. Analysis of variance using the statistical package MINITAB, showed no evidence of a reduction in APC due to the use of the electrolysed water when carcasses were tested at Day K+2 ($p=0.298$) or Day K+7 ($p=0.214$).

Few of the *Campylobacter* counts were below the limit of detection (10 per g) and the logs of these values were replaced with $\log(10/\sqrt{2})$ (=0.85) in the tables. Analysis of variance showed very weak evidence of a reduction in the *Campylobacter* counts due to the treatment when examined at Day K+2,3 ($p=0.046$) and there was no evidence of an effect at Day K+8 ($p=0.193$).

4.4.3 Conclusions - Electrolysed Water Trial 3

There was no evidence of an effect of the electrolysed water treatment on the APC. The very weak evidence of an effect on *Campylobacter* at Day K+2,3 was only a 0.3-log reduction.

In the chiller, a few of the carcasses showed visible signs of clumps of contamination that had come from the feet of the carcasses. Some of the *Campylobacter* counts (four values highlighted in red in the Tables 12a and 12b) showed counts that were clearly higher than those found on other carcasses. However, the carcasses with localised visual contamination in the chiller were not the same as those found to have high counts at the laboratory.

4.5 Electrolysed Water Trial 4 (Electrolysed NaCl tested on-line)

This trial was carried out with an in-line tunnel applying an electrolysed sodium chloride solution to chicken carcasses.

4.5.1 Methods - Electrolysed Water Trial 4

The site where the trial was carried out already had a water spray unit located within the first chiller. In this trial, carcasses were either treated using the plain water that was usually applied, or treated with electrolysed water through the same spray unit, or no water was applied to the unit. The electrolysed water generator was provided by Eden BioSystems (East Lothian, UK EH32 0UG). Around one hour prior to the trial, the equipment was adjusted by the company to produce a liquid with a redox potential of 1100 mV, pH less than 3 and free chlorine concentration of 60 ppm. This solution was dosed into the plain water spraying system to produce a solution with an ORP of 747 mV and free chlorine concentration of 3 ppm. At the time of the trial, the ORP, pH, and chlorine concentration of the actual solution used at that time were measured.

A clearance flock, from a farm known to produce birds with high *Campylobacter* counts, was selected for the trial. Ten carcasses were removed from the production line just prior to the spray unit and around 100 carcasses were then allowed through the unit before a further ten carcasses were removed from the line. The first and last carcasses of the group of 100 were tagged using a metal detectable cable tie. After the spraying operation, the carcasses continued along the line through the chillers and into the grading area. The two 10 carcass gaps, and the cable ties, helped in identifying the 100 carcasses from which we would gather carcasses for microbiological sampling. Those birds were the plain water treated samples.

The electrolysed water solution was then dosed into the plain water spray supply and the ORP of the electrolysed water spray was sampled by Eden BioSystems. This procedure gave an indication that the electrolysed water was exiting the spray nozzles. Ten carcasses were then removed from the line just before the chiller to create an identifying gap. The first and last of around 100 birds were tagged and then passed through the electrolysed water spray and on through the chiller. Another 10 carcasses were removed to identify the end of the batch of carcasses treated with the electrolysed water.

The water supply to the spray unit was then switched off and the process of removing 10 carcasses from the line, allowing 100 carcasses to continue along the line and then removing another 10 carcasses was repeated. These carcasses were those not treated with

any spray. Finally, the production system was returned to its usual status with carcasses treated with plain water.

The flow rate of the water supply to the spray unit was measured by Eden BioSystems and the ORP, pH, and the free and total chlorine concentrations of the plain and electrolysed water were measured at the start, middle and end of each part of the trial. Redox potential and pH were measured using a Metrohm 825 meter (Metrohm AG, Herisau, Switzerland) and the chlorine concentrations were measured using a Palintest Chlorometer Duo (Palintest, Tyne and Wear, NE11 0NS, UK).

As the birds left the final chiller, 38 carcasses treated with plain water, 38 carcasses treated with electrolysed water, and 38 untreated (no spray) carcasses were removed from the production line and placed into lined crates (6 or 7 carcasses per crate, only carcasses from a single treatment into each crate). The lining was pulled over the top of the carcasses in each crate. The carcasses were then taken by chilled courier (4ºC) to the microbiology laboratory where they were held overnight in a chill store (4ºC) and then weighed and put individually into numbered sterile bags. Thirty-six carcasses from each treatment were used in microbiological testing. The left side breast of each bird was tested on the day after treatment, and six days later the right side breast was tested, for aerobic plate count and *Campylobacter* enumeration and confirmation. The other two carcasses from each treatment were used for photographing for up to 7 days after treatment to record any changes in appearance.

4.5.2 Results - Electrolysed Water Trial 4

Tables 13a to 13c show the weights of the carcasses and properties of the liquid applied to the carcasses. The average weights of the carcasses treated with plain water, electrolysed water, or no water were 1663 g (s.d.=220g), 1618 g (s.d.=212g), and 1717 g (s.d.=233g), respectively. The air in the chiller was around 3.5ºC. The plain water taken from the supply tank before spraying, at the beginning of the trial, had a temperature of 12.9ºC, pH of 7.5, ORP of 426 mV, and free (FC) and total chlorine (TC) concentrations of 0.11 and 0.33 ppm (Table 13a). Midway through the trial, water taken from the tank showed very similar properties (12.9ºC, pH=7.55, ORP=446 mV, and FC and TC of 0.15 and 0.2 ppm). However, samples taken from the drip coming from the washer show slightly higher pH (7.89 and 7.95) and lower ORP (130 and 130 mV). Clearly, passing the water through the pipe system and spraying onto the carcasses, which include much organic material, has lowered the ORP of the plain water.

The ORP of the electrolysed water (EW) prior to the run with EW was found to be 735 mV and a measurement after all of the trials showed a value of 730 mV. Between taking those readings, the ORP of the electrolysed water in the supply was lower being between 574 and 697 mV. The measured free chlorine concentration was around 1 to 1.4 ppm and the total chlorine was 1.6 to 1.9 ppm. The water taken from the drip from the sprayer unit showed lower ORP values (143 and 208 mV) and lower chlorine concentrations (around 0.4 ppm free chlorine and 0.6 to 0.9 ppm total chlorine). Passage through the piping and spray unit clearly reduced the ORP.

Tables 14a to 14c and Figure 5 and 6 show the results of the microbiological testing at Days 1 and 7. The figures show the average log counts and the 95% confidence interval either side of the average. The aerobic plate counts were around 5-log at Day 1 and 7.5-log at Day 7. There was no practically significant difference between the APC from carcasses treated with electrolysed water and those treated with plain water or no water spray treatment. However, there were statistically significant differences between the average APC following different treatments at Day 1 ($p<0.001$) and Day 7 ($p<0.001$). At Day 1, the use of no water produced lower APC than the use of plain water spraying ($p<0.001$) or electrolysed water ($p<0.001$). There was no evidence of a difference in APC from spraying with plain water compared to electrolysed water ($p=0.399$). At Day 7, there was no evidence of a difference in APC from using no water or spraying with electrolysed water ($p=0.286$). Spraying with plain water led to lower APC than using no water ($p=0.002$) or electrolysed water ($p<0.001$).

Fisher Exact tests showed no statistically significant differences between the proportions of *Campylobacter* positive samples in each of the treatment groups. At Day 1, there was no evidence of a difference between the prevalence of *Campylobacter* positive samples on carcasses treated with no water or plain water ($p=0.594$), or between the counts on samples treated with no water or electrolysed water ($p=0.415$). At Day 7, there was no evidence of a difference between the prevalence of *Campylobacter* positive samples on carcasses treated with no water or plain water ($p=0.627$), or between the counts on samples treated with no water or electrolysed water ($p=1.000$).

The counts of *Campylobacter* were around 1.6-log cfu/g at Day 1 and 1-log cfu/g at Day 7. In calculating these averages, any log counts found to be below the limit of detection (10 cfu per g) were replaced with a value of $\log(10/\sqrt{2})$ (=0.85). At Day 1, there was no evidence of a difference in the *Campylobacter* counts from carcasses treated with no water or plain

water (p=0.316), no water or electrolysed water (p=0.614), or plain water versus electrolysed water (p=0.865). At Day 7, there was no evidence of a difference in the *Campylobacter* counts from carcasses treated with no water or plain water (p=0.984), no water or electrolysed water (p=1.000), or plain water versus electrolysed water (p=0.982). It should be noted that high proportions of the samples had counts of *Campylobacter* below the limit of detection so that these analyses are based on large numbers of log counts of 0.85 and the outputs from the Fisher Exact tests are more rigorous.

4.5.3 Conclusions - Electrolysed Water Trial 4

The results showed no practically significant effects, on APC or *Campylobacter* counts, of using the electrolysed water treatment compared to having no spray treatment or spraying with plain water. The measurements of ORP and chlorine concentration in the water in the tank and the water collected as drip from the sprayer suggested that organic material from the chicken carcasses was reducing the ORP and chlorine concentration and this may have been negating the effect of the electrolysed water on organisms on the carcasses.

4.6 Conclusions on the Use of Electrolysed Waters

There was considerable interest from the industry in the use of electrolysed water. However, the tests described here do not show strong evidence of an effect of electrolysed water on the counts of *Campylobacter* (see Table 15 summarising the results from each test). In Trial 1, the chlorine concentration was low and that may be the reason for the lack of an effect on the *Campylobacter*. However, in Trial 2, the chlorine concentration was much higher and the pH was around 7.3. The supplier of the electrolysis equipment advised that the pH should be below 7. It is unlikely that the pH was sufficiently above 7 to greatly alter the efficacy of the treatment.

In vegetable washing where sodium hypochlorite is used, a target pH around 7 to 7.5 has been reported (Dawson, 2002) although some factories will use lower levels of pH=6 to 7. Those processes also use higher concentrations of free chlorine of around 75 to 125 ppm although much higher levels can be used (Dawson, 2002). Concentrations below 50 ppm are considered to be ineffective. Beuchat (1998) states that concentrations of 200 ppm chlorine generally reduces microbial populations by 1- to 2-log. Dawson (2002) reports bacterial reductions on fresh produce of around 0.7-log by using a 10 ppm concentration of free chlorine for 2 minutes exposure time. Further comments on the effects of chlorine, in relation to interventions on poultry, are given in a later section.

5. CHLORINE/CHLORINE DIOXIDE

5.1 Published Data and Industry Data - Chlorine/Chlorine Dioxide

Chlorine is most active in its hypochlorous form when it penetrates bacterial cell walls and reacts with enzymes so preventing normal respiration (Fabrizio et al., 2002). However, it quickly binds to organic material which reduces its efficacy.

The effectiveness of chlorinated water depends on temperature, pH, chlorine concentration and organic load. The goal is to add sufficient chlorine to produce free residual (unreacted) chlorine. For maximum efficacy at low temperature, the pH needs to be between 4 and 6 (Bashor et al., 2004). In this range, chlorine hydrolyses completely to HOCl which is a very effective antimicrobial. Above pH=6, a portion of the HOCL is converted to OCl^- which has lower efficacy (Gavin and Weddig, 1995). No HOCL remains above pH=9. Bashor et al. (2004) give a useful summary of the efficacy of chlorine under commercial processing conditions when applied as a pre-chill wash or spray. They show that mixed results have been found. Mead et al. (1975) found that neither contamination levels or cross-contamination were reduced by spray washing with chlorinated water. Sanders and Blackshear (1971) found little effect of the final wash unless at least 40 ppm chlorine was used. Waldroup et al. (1992) included 20ppm chlorine throughout the processing line and 1 to 5 ppm in the chill tank overflow but still only achieved 0.2 to 0.6-log reduction in APC, 0 to 0.3-log reduction in coliforms and 0 to 0.4-log reduction in *E. coli*.

There is some cross-over in referenced studies that looked at the use of hot water and the use of chlorinated water (Tables 1 and 16). The majority of studies used over 10 ppm chlorine. Bashor et al. (2004) found a 0.5-log reduction in *Campylobacter* on naturally contaminated chicken carcasses when treated with water containing 25 to 35 ppm chlorine. Northcutt et al. (2005) found that *Campylobacter* on inoculated carcasses was removed by spraying with chlorinated water but the natural *Campylobacter* contamination was not removed. Reductions in *Campylobacter* that had been artificially applied to carcasses tend to lie between 1.6 and 3.0-log. The review by EFSA (2011) notes that chlorine, as hypochlorite, has traditionally been used at levels of 50ppm and higher in poultry. That report concludes that there is general agreement that, even at 50 ppm, there is little effect on *Campylobacter* attached to carcasses. Burfoot et al. (2013d) sprayed a solution with 80 ppm free chlorine onto chicken carcasses pre-chill. The solution was applied over 20s. Aerobic plate counts were reduced by 0.4-log ($p<0.001$). 28% of the 36 control samples and 58% of the treated samples, had *Campylobacter* counts below the Limit of Detection (10 cfu per g). A Fisher Exact test showed a significant reduction in *Campylobacter* positive samples ($p=0.017$) due to treatment. Replacing log counts below log(10) with a value of $\log(10/\sqrt{2})$

showed *Campylobacter* counts on control and treated samples of 1.34-log and 1.06-log, respectively, and a significant reduction (p=0.003). Greater reductions in *Campylobacter* (3-log) have been reported in New Zealand when similar concentrations of chlorine have been used in water chillers with a residence time of 90 minutes (unpublished industry data).

The EFSA (2011) report indicates that chlorine dioxide may be more effective than hypochlorite because it is less easily inactivated by organic matter. However, Vandekinderen et al. (2009) suggested that gaseous chlorine dioxide would be effective as an intervention on carbohydrate-rich foods but less effective for the decontamination of high-protein and fatty foods: the study did not look at *Campylobacter*. Bolder et al. (2007) compared the use of the inside-outside washer with and without the application of chlorine dioxide. They found reductions of 0.7-log and 0.35-log using 4.25 ppm chlorine dioxide or just water, respectively. Hong et al. (2008) found that using longer treatment times (10 min) and higher concentrations (50 or 100 ppm) reduced the number of inoculated *Campylobacter* by 1 to 1.2-log. Corry et al. (2008) found negligible effect of chlorine dioxide in a water spray on the *Campylobacter* counts on naturally contaminated carcasses.

Several processors use chlorine dioxide to treat bore hole water and this is used in the sprays in the evisceration area. The free chlorine level is controlled to be 0.5 ppm or less and, at this level, is unlikely to have an effect on *Campylobacter* on carcasses.

5.2 Trial with Chlorine Dioxide

The aim of this trial was to test whether using chlorine dioxide treated water has an effect on *Campylobacter* counts (and aerobic plate counts) on chicken carcasses when applied throughout an evisceration area.

5.2.1 Methods - Chlorine Dioxide Trial

Water treated with chlorine dioxide was supplied from a 1 m^3 tank at the rate of 8m^3/h. Water at this flow rate was supplied to the equipment in the evisceration room. The pressure of the water supplied to the inside-outside washer was boosted significantly to 6 bar and 4 bar (two supplies). The plant was operating at 9960 birds per hour at the time of the trial. Data on flow rates, volumes, and throughput were provided by the processor.

During the trial, 36 birds that had been treated with the water containing chlorine dioxide were removed from the process line post-chiller. Whilst these birds had passed through the evisceration area, three samples of water had been taken from the inside-outside washer and tested for pH, free chlorine, total chlorine, chlorine dioxide, and temperature. The

chlorine and chlorine dioxide concentrations were measured using a Chlorometer Duo (Palinest Ltd, Gateshead, NE11 0NS UK) using diethyl-p-phenylene diamine (DPD) No.1 tablets to assess free chlorine, No.1 and No. 3 tablets to assess total chlorine, and glycine and No.1 tablets to access chlorine dioxide according to the manufacturers instructions. A sample of water from a hand wash was similarly tested. After these birds had entered the chill room, the supply of chlorine dioxide to the feed tank was switched-off and the chlorine concentration in the water was measured over the next hour. At that time, the pH, free chlorine, total chlorine, and temperature of three samples of water from the inside-outside washer were measured whilst 36 birds passed along the line and into the chiller. The carcasses were removed from the line and weighed on exit from the chiller. These birds had been treated with water that had not been dosed with chlorine dioxide at the feed tank. All carcasses were in the chiller for 2.5 hours and came from the same flock.

The 36 chlorine-dioxide-treated and 36 untreated (water-only) carcasses were placed individually into sterile bags on exit from the chiller. The carcasses were then sent by refrigerated van (4°C) to the microbiology laboratory were they were tested the next day (K+1) and six days later (K+7) for aerobic plate counts and *Campylobacter* (enumeration and confirmation).

5.2.2 Results - Chlorine Dioxide Trial

Tables 17a and 17b show the weights of the birds and the properties of the water applied to the carcasses. The average weights of the treated and untreated (water-only) birds were 1.35 kg (s.d.=0.23 kg) and 1.83 kg (s.d.=0.17 kg), respectively. The water temperature at the I/O washer was around 12°C and the pH was around 7.2 to 7.6 units. Free chlorine concentration was 0.5ppm in the I/O washer water during both the tests with treated and untreated water. Similarly, the total chlorine concentration was 0.7 ppm. The chlorine dioxide concentration at the time of applying chlorine dioxide was 1.0 to 1.1 ppm chlorine dioxide, however, even after the chlorine dioxide had been switched-off for over an hour, the chlorine dioxide concentration in the water in the I/O washer was between 0.9 and 1.4 ppm chlorine dioxide. This suggests that either the chlorine dioxide had not been switched-off (not the case), or the water entering the supply tank had already been treated, or there was some build up of chlorine dioxide within the system. It was not possible on the day to measure the chlorine and chlorine dioxide concentrations in the water entering the supply tank but water from a nearby hand washer had free and total chlorine levels of 0.04 and 0.23 ppm, respectively. On a later date, the staff at the plant measured the chlorine dioxide concentration in the water entering the tank and found it to be 0.07 ppm chlorine dioxide.

The readings from the chlorine meter may appear confusing as the chlorine dioxide concentration is greater than the total chlorine concentration. We spoke with Palintest, the manufacturers of the meter, about this anomaly and were told that the total chlorine reading is actually a measure of the concentrations of mono- di- and tri-chloramine (resulting from the reaction of chlorine with the DPD tablets). Chlorine dioxide is a different compound and therefore is not included in the total chlorine measurement.

Tables 18a and 18b, and Figures 7 and 8 show the aerobic plate counts and *Campylobacter* counts for each treatment at Days K+1 and K+7. There was no evidence of a change in the APC due to the use of the chlorine dioxide at either Day K+1 (p=0.220) or Day K+7 (p=0.571). Neither was there any evidence of an effect of the chlorine dioxide on the *Campylobacter* counts at Day K+1 (p=0.069) or Day K+7 (p=0.684).

5.3 Conclusions on Use of Chlorine Dioxide

This trial found no evidence of an effect of the addition of chlorine dioxide to the water in the supply tank on the APC or *Campylobacter* counts. However, the concentration of chlorine dioxide in the water supply to the evisceration room was not found to decrease when the chlorine dioxide supply to the holding tank was switched off. The reason for this lack of reduction in the chlorine dioxide concentration is not known. In view of the lack of a change in the chlorine dioxide , the lack of any reduction in microbial counts is not surprising.

6. ELECTRO-OXIDATION OF SCALD WATER

6.1 Published Data and Industry Data - Electro-oxidation of Scald Water

No published paper was found on the effect of electro-oxidising scald water i.e. adding salt and passing a current through the water. One published paper (Table 19) was found on electro-oxidation of poultry chill water but that only considered the effect on *Campylobacter* in the water rather than on any poultry passed through the water. *Campylobacter* reductions in the water ranged from 0.5 to 1.4-log with salt concentrations between 0.1 and 0.3% and application for 10 minutes.

One company had carried out a trial with electro-oxidation of scald water. They found no reduction in microbial counts but the scald water became very malodorous and no further work was carried out with the system.

6.2 Trials with Electro-oxidation of Scald Water

The decision was made not to carry out any trials on the electro-oxidation of scald water for the following reasons:

a. poor experience by the poultry processor
b. the provider of the equipment used in the trial with the poultry processor did not want to take the work further without funding for them
c. the organic loading of scald water would be likely to quickly overcome any effect of the lector-oxidation process
d. earlier tests within this project, applying electro-oxidised water to poultry carcasses, showed no statistically significant effect on the numbers of *Campylobacter* on the carcasses.

Trials on the effect of rapid cooling on the numbers of *Campylobacter* on the surfaces of carcasses were carried out to replace the work that would have been carried out on electro-oxidation of scald water and the UV-disinfection of air. Reports of these trial have not been published as they include commercially sensitive material and are covered by a confidentiality statement (Burfoot et al., 2013b,c).

7. ULTRA-VIOLET RADIATION

7.1 Published Data and Industry Data - UV Radiation

Guerrero-Beltrán and Barbosa-Cánovas (2004) suggest that UV radiation in the range 220 to 300 nm contains high energy photons that generate pyrimidine dimers and denature bacterial DNA leading to degradation of bacterial cell walls and consequently destruction of the bacteria. The wavelength range 200 to 280 nm is often called the germicidal UVC range with 254nm being specifically identified as a germicidal wavelength (Chevrefils et al. ,2006)

Chevrefils et al. (2006) provide a listing of the effects of UVC dose on a wide range of bacteria, protozoa and viruses. They note the work by Wilson et al. (1992) that found a 1-log reduction in *Campylobacter* numbers using a UVC dose of 1.6 mJ/cm^2 and a 2-log reduction using 3.4 mJ/cm^2. However, that work was concerned with reducing *Campylobacter* numbers in water. The published research on the effect of UVC radiation on organisms on poultry only describes work using artificially contaminated carcasses; no research was found that used naturally contaminated carcasses (Table 20). Isohanni and Lyhs (2009) report a 6.3-log reduction on agar plates inoculated with *Campylobacter*, a 0.8-log reduction on inoculated chicken skin, and a 0.4-log reduction on whole carcasses. No effect on colour, sensory quality, or fat content were found relative to the controls. Haughton et al. (2011) report similar results with a 7-log reduction to undetectable levels of *Campylobacter* in liquid and maximum reductions of 0.76-log and 0.58-log reductions on breast meat and skin, respectively. Again, overall there was no adverse effect on colour.

Several companies reported an interest in the use of UVC perhaps incorporating the technology into the evisceration line as opposed to using it post-chill. A major concern is one of shadowing and this would require some system that may move the legs and wings to enable a good UVC coverage and also the UVC radiation would need to be directed into the body cavity. These operations were thought to be prohibitively expensive. Also, the application of UVC in wet environments, such as near to the spray systems in evisceration areas, is impractical. Treating portions post-chill was considered to be feasible.

7.2 Trial with UVC Radiation

Haughton *et al.* (2011) used UV dose of 0.192 J/cm^2 to achieve the reductions described above. This dose was achieved with a flux of 6 mW/cm^2 for 32 s. The skin was exposed to that UVC dose on both sides and a similar dose was used in the trial described below. Chicken breast fillets were used to avoid shadowing effects that may be found on whole birds. If successful, further developments would be needed to treat whole birds.

7.2.1 Methods - UVC Trial

Five days before the trial (a Friday), boot swab samples from 10 sheds were sent to a laboratory (AFBI, Belfast, Northern Ireland) for testing for *Campylobacter* using real time PCR. The samples arrived at AFBI at 13:20 on the following Monday and results, available at 16:20, showed that all ten sheds were positive for *Campylobacter*. The following day 30 chickens originally from one of the sheds, were removed from the production line as they left the chiller and were put into 3 cardboard boxes. The carcasses were transported by car (1 hour journey) to Campden BRI where the outer breast portions (Pectoralis Major), with skin attached were removed from each carcass. The portions were placed individually into food trays (Cryovac, BT3-32 Nat Bird Flexi 8160) that were placed inside bags. The bagged portions were then placed in BOC crates and put into a chiller at 2°C for 1 hour.

Twenty samples were then treated in a UVC tunnel sourced from Advanced Air Hygiene (Model No. BARO SDT 1 Test). An inverted food tray was located within the tunnel directly beneath one of the lights. Earlier tests had shown that the flux at this height would be around 12 mW/cm^2. The tunnel was switched on and left running for 1 hour and the light flux measured using a UV-VIS radiometer (Model No. RM12, Dr Gröbel UV-Electronik GmbH, Ettlington, Germany) and the air temperature measured (Model Thermapen, ETI Ltd). A chicken breast fillet, skin side up, was removed from the bag and placed, still in the food tray, on to the inverted food tray on the belt of the tunnel. The fillet was treated for 20s, removed from the tunnel, and the breast skin removed using sterile tweezers and a scalpel and placed into a sterile bag. The flux and temperature in the tunnel were then measured whilst, at the same time, a control chicken breast fillet was exposed for 20s. This untreated control sample was located directly next to one of the air exhaust vents of the tunnel such that the sample was in the air stream exiting the tunnel. The treated and untreated samples were from the same bird. This procedure, using a fresh scapel and tweezers each time, was repeated 20 times and the samples placed in a chiller at 2°C for 4 hours and then into a cool box containing ice packs covered with bubble wrap. The ice box was transported in a refrigerated van (0.5 hour journey) and held overnight in a chiller and then transported (2 hour journey) to the microbiology laboratory were the samples were tested for aerobic plate counts and *Campylobacter* (enumeration and conformation).

7.2.2 Results from UVC Trial

Table 21b shows that the average flux during the trial was 12 mW/cm^2 (s.d.=0.3 mW/cm^2) producing an energy density of 12 mW/cm^2 which equates to 12 x 20s /1000 = 0.240J/cm^2. This is slightly higher than the minimum of 0.220 J/cm^2 suggested by the tunnel supplier and was used to ensure that all of the samples were treated to at least the 0.220 J/cm^2 minimum.

There was no control of the energy but the lamps cooled quickly and as they cooled the power rose. For this reason the time that the door of the tunnel was open was kept consistent. The average air temperature in tunnel during the trial was 39°C (s.d.=3°C).

Tables 21a and 21b show that the average counts of *Campylobacter* on the untreated and UVC treated samples were 2.3-log and 2.2-log, respectively. There was no evidence of an effect of the UVC on the counts of *Campylobacter*. The aerobic plate counts from the untreated and UVC treated samples were 6.7-log and 6.3-log showing a difference of 0.4-log (p=0.000).

The UVC treatment had an adverse effect on the odour of the chicken samples producing a slightly singed odour. The suppliers of the tunnel investigated the cause of this odour but drew no firm conclusions.

7.3 Conclusions on the Use of UVC

Figure 9 shows the reduction in *Campylobacter* versus UV dose based on data from Wilson et al. (1992), Haughton et al. (2011) and the trial described above. The reduction found in this study tends to be more in line with the data from Wilson et al., suggesting that low UV dose gives only small reductions in *Campylobacter* numbers. The reasons that larger reductions in the *Campylobacter* were not found in this study could be that the samples were naturally contaminated and within the pores and crevices of the skin. The work by Haughton et al. used inoculated samples however, the data from Wilson et al., who used *Campylobacter* in a liquid medium, also suggest that the *Campylobacte*r reduction around 0.2 mJ/cm^2 would be low. Unwanted changes in the odour of the chicken were found at those low doses and higher doses would have created greater changes in the odour. For those reasons no further trials were carried out with this technique.

A study on the use of ultra-violet radiation to reduce counts of *Campylobacter* in the air in scalding and plucking areas had been suggested by the industry at the time of preparing the project proposal. The concept was that reducing the airborne count of *Campylobacter* might reduce carcass contamination. Earlier FSA-funded research (M01029, Burfoot et al., 2007) had shown that the airborne route contributed less than 1% of the total numbers of bacteria on carcasses in the evisceration area, however, the suggestion was that numbers of organisms, including *Campylobacter*, in the air near to scalders and pluckers may have a greater contribution to the carcass contamination. Data from that project and M01037 (Allen et al. (2008) on air exchange rates and concentrations of airborne microorganisms in

scalder rooms were provided to a company that supplies UV-based air disinfection systems so that they could estimate the number of UV units that would be required to handle those flow rates and microbial loads. They estimated that at least six of their UV units would be required. The conclusion was drawn that it was not feasible to provide 6 units for a commercial trial to test the efficacy of the technology. In addition, because the source of the airborne organisms are the carcasses themselves, reducing the concentration of organisms in the air might not affect the numbers of organisms on the carcasses: only a fraction of the organisms on the carcasses will be removed by processing. For these reasons, no experimental work was carried out using UV-disinfection of the air. Trials with rapid surface cooling were carried out instead and are reported in Burfoot et al. (2013b,c). Reports of these trials have not been published as they include commercially sensitive material and are covered by a confidentiality statement.

8. Overall Conclusions

None of the currently available interventions that are allowed in the EU showed promise when tested at full-scale using naturally contaminated carcasses and, for this reason, a comparison of the costs of the different treatments was not carried out. The applications of hot water or steam rely on thermal effects but these cause adverse effects on the exposed flesh and skin of the birds. The four trials spraying of electrolysed water onto carcasses showed no substantial effect on the numbers of *Campylobacter*. Similarly, at the levels accepted in the EU, the use of chlorine dioxide showed no effect on the numbers of *Campylobacter*. Although electrolysed water and chlorine dioxide had no direct effect on the numbers of campylobacter on the carcasses, they could have possible beneficial effects in long term use by reducing cross-contamination and the numbers of *Campylobacter* on equipment.

Tests with these methods were not taken further because of the lack of evidence of on effect on *Campylobacter* numbers. However, trials were carried out on an intervention that is also likely to be acceptable in the EU, namely the use of rapid surface chilling. Those trials, and the results of those carried out by industry, are detailed in the reports by Burfoot et al. (2013b,c). Reports of these trials have not been published as they include commercially sensitive material and are covered by a confidentiality statement.

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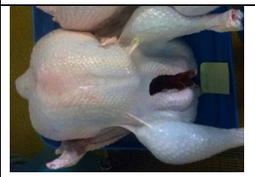
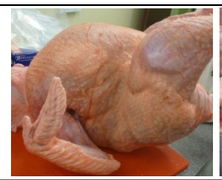
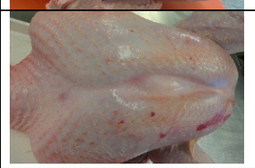
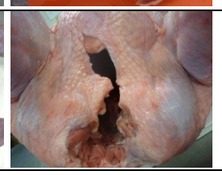
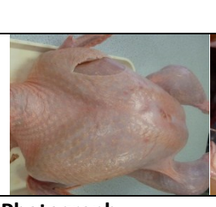
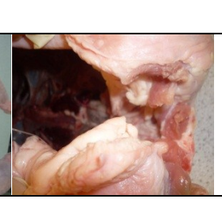
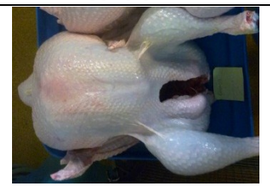
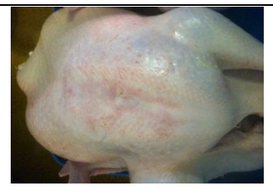
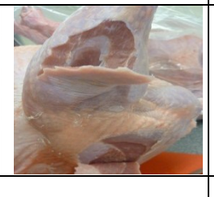
Table 1: Published data on the efficacy of hot water for reducing the microbial counts on poultry

Approach	Microbial Reduction log CFU. Means shown unless otherwise stated)		Method eg Spraying	Application Point eg post-EV	Sampling point eg post-chill	Material			Conditions		Quality Acceptance	Comments	Reference	Refereed
	Organisms	Campylobacter				Type eg chicken	Portion eg whole	Contamination, sample	Temp, °C	Time, s	Y/N			Y/N
Water	EcoliK12=1.16 to 1.31 log cfu cm^{-2}	Campy=0.98 to 1.66	Immersion	Pilot plant	Post treatment	Chicken, previously frozen	Whole	Artificial, breast skin	70, 75, 80	40,30,20	Some slight appearance changes noted - mostly to cut edges and exposed muscle. Also some shrinking of the skin.	Also lists appearance effects found by others.	Corry et al., 2007	Y
	EcoliK12=1.63 to 2.95 log cfu cm^{-2}	Campy=1.63 to 2.91 log cfu cm^{-2} dependent on chill method	Immersion	Experimental	Post-immersion	Chicken, previously frozen	Whole	Artificial, breast skin	80	10, 20	Best method considered to be 80°C/20s followed by crust freezing which didn't produce "extensive degrdation" of appearance.	Also examined the effect of chilling treatment	James et al., 2007	Y
	Initial trials: APC=1.01 log cfu ml^{-1} (75°C,30s), 1.10 (70°C, 40s); Full trial: 0.61 log (75°C/30s/8 days); 0.87 log (70°C/40s/8 days)	Initial trials: Campy = 1.10 log cfu ml-1 (70°C,40s); No effect at 70°C/40s; Full trial: 0.96 log (75°/30s/0 days); 0.75 log (70°/40s/1 day); 1.36 (70≤/40s/8 days	Immersion and mains water spray chill.	Initial trials post I/O& grading.	Initial trials post I/O&grading. Final tests post-storage	Chicken	Whole	Natural, neck skins	65,70, 75,80 °C (initial trials)	10,20,30, 40,50,60, 70s (initial trials)	All 65°C treatments were acceptable, 70°C and ≤40s and 75°C and ≤30s were acceptable. However, in full scale trails 60% of carcasses at 75C/30s were unacceptable and at 70C/40s up to 9% were unacceptable.		Purnell, Mattick, Humphrey, 2004	Y
		Campy=0.5, 1.28, 1.43 log cfu/carcass at 20,55,60°C (no chlorine, before chill); Campy=1.43,2.36,2.46 log cfu/carcass at 20,55,60°C (no chlorine in spray, after chlorine chill); Campy = 1.21,1.81,2.16 log at 20,55,60°C (chlorine in water before chill) and 1.89,2.05,2.53 at 20,55,60°C (with chlorine and chlorine chill)	I/O washer	Pilot plant	Post-treatment	Chicken	Whole	Artificial,	20, 55, 60	12	No significant difference in colour from using spray at 20, 55 or 60°C.	80 psi. 18.9 l/min. 0 or 50 ppm in water and then 50 ppm in chlorinated ice at 4°C for 50 min. Lab tests showed C.jejuni reduction of 1.4,1.1,0.6 log on skin in water at 65,60,55C for 15s. With 50ppm chlorine, the reductions were 1.7,1.3,0.7 (and 0.5 log at 20C). Greater reductions achieved with chlorinated water spray but not significantly. 55 and 60°C better than 20°C. Chlorine chill reduced counts by around 1 log for water spray and 0.2-0.6 log (not sig.) for chlorine spray. Used chill water with organic materials may affect the conclusions.	Li, Yang, Swem, 2002	Y
	APC=1.2 log g^{-1} Entero=0.1 to 0.2 log g^{-1}	Campy=0.5 to 0.7	Spraying	At I/O wash	Post-I/O	Chicken	Whole	Natural, neck skin	?	?	Standard procedure so OK	Micro counts were very high	Abu-Ruwaida et al., 1994	Y
		Salmonella eliminated on skin samples but not drums, halves, whole birds	Immersion			Turkey	Skin, drumstick, halves, whole	Natural, skin	87.5	15		Exposure of organisms to treatment seemed to be limiting factor. Heat may kill Salmonella allowing other organisms to multiply.	Avens and Miller, 1972	Abstract
	APC=3log (93.3°C,15s); 1.35 log (87.7°C,12s); 1.16 log (82.2°C,12s); 1.36 log (76.6°C,15s); 0.96 log (71.1°C,20s)		Immersion			Turkey	New York dressed whole		71.1 to 93.3	12 to 20	93.3°C/15s - yellowing of skin and removal of epidermis; below 76.6°C no appreciable yellowing.		Pickett and Miller, 1966	Abstract
	APC (natural)=1.09 (80°C,10s) and 1.25 log cfu g-1 (85°C,10s)	Campy(artificial)=0.92,0.84,1.08 log (75,80,85°C,10s); 0.87,1.77,1.89 log (75,80,85°C,20s)	Immersion	Experimental	Post water treatment	Chicken (previously chilled)	Thigh	Natural or artificial, thigh	75, 80, 85	10, 20	Visible damage to outer epidermal skin tissue in all cases.		Whyte, McGill, Collins, 2003	Y
												Reviews available data. Specifically addresses recycling and concludes acceptable if sufficient heat treatment is used and there is no build-up of veterinary drugs.	EFSA, 2010	N

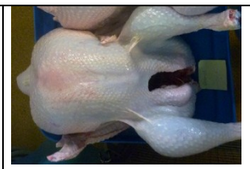
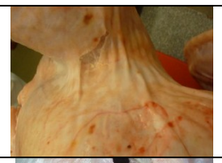
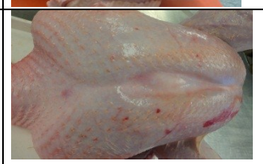
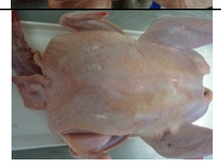
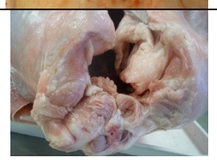
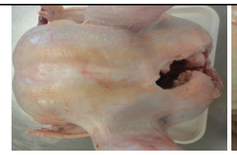
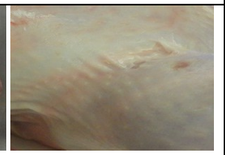
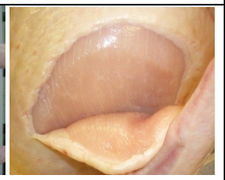
	APC=0.5 log m-1 (Immersion, 60°C,28s, 30 min after defeather);APC=0.4 log m-1 (Spray, 73°C,20s, 30 min after defeather);APC=0.3 log m-1 (Immersion, 60°C,28s, straight after defeather);APC=0.3 log m-1 (Spray, 00°C,20s, straight after defeather)	Campy=0.5 log ml-1 (Immersion, 60°C,28s, 30 min after defeather);Campy=0.1 log ml-1 (Spray, 73°C,20s, 30 min after defeather);Campy=0.0 log ml-1 (Immersion, 60°C,28s, straight after defeather);Campy=0.4 log ml-1 (Spray, 70°C,20s, straight after defeather)	Immersion or spray	Post defeathering or at pilot plant	Post water	Chicken	New York dressed whole	Natural, rinse	Immersion = 60; Spray = 79-77 in tank and 73-70 in spray.	Immersion = 28s; Spray = 20s	Campylobacter not lowered by a second scald if it is gentle enough not to alter appearance.		Berrang, Dickems, Musgrove, 2000	Y
	Killed/inactivated virtually all mesophiles and psychrophiles (>180s)					Turkey	Trurkey carcass tails, previously frozen	Natural, turkey tails	97	60 to 360	Some cooking of the skin at 60 and 120s. Considerable cooking at 180 and 240s, and cooked appearance with browning at 300 and 360s.	Concentrated on treatments that killed/inactivated virtually all mesophiles and psychrophiles (>180s)	Avens, Morton, 1999	Y
	APC=1.10 to 1.28 log cm^{-1} (Immersion); APC=1.01 to 1.21 log cm^{-1} (Spray)		Immersion or Spray	Lab	0, 24, and 48h storage	Chicken	Halves	Natural, swab	70	60	Only meat cooked after the treatment was tested. It did not differ significantly from control.		Sinhamahapatra et al., 2004	Y
	APC=No reduction achieved by washing relative to natural control but it did remove artificial contamination.	Campy=No reduction achieved by washing relative to natural control but it did remove artificial contamination.	Spraying	Pilot I/O washer		Chicken	Whole	Natural and artificial, rinse	21 to 54	5	No effect of temperature on colour.	80 psi, 0.5ppm tap water	Northcutt et al., 2005	Y
	APC = 0.3 to 1.3 log cm-2 increasing with temp.		I/O washer	Pilot I/O washer	Post I/O	Chicken	Whole	Natural, swabbing	21,54,60,66, 71	Total 12 - Full spray around 4s	Treatment at 71°C affected appearance but not greatly.	20 or 30 psi water.	Thomson et al., 1974	Y
	APC=0.57 to 1.83 log cfu cm-2 (24 to 71°/60s/ still), 0.32 to 1.95 (24 to 71°C/180/still), 0.1 to 0.83 (24 to 71C/60s/aerated), 0.24 to 1.2 (24 to 71C/180s/ aerated).		Immersion	After chilling	After treatment and stored to 9 days	Chicken (previously chilled)	Whole	Natural, swabbed	24, 49, 60, 66, 71	60, 180	Appearance became worse with increasing temperature. 60C or higher gave partially cooked appearance. Shelf life was not extended significantly by treatment at 71°C.	Still or aerated water	Cox et al., 1974	Y
	Entero= -0.58 to 2.23 log $cm^{-2;}$ Pseudo= 0.04 to 2.91 log cm^{-2}	Campy=0.20 to 1.99	Immersion	Pre-chill	Pre-chill	Chicken	Whole	Natural, breast skin	80	20	20s and 10s immersion showed differences to control on day of treatment. Some carcasses split at the vent on trussing. Some carcasses showed wrinkled appearance. Researchers considered birds acceptable but retailer suggested there was a difference between control and treated and therefore unacceptable.	Micro counts were low	Corry et al., No date	N

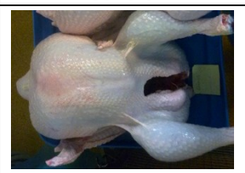
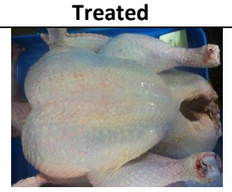
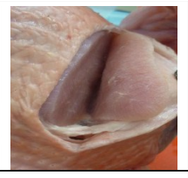
	No reduction in APC or E.coli	No reduction in Campy	Scalding/ plucking	Scalder		Chicken	Whole	Natural, rinse				Non conventional system involving some plucking between scald tanks.	Cason et al., 1999	Y
												Considers hot water treatments to reduce APC to below 10 cm^{-2}. Not concerned whether surface is cooked as material to be used in processed product. Used 95^{o}C for 180s. Not relevant.	Avens et al., 2002	Y

Table 2: Photographs and comments on the appearance of control stag carcasses and those treated with hot water at various temperatures in Hot Water Trial 1

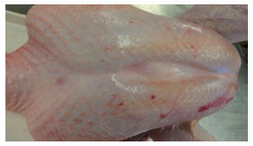
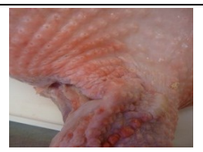
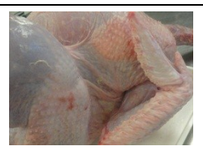
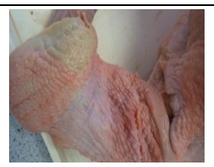
Treatment	Day	Photograph Control	Photograph Treated	Comments
Hot water Sprayed 85°C for 20 seconds. No ice bath used. (Stag 1)	K+0			Slightly redder skin than control. Client would still be pleased. Acceptable appearance and texture. Bird weight = 16.38 kg; Temp pre-treat = 41.4°C; Bird temp post treat = 43.0°C; Into chiller at 10:30 on Day 0.
	K+1		 	Texture acceptable. Flesh still acceptable; not cooked or denatured. Some red spots on skin.
	K+2		 	Skin remains redder than control with clear red spots on breast and wing areas. Pores more open around neck area. Rubbery texture at leaf fat area.
	K+3		 	Skin texture tight and rubbery at breast and leg. Skin not easily tore. Control wing skin already broken. Moist and red neck flap compared to slightly red wings and neck of Control.
	K+7		 	Reddened skin over entire carcass with some grey/white. Streaking at neck flap. Slightly slimy texture/control very slimy texture. More rubber texture at leaf fat area. Control grey coloured leaf fat area. Brown/yellow streaky growth on left breast.
Treatment	**Day**	**Photograph Control**	**Photograph Treated**	**Comments**
Hot water Dipped 84.8°C for 10 seconds and then ice batch for 30 s (Stag 2)	K+0			Absolutely awful – blown skin, easily tore, stretched appearance, not as moist as control. Very smooth, lost pores. Also put into an ice bath after taking the photo and the carcass then appeared to be whiter. Bird weight = 16.82 kg; Temp pre-treat = 41.7°C; Bird temp post treat = 42.4°C; Into chiller at 10:45 on Day 0. Photograph before ice bath.
	K+1		 	Swollen appearance, skin easily ripped. Colour similar to 30 minute blast in oven. Flesh and fat layer still acceptable on breast and leg.
	K+2			N/A
	K+3			N/A
	K+7			N/A

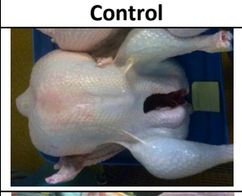
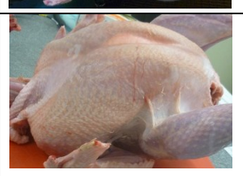
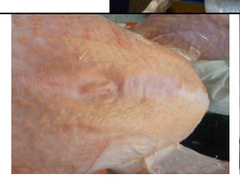
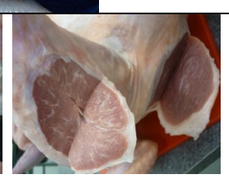
Treatment	Day	Photograph Control	Photograph Treated	Comments

Hot water Dipped 85°C for 10 s followed by cooling in ice bath for 20 s (Stag 3)	K+0	 	Skin less brittle but easily torn. Similar colour over entire carcass. Rubbery texture but less swollen appearance. Denaturation at extremities. Bird weight = 18.02 kg; Temp pre-treat = 40.4°C; Into chiller at 10:55 on Day 0. Photograph after ice bath.
	K+1	  	Skin, neck and breast flesh has a 'cooked' appearance. Denaturation of leaf fat area and slightly on the inside of the carcass. Skin taut at upper leg area. Skin beginning to split at neck.
	K+2	  	Skin very stretched and split at neck area with a slight cooked appearance. Rubbery texture. Clear denaturation at anal area.
	K+3	  	Skin very stretched and split at neck area with a slight cooked appearance. Clear denaturation at leaf fat and neck areas. Dry texture on breast skin compared to Control. Skin colour very pale pink compared to red blotting of control bird.
	K+7	  	Skin tight and split on breast areas. Neck flap and leaf fat areas have rubbery textures with obvious grey/white streaking on skin, similar to control. Skin colour, pale pink with slight bruising on legs. Cut flesh still acceptably pink and moist. No difference with control bird flesh. Closed pores on skin, very smooth, rubbery texture.

Treatment	Day	Photograph Control Treated	Comments
Hot water Dipped 80°C 12 seconds followed by 20 s in ice bath (Stag 4)	K+0	 	Denaturation at neck and leaf fat areas. Looked cooked and swollen at anal region. Slight blown appearance at leaf fat area. Follicles still present on skin. Bird weight = 16.56 kg; Temp pre-treat = 39.3°C; Temp post-treat = 38.4°C; Into chiller at 11:05 on Day 0. Photograph before ice bath.
	K+1	  	Slight discolouration of skin due to initial "cooking". Skin taut at leaf fat area, other skin is fine. Breast, leg and thigh flesh pink and moist, not affected.
	K+2		N/A
	K+3		N/A
	K+7		N/A

Treatment	Day	Photograph Control Treated	Comments

Hot water Dipped 80°C for 10 seconds followed by ice bath for 20 s (Stag 5)	K+0	 	Overall similar to control in appearance, texture and colour. Slight denaturation at anal area. Not swollen. Bird weight = 14.26 kg; Temp pre-treat = 40.9°C; Temp post-treat = 38.7°C; Into chiller at 11:15 on Day 0. Photo before ice bath.
	K+1	  	Leaf fat area slightly pale in colour, some denaturation. Flesh pink and moist similar to control. Overall still acceptable.
	K+2	  	Skin slightly red, especially at neck and upper breast areas. Stretched appearance but skin quite loose with a rubbery texture. Open pores on wings, breast and neck areas. Control had very few open pores.
	K+3	  	Skin taut and rubbery, especially at legs and breasts. Skin slightly red similar to control, but some dark spots developed on leaf fat area.
	K+7	  	Rubber texture to skin with a degree of slime. Skin quite pink compared to red colour of control, but similar grey/white streaking to neck flap and leaf fat areas. Exposed flesh still pink and moist; acceptable.

Treatment	Day	Photograph Control Treated	Comments
Hot water Dipped 80°C for 10 seconds then ice bath for 20 s (Stag 6)	K+0	 	Overall similar to control in appearance, texture and colour. Slight denaturation at anal area. Bird weight = 13.42 kg; Temp pre-treat = 35.5°C; Into chiller at 11:21 on Day 0. Photo after ice bath.
	K+1	  	Leaf fat area slightly pale in colour, some denaturation. Slight yellowing of skin but breast, leg and thigh flesh still pink and moist similar to control. Overall still borderline acceptable.
	K+2	  	Skin slightly red, especially at neck, wings and upper breast areas with many open pores. Similar colour to control but few open pores. Quite loose skin with a rubbery texture over carcass. Slight denaturation at leaf fat area.

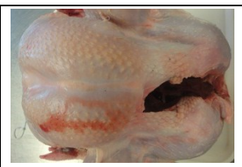
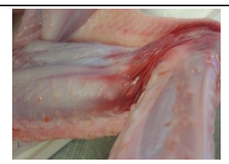
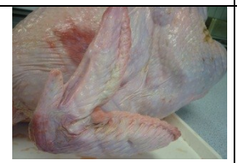
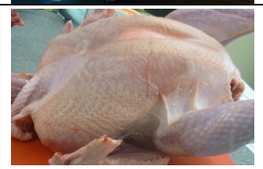
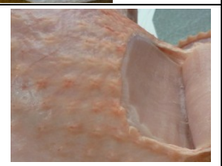
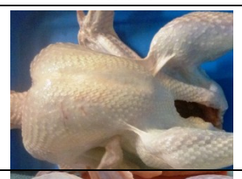
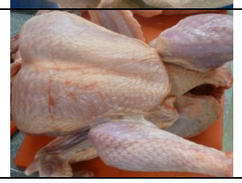
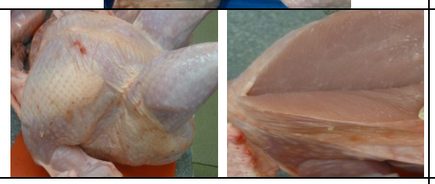
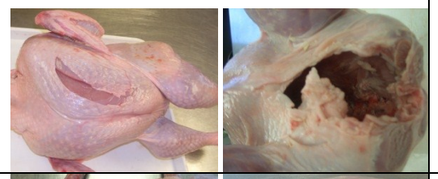
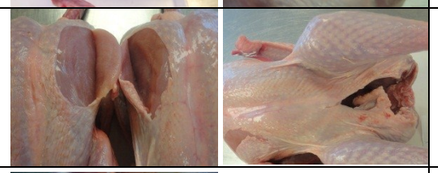
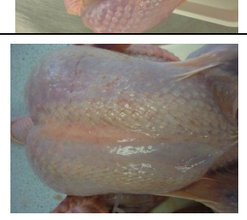
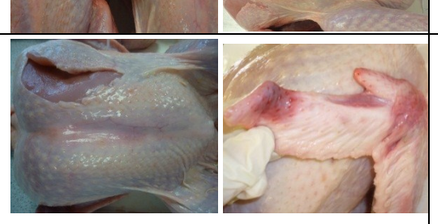
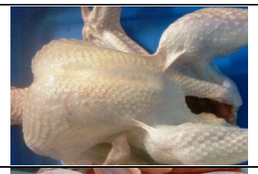
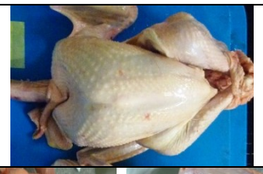
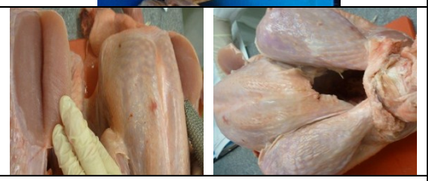
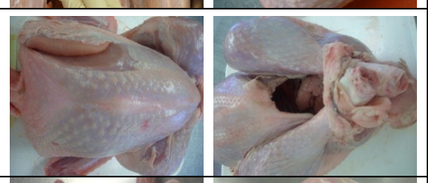
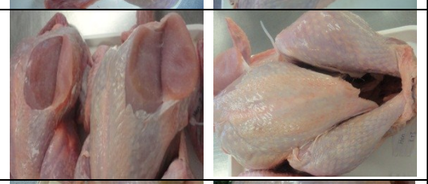
	K+3	  	Skin still slightly red similar to control. Growth developed on left leg. Quite loose skin with a rubbery texture over carcass. Slight denaturation at leaf fat area.
	K+7	  	Rubber texture to skin with a slime layer. Skin pale compared to red colour of control, but similar grey/white streaking to neck flap and leaf fat areas. Very open pores on wings. Exposed flesh still pink and moist; acceptable.
Treatment	**Day**	**Photograph** **Control** **Treated**	**Comments**
Hot water Dipped 80°C for 10 seconds then into ice bath for 20s (Stag 7)	K+0	 	Reddened skin colour with a slightly swollen appearance. Skin has a smoother texture with pores all closed. Bird weight = 15.06 kg; Temp pre-treat = 31.3°C; Into chiller at 11:30 on Day 0. Photo after ice bath.
	K+1	  	Skin slightly red, especially at neck, wings and upper breast areas, similar colour to control. Slight denaturation at anal area. Skin texture feels slightly tougher than control.
	K+2		N/A
	K+3		N/A
	K+7		N/A

Table 3: Photographs and comments on the appearance of control hen carcasses and those treated with hot water at various temperatures in Hot Water Trial 1

Treatment	Day	Photograph Control	Photograph Treated	Comments
Hot water sprayed 85°C for around 10 seconds but hose to pump burst and bird left suspended in tank in steamy environment for around 120 s . Then 20 s in ice bath. (Hen 1).	K+0			Skin slightly paler than control. Slight denaturation at neck area. Bird weight = 6.36 kg; Temp pre-treat = 41.7°C; Into chiller at 12:15 on Day 0. Photo after ice bath.
	K+1			Skin slightly dry where tail cut off as denaturation has occurred. Thigh skin more taut than control. Flesh remains acceptable.
	K+2			Neck slightly dry and rubbery texture. Denatured leaf fat area slightly paler. Skin loose at breasts. Wings developed redness.
	K+3			Neck dry and rubbery texture. Denatured leaf fat area slightly paler. Skin loose at breasts and legs. Reddened wings and adjacent breast areas.
	K+7			Neck and leaf fat areas developed redness. Skin paler than red skin of control. Slightly slimy texture compared to very slimy texture of the control. Slight browning underneath neck flap area and exposed flesh area.

Treatment	Day	Photograph Control	Photograph Treated	Comments
Hot water dipped at 80°C for 10 s , then 20 s in ice bath, and then trussed. (Hen 2)	K+0			Large split of skin between leg and main body. Photo after ice bath and trussing.
	K+1			Skin colour more yellow and slightly drier than control. Flesh still pink and moist similar to control. Trussed as easily as control bird.
	K+2			Skin particularly red and dry at neck.
	K+3			Skin particularly red and dry at neck. Skin colour less red and bruised than control.
	K+7			Skin colour remains paler red than control. Neck flap grey/white. Slight slimy texture developed but less than control. Overall, more acceptable than stags at similar treatments.

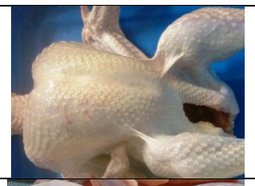
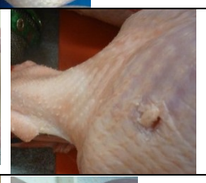
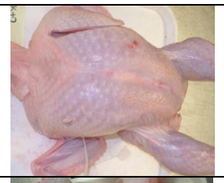
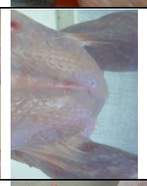
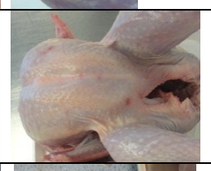
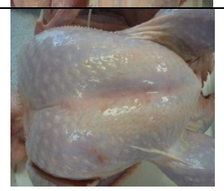
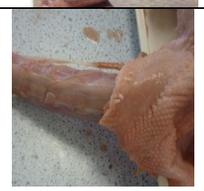
Treatment	Day	Photograph Control	Photograph Treated	Comments
Hot water dipped 80°C 10 seconds and then 20s in ice bath. (Hen 3)	K+0			Skin similar colour and appearance to control. Texture slightly smoother than control. Photo after ice bath.
	K+1		 	Skin very taut over entire carcass. Dry leaf fat area compared to control. Rubbery texture of neck flap compared to control.
	K+2		 	Slight rubbery texture around neck. Redness to skin colour around neck and wings. Skin taut on lower leg areas.
	K+3		 	Tough, dry skin texture around neck and breast areas. Skin feels rubbery at leg and breast areas.
	K+7		 	Rubber texture develops over entire carcass. Red/brown colouring at neck area, similar to control. Slimy texture developed to a lesser degree than control.

Table 4: Photographs of untreated control and hot water spray treated carcasses after 1, 3, and 7 days storage at 4ºC (Hot Water Trial 2)

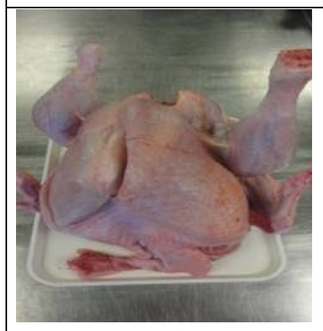
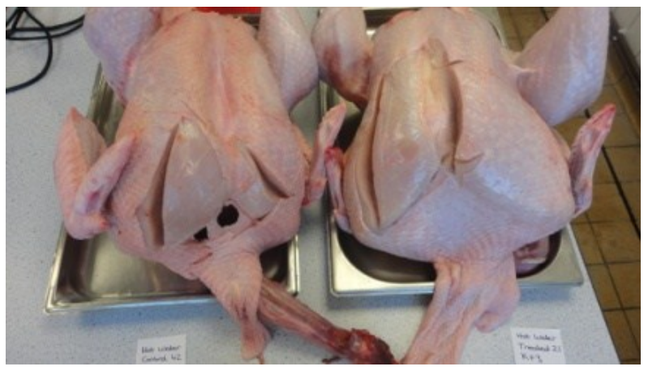
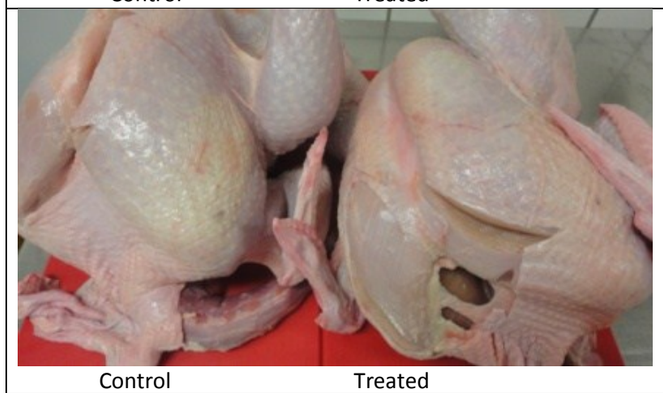
Control	Treated	Day and Comments
 Control	 Treated	Day K+1 Skin of the treated bird is beige/light brown and does not have the fresh red hue of the untreated bird.
 Control Treated		Day K+3 Skin of the treated bird is still more beige/light brown compared to the pale fresh pink colour of the untreated bird.
 Control Treated		Day K+7 Although the pigment of the untreated bird has oxidised from a pink to a brown colour, there has been greater pigment change in the treated bird.

Table 5a: Aerobic plate counts and *Campylobacter* counts on untreated control carcasses at Days K+1 and K+7 (Hot Water Trial 2)

Carcass No.	Treatment	Day 1				Day 7	
		Aerobic Plate Count per g	log(APC)	Count of confirmed Campylobacter per g	log(Campy)	Count of confirmed Campylobacter per g	log(Campy)
22	Control	23000	4.36	10	1.00	<10	0.85
23	Control	8400	3.92	<10	0.85	IN	IN
24	Control	24000	4.38	10	1.00	<10	0.85
25	Control	120000	5.08	10	1.00	<10	0.85
26	Control	210000	5.32	<10	0.85	<10	0.85
27	Control	76000	4.88	<10	0.85	<10	0.85
28	Control	85000	4.93	<10	0.85	<10	0.85
29	Control	130000	5.11	10	1.00	IN	IN
30	Control	68000	4.83	<10	0.85	<10	0.85
31	Control	39000	4.59	<10	0.85	<10	0.85
32	Control	370000	5.57	<10	0.85	<10	0.85
33	Control	460000	5.66	<10	0.85	IN	IN
34	Control	650000	5.81	10	1.00	IN	IN
35	Control	28000	4.45	30	1.48	IN	IN
36	Control	22000	4.34	<10	0.85	<10	0.85
37	Control	190000	5.28	130	2.11	<10	0.85
38	Control	85000	4.93	<10	0.85	IN	IN
39	Control	61000	4.79	<10	0.85	<10	0.85
40	Control	54000	4.73	80	1.90	<10	0.85
41	Control	85000	4.93	50	1.70	40	1.60
42	Control	35000	4.54	80	1.90	IN	IN
Av			4.88		1.12		0.90
SD			0.48		0.42		0.20
N					21		14
n<10					11		13

IN = Insufficient material available to test

Table 5b: Aerobic plate counts and *Campylobacter* counts on treated carcasses at Days K+1 and K+7 (Hot Water Trial 2)

Carcass No.	Treatment	Day 1				Day 7	
		Aerobic Plate Count per g	log(APC)	Count of confirmed Campylobacter per g	log(Campy) Control	Count of confirmed Campylobacter per g	log(Campy) Control
1	Treated	860000	5.93	<10	0.85	<10	0.85
2	Treated	110000	5.04	<10	0.85	<10	0.85
3	Treated	690000	5.84	<10	0.85	<10	0.85
4	Treated	22000	4.34	<10	0.85	<10	0.85
5	Treated	39000	4.59	<10	0.85	<10	0.85
6	Treated	110000	5.04	10	1.00	<10	0.85
7	Treated	370000	5.57	20	1.30	<10	0.85
8	Treated	310000	5.49	50	1.70	<10	0.85
9	Treated	95000	4.98	<10	0.85	<10	0.85
10	Treated	300	2.48	<10	0.85	<10	0.85
11	Treated	95000	4.98	<10	0.85	<10	0.85
12	Treated	110000	5.04	<10	0.85	<10	0.85
13	Treated	49000	4.69	<10	0.85	IN	IN
14	Treated	25000	4.40	100	2.00	IN	IN
15	Treated	240000	5.38	40	1.60	<10	0.85
16	Treated	7100	3.85	<10	0.85	IN	IN
17	Treated	95000	4.98	20	1.30	<10	0.85
18	Treated	110000	5.04	20	1.30	<10	0.85
19	Treated	7600	3.88	10	1.00	<10	0.85
20	Treated	39000	4.59	<10	0.85	IN	IN
21	Treated	95000	4.98	<10	0.85	IN	IN
Av			4.81		1.06		0.85
SD			0.77		0.34		0.00
N					21		16
n<10					13		16

IN = Insufficient material available to test

Table 6: Published data on the efficacy of steam treatments in reducing the microbial counts on poultry

Approach	Microbial Reduction log CFU(means unless otherwise stated)		Method eg Spraying	Application Point	Sampling point	Material			Conditions		Quality Acceptance	Comments	Reference	Refereed
	Organisms	Campylobacter				Type eg chicken	Portion eg whole	Contamination eg natural	Temp, ^{o}C	Time, s	Y/N			Y/N
Steam	Entero= -0.33 to 2.37 $cm^{-2;}$ Pseudo= -0.02 to 2.91 cm^{-2}	Campy=0.39 to 1.77	Cabinet	Pre-chill	Pre-chill	Chicken	Whole	Natural, breast skin	100	10	10s and 5s treatment showed differences to control. Yellow, taughter, shinier skin. Skin shrinkage. Wrinkled appearance.	Micro counts were low	Corry et al., No date	N
		C.jejuni=1.8, 2.6, 3.3 log cfu cm-2	Cabinet	Experimental	Post steam	Chicken, previously frozen	Whole	Artificial, breast skin	100	10, 12, 20	Skin shrunk and colour changed. Best condition regarded as 12s.		James et al. (2007)	Y
	TVC=0.43 and Entero=0.61 log cm-2 after 12s (no diff). TVC=0.75 and Entero=0.69 log cm^{-2} after 24s	Campy=0.46 log cm-2 after 12s (no diff); Campy=1.3 log cm^{-2} after 24s	Commercial pasteuriser	Experimental	Post steam	Chicken	Whole (cold bird)	Natural breast	90	12, 24	Visible skin damage occurred after both treatment times.		Whyte, McGill, Collins (2003)	Y
						Turkey	Turkey carcass tails, previously frozen	Natural, turkey tails	96 to 98	180 to 360	Considerable cooking of skin at 180 to 300s, and cooked appearance with browning at 360s.	Concentrated on treatments that killed/inactivated virtually all mesophiles and psychrophiles (>180s)	Avens, Morton, 1999	Y
	Listeria = 2.8 log (130^{o}C, 4.12s), 3.9 log (139^{o}C, 2.08s)		Exptl steam chamber	Experimental	Post steam	Chicken	Sections of muscle	Artificial, breast meat	100 to 150	0.08 to 1	Cooking of muscle begins after 0.08 s at 150^{o}C and after 1s at 100^{o}C. Other data in this range also given.	Very high temps used and extrapolation not possible.	Morgan et al., 1996	Y
												Considers steam treatments to reduce APC to below 10 cm^{-2}. Not concerned whether surface is cooked as material to be used in processed product. Used 96-98^{o}C for 180s. Not directly relevant.	Avens et al., 2002	Y
SonoSteam		Campy≥2.51 log cfu per carcass	SonoSteam	Post ev, pre-I/O but not on the line	Pre-chill	Chicken	Whole, or breast	Natural, rinse	100	5s inside and 10s outside	Adverse effect . Slightly boiled appearance.	Micro counts were low	Boysen, Rosenquist, 2009	Y

Table 7: Conditions used in the tests to assess the effect of treatments on appearance. The table also shows the average surface temperature of samples before treatment and maximum temperature after treatment. Some samples had a small section of skin removed to expose flesh prior to treatment.

* No thermal image taken

Bird No.	Treatment temp, °C	Treatment time, min	Bird size	Small skin section removed (Yes/No)	Average temperature pre-treatment, °C	Maximum temperature post-treatment, °C
1	125	2	Large half	No	*	*
2	125	2	Large half	No	*	53
3	125	2	Large half	No	34	52
4	150	2	Large whole	No	36	57
5	150	1	Large half	No	34	52
6	150	1	Large whole	Yes	36	56
7	130	1	Large whole	Yes	36	53
8	135	1	Large whole	No	*	55
9	135	1	Small whole	Yes	35	52
10	130	1	Small whole	Yes	36	52
11	130	0.5	Small whole	Yes	36	47
12	125	1	Small whole	Yes	36	53
13	125	0.5	Small whole	Yes	37	50
14	125	0.33	Small half	Yes	*	*
15	125	0.33	Small half	No	*	46
16	125	0.33	Small whole	No	36	44
17	115	1	Small whole	No	37	51
18	115	0.5	Small whole	No	37	48
19	115	0.5	Small half	No	37	44

Table 8: Aerobic plate counts and campylobacter counts from breast skin samples taken from chicken halves that were either treated with superheated steam at 115°C for 30 seconds or left untreated.

Bird Number	Side	Sample number	Treatment	Aerobic plate count per g	log(APC)	Campylobacter count per g	log(Campy)
1	Left	1	Untreated	110500	5.04	4280	3.63
2	Right	3	Untreated	210500	5.32	28500	4.45
3	Left	5	Untreated	237000	5.37	7700	3.89
4	Right	7	Untreated	262500	5.42	6600	3.82
5	Left	9	Untreated	87500	4.94	5130	3.71
6	Right	11	Untreated	11400	4.06	640	2.81
7	Left	13	Untreated	51000	4.71	40	1.60
8	Right	15	Untreated	158000	5.20	2270	3.36
9	Left	17	Untreated	55500	4.74	1520	3.18
10	Right	19	Untreated	34500	4.54	1040	3.02
11	Left	21	Untreated	95000	4.98	945	2.98
12	Right	23	Untreated	64500	4.81	875	2.94
13	Left	25	Untreated	76500	4.88	275	2.44
14	Right	27	Untreated	78000	4.89	620	2.79
15	Left	29	Untreated	76500	4.88	40	1.60
16	Right	31	Untreated	17850	4.25	170	2.23
17	Left	33	Untreated	205000	5.31	790	2.90
18	Right	35	Untreated	65000	4.81	85	1.93
19	Left	37	Untreated	269000	5.43	2340	3.37
20	Right	39	Untreated	126500	5.10	705	2.85
Average					4.94		2.97
S.D.					0.37		0.76
C.I.					0.17		0.35
N					20		20
n<5							0

Bird Number	Side	Sample number	Treatment	Aerobic plate count per g	log(APC)	Campylobacter count per g	log(Campy)
1	Right	2	Treated	135000	5.13	1205	3.08
2	Left	4	Treated	89500	4.95	6940	3.84
3	Right	6	Treated	241500	5.38	9500	3.98
4	Left	8	Treated	159500	5.20	5710	3.76
5	Right	10	Treated	15000	4.18	1425	3.15
6	Left	12	Treated	54500	4.74	2520	3.40
7	Right	14	Treated	66500	4.82	150	2.18
8	Left	16	Treated	64000	4.81	1310	3.12
9	Right	18	Treated	89000	4.95	70	1.85
10	Left	20	Treated	71000	4.85	2920	3.47
11	Right	22	Treated	24500	4.39	105	2.02
12	Left	24	Treated	85500	4.93	640	2.81
13	Right	26	Treated	82000	4.91	485	2.69
14	Left	28	Treated	48000	4.68	310	2.49
15	Right	30	Treated	49000	4.69	610	2.79
16	Left	32	Treated	109000	5.04	340	2.53
17	Right	34	Treated	94000	4.97	635	2.80
18	Left	36	Treated	180500	5.26	140	2.15
19	Right	38	Treated	129000	5.11	1335	3.13
20	Left	40	Treated	56500	4.75	1475	3.17
Average					4.89		2.92
S.D.					0.28		0.61
C.I.					0.13		0.28
N					20		20
n<5							0

Table 9: Published data on the efficacy of electrolysed water for reducing the microbial counts on poultry

Approach	Microbial Reduction log CFU (means unless otherwise stated)		Method eg Spraying	Application Point eg post-EV	Sampling point eg post-chill	Material			Conditions						Quality Acceptance	Comments	Reference	Refereed
	Organisms	Campylobacter				Type eg chicken	Portion eg whole	Contamination, sample	Temp, °C	Time, s	Conc, ppm	pH	ORP, mv	Presure, psi	Y/N			Y/N
Electrolysed Water	N/A	C.jejuni=3 log CFU g^{-1} with little effect of temp or time	ROX 20 for water generation and stomacher	Lab	Lab	Chicken	Wing	Artificial, wing skin	4 or 23	600 or 1800	25 or 52 ppm chlorine	2.57 to 2.95	1050 to 1092	?	?	7-log CFU ml^{-1} reduction in liquid sample in 10 s	Park et al., 2002	Y
	Psychrotrophs (relative to water spray)= 0.55 to 3.02 log cfu ml^{-1} depending on storage time. Yeast (rel to water spray)=0.66 to 1.71 log cfu ml^{-1}	N/A	Electric Aquagenics Unlimited generator and I/O washer	Pilot plant	post-I/O	Chicken (cold)	Whole bird	Natural, rinse	?	5	50 ppm chlorine	2.4	1180	80	?	Carcasses stored for 0 to 14 days at 4°C	Hinton et al., 2007	Y
	E.coli0157:H7=9 log cfu ml^{-1}		ROX20TA and JAW-020 generators	Lab	Lab	Liquid	Liquid	Artificial, liquid	24	30	56 ppm (ROX) 10 ppm (JAW)	2.6 (ROX) 2.5 (JAW)	1160 (ROX) 1123 (JAW)	N/A		Tests on liquid alone	Kim, Hung and Brackett (2000)	Y
	APC=1.34 log cfu ml-1 (immersion, Day0), 2.02 log (not sig., immersion Day7); Salmonella=0.83 log (not, sig, immersion, Day0), 0.98 (not sig., immersion, Day7). APC=no reduction (spray); Salmonella = no reduction (spray, Day0), 1.06 log (spray, Day 7).		Immersion or spray	Lab	After chilling and Day 7	Chicken	Whole bird	Artificial, rinse	4°C (immersion), 25°C (spray, 85psi)	2700s (immersion), 15s spray)	20 to 50ppm (free chlorine fater immersion <1ppm	2.6	1150			2.78 log reduction in APC and 3.81 log reduction in Salmonella achieved at 7 days by spraying basic EO and then immersing in acidic EO.	Fabrizio et al., 2002	Y
	APC=1.0 log cfu ml^{-1}; Ecoli=1.7 log; Salmonella=2.7log	Campy=1.9 log cfu ml^{-1}	Spray	pre-I/Owasher	Pilot plant	Chicken	Whole bird	Artificial, rinse	?	5,10,15	50mg/l sodium hypochlorite	2.4	1180 (Electric Aquageneics)	5		10A, 20% NaCl. 36 l/min. Increasing itme from 5 to 15 s increased log reduction by 0.3 to 1.0 log.	Northcutt et al., 2007	Y

Table 10a: Aerobic plate counts and confirmed *Campylobacter* counts on control (untreated) carcasses on Days K+1 and K+7 (Electrolysed Water Trial 1)

Sample No.	Treatment	Day 1				Day 7			
		Aerobic Plate Count per g	log(APC)	Count of confirmed Campylobacter per g	log(Campy)	Aerobic Plate Count per g	log(APC)	Count of confirmed Campylobacter per g	log(Campy)
1	Control	3,700	3.57	10	1.00	4,700,000	6.67	<10	0.85
2	Control	2,300	3.36	<10	0.85	490,000	5.69	<10	0.85
3	Control	3,600	3.56	24	1.38	150,000	5.18	<10	0.85
4	Control	4,000	3.60	<10	0.85	310,000	5.49	<10	0.85
5	Control	3,900	3.59	<10	0.85	5,800,000	6.76	<10	0.85
6	Control	5,800	3.76	<10	0.85	3,800,000	6.58	<10	0.85
7	Control	5,000	3.70	<10	0.85	770,000	5.89	<10	0.85
8	Control	7,200	3.86	<10	0.85	390,000	5.59	<10	0.85
9	Control	8,800	3.94	42	1.62	250,000	5.40	<10	0.85
10	Control	1,300	3.11	10	1.00	6,900,000	6.84	<10	0.85
11	Control	51,000	4.71	40	1.60	110,000	5.04	<10	0.85
12	Control	12,000	4.08	330	2.52	5,000,000	6.70	<10	0.85
13	Control	12,000	4.08	10	1.00	150,000	5.18	<10	0.85
14	Control	7,300	3.86	<10	0.85	500,000	5.70	<10	0.85
15	Control	11,000	4.04	176	2.25	770,000	5.89	<10	0.85
16	Control	6,500	3.81	<10	0.85	1,400,000	6.15	<10	0.85
17	Control	27,000	4.43	<10	0.85	17,000,000	7.23	<10	0.85
18	Control	65,000	4.81	70	1.85	600,000	5.78	<10	0.85
19	Control	4,800	3.68	100	2.00	290,000	5.46	<10	0.85
20	Control	44,000	4.64	<10	0.85	29,000	4.46	<10	0.85
Mean			3.91		1.24		5.88		0.85
S.D.			0.45		0.54		0.72		0.00
C.I.			0.21		0.25		0.34		0.00
N			20		20		20.00		20
n<10					10				20

Table 10b: Aerobic plate counts and confirmed *Campylobacter* counts on carcasses treated with plain water and microbiologically tested on Days K+1 and K+7 (Electrolysed Water Trial 1)

Sample No.	Treatment	Day 1				Day 7			
		Aerobic Plate Count per g	log(APC)	Count of confirmed Campylobacter per g	log(Campy)	Aerobic Plate Count per g	log(APC)	Count of confirmed Campylobacter per g	log(Campy)
21	Plain	814	2.91	<10	0.85	850,000	5.93	<10	0.85
22	Plain	7,500	3.88	<10	0.85	89,000	4.95	<10	0.85
23	Plain	552	2.74	50	1.70	3,100,000	6.49	<10	0.85
24	Plain	671	2.83	110	2.04	1,300,000	6.11	<10	0.85
25	Plain	4,900	3.69	30	1.48	1,500,000	6.18	<10	0.85
26	Plain	2,500	3.40	<10	0.85	200,000	5.30	<10	0.85
27	Plain	6,100	3.79	30	1.48	280,000,000	8.45	<10	0.85
28	Plain	1,000	3.00	<10	0.85	1,200,000	6.08	<10	0.85
29	Plain	8,900	3.95	20	1.30	7,400,000	6.87	<10	0.85
30	Plain	2,700	3.43	<10	0.85	1,400,000	6.15	<10	0.85
31	Plain	578	2.76	<10	0.85	1,200,000	6.08	<10	0.85
32	Plain	3,100	3.49	<10	0.85	1,700,000	6.23	<10	0.85
33	Plain	3,500	3.54	<10	0.85	2,800,000	6.45	<10	0.85
34	Plain	1,500	3.18	<10	0.85	710,000	5.85	<10	0.85
35	Plain	4,600	3.66	<10	0.85	4,300,000	6.63	<10	0.85
36	Plain	4,500	3.65	<10	0.85	26,000,000	7.41	<10	0.85
37	Plain	5,800	3.76	<10	0.85	15,000,000	7.18	<10	0.85
38	Plain	3,200	3.51	50	1.70	2,000,000	6.30	<10	0.85
39	Plain	61,000	4.79	<10	0.85	3,500,000	6.54	<10	0.85
40	Plain	3,100	3.49	<10	0.85	2,700,000	6.43	<10	0.85
Mean			3.47		1.08		6.38		0.85
S.D.			0.49		0.38		0.74		0.00
C.I.			0.23				0.35		
N					20				20
n<10					14				20

Table 10c: Aerobic plate counts and confirmed *Campylobacter* counts on carcasses treated with electrolysed NaCl solution and microbiologically tested on Days K+1 and K+7 (Electrolysed Water Trial 1)

Sample No.	Treatment	Day 1				Day 7			
		Aerobic Plate Count per g	log(APC)	Count of confirmed Campylobacter per g	log(Campy)	Aerobic Plate Count per g	log(APC)	Count of confirmed Campylobacter per g	log(Campy)
41	NaCl	914	2.96	<10	0.85	2,700,000	6.43	<10	0.85
42	NaCl	857	2.93	<10	0.85	120,000	5.08	<10	0.85
43	NaCl	1,300	3.11	24	1.38	600,000	5.78	<10	0.85
44	NaCl	2,500	3.40	40	1.60	2,100,000	6.32	<10	0.85
45	NaCl	2,800	3.45	258	2.41	35,000	4.54	<10	0.85
46	NaCl	743	2.87	28	1.45	320,000	5.51	<10	0.85
47	NaCl	762	2.88	<10	0.85	4,800,000	6.68	<10	0.85
48	NaCl	1,100	3.04	<10	0.85	130,000	5.11	<10	0.85
49	NaCl	1,200	3.08	70	1.85	240,000	5.38	<10	0.85
50	NaCl	1,600	3.20	100	2.00	250,000	5.40	10	1.00
51	NaCl	1,600	3.20	<10	0.85	8,500,000	6.93	<10	0.85
52	NaCl	15,000	4.18	12	1.08	17,000,000	7.23	<10	0.85
53	NaCl	2,600	3.41	72	1.86	2,700,000	6.43	<10	0.85
54	NaCl	11,000	4.04	30	1.48	190,000	5.28	<10	0.85
55	NaCl	3,600	3.56	<10	0.85	2,400,000	6.38	<10	0.85
56	NaCl	3,400	3.53	<10	0.85	79,000	4.90	<10	0.85
57	NaCl	40,000	4.60	234	2.37	2,800,000	6.45	30	1.48
58	NaCl	3,500	3.54	188	2.27	550,000	5.74	<10	0.85
59	NaCl	1,100	3.04	<10	0.85	250,000	5.40	<10	0.85
60	NaCl	1,000	3.00	<10	0.85	13,000,000	7.11	<10	0.85
Mean			3.35		1.37		5.90		0.89
S.D.			0.47		0.58		0.78		0.14
C.I.			0.22				0.38		
N					20				20
n<10					9				18

Table 10d: Aerobic plate counts and confirmed *Campylobacter* counts on carcasses treated with electrolysed $NaCO_3$ solution and microbiologically tested on Days K+1 and K+7 (Electrolysed Water Trial 1)

Sample No.	Treatment	Day 1				Day 7			
		Aerobic Plate Count per g	log(APC)	Count of confirmed Campylobacter per g	log(Campy)	Aerobic Plate Count per g	log(APC)	Count of confirmed Campylobacter per g	log(Campy)
61	$NaCO_3$	1,500	3.18	<10	0.85	260,000	5.41	<10	0.85
62	$NaCO_3$	1,300	3.11	<10	0.85	480,000	5.68	<10	0.85
63	$NaCO_3$	3,600	3.56	16	1.20	120,000	5.08	<10	0.85
64	$NaCO_3$	13,000	4.11	<10	0.85	210,000	5.32	<10	0.85
65	$NaCO_3$	4,400	3.64	<10	0.85	1,500,000	6.18	10	1.00
66	$NaCO_3$	1,900	3.28	<10	0.85	72,000	4.86	<10	0.85
67	$NaCO_3$	2,500	3.40	10	1.00	910,000	5.96	<10	0.85
68	$NaCO_3$	3,600	3.56	<10	0.85	140,000	5.15	<10	0.85
69	$NaCO_3$	1,300	3.11	<10	0.85	3,700,000	6.57	<10	0.85
70	$NaCO_3$	6,800	3.83	<10	0.85	280,000	5.45	<10	0.85
71	$NaCO_3$	5,700	3.76	<10	0.85	2,800,000	6.45	360	2.56
72	$NaCO_3$	4,400	3.64	<10	0.85	1,100,000	6.04	<10	0.85
73	$NaCO_3$	2,300	3.36	<10	0.85	3,500,000	6.54	<10	0.85
74	$NaCO_3$	2,900	3.46	<10	0.85	190,000	5.28	<10	0.85
75	$NaCO_3$	2,500	3.40	<10	0.85	5,900,000	6.77	<10	0.85
76	$NaCO_3$	795	2.90	<10	0.85	65,000	4.81	<10	0.85
77	$NaCO_3$	1,700	3.23	<10	0.85	14,000,000	7.15	<10	0.85
78	$NaCO_3$	3,500	3.54	<10	0.85	1,300,000	6.11	<10	0.85
79	$NaCO_3$	2,200	3.34	10	1.00	2,300,000	6.36	<10	0.85
80	$NaCO_3$	4,100	3.61	<10	0.85	2,800,000	6.45	10	1.00
Mean			3.45		0.88		5.88		0.95
S.D.			0.28		0.09		0.68		0.38
C.I.			0.13				0.32		
N					20				20
n<10					17				17

Table 11a: Aerobic plate counts and confirmed *Campylobacter* counts on untreated carcasses on Days K+1 and K+7 (Electrolysed Water Trial 2)

Sample No.	Treatment	Day K+2				Day K+7			
		Aerobic Plate Count per g	log(APC)	Count of confirmed Campylobacter per g	log(Campy)	Aerobic Plate Count per g	log(APC)	Count of confirmed Campylobacter per g	log(Campy)
1	No EW	44000	4.64	90	1.95	75000	4.88	<10	0.85
2	No EW	48000	4.68	10	1.00	70000	4.85	<10	0.85
3	No EW	142000	5.15	10	1.00	275000	5.44	80	1.90
4	No EW	700000	5.85	120	2.08	375000	5.57	20	1.30
5	No EW	800000	5.90	80	1.90	22500000	7.35	<10	0.85
6	No EW	900000	5.95	50	1.70	15000000	7.18	<10	0.85
7	No EW	100000	5.00	100	2.00	28000000	7.45	30	1.48
8	No EW	unavailable		80	1.90	76500000	7.88	<10	0.85
9	No EW	800000	5.90	40	1.60	6000000	6.78	10	1.00
10	No EW	580000	5.76	80	1.90	490000	5.69	10	1.00
11	No EW	46000	4.66	130	2.11	385000	5.59	10	1.00
12	No EW	200000	5.30	1670	3.22	95000	4.98	30	1.48
13	No EW	206000	5.31	120	2.08	100000	5.00	10	1.00
14	No EW	6000	3.78	110	2.04	5000	3.70	20	1.30
15	No EW	187000	5.27	100	2.00	450000	5.65	10	1.00
16	No EW	21500	4.33	10	1.00	20000	4.30	<10	0.85
17	No EW	55000	4.74	100	2.00	180000	5.26	<10	0.85
18	No EW	760000	5.88	120	2.08	1055000	6.02	<10	0.85
19	No EW	43500	4.64	190	2.28	570000	5.76	<10	0.85
20	No EW	186000	5.27	50	1.70	60000	4.78	<10	0.85
21	No EW	87000	4.94	330	2.52	330000	5.52	30	1.48
22	No EW	720000	5.86	50	1.70	9500000	6.98	10	1.00
23	No EW	unavailable		20	1.30	100000000	8.00	60	1.78
24	No EW	unavailable		50	1.70	1500000	6.18	10	1.00
25	No EW	600000	5.78	70	1.85	3120000	6.49	<10	0.85
26	No EW	800000	5.90	30	1.48	1570000	6.20	20	1.30
27	No EW	97000	4.99	1650	3.22	925000	5.97	30	1.48
28	No EW	64000	4.81	120	2.08	760000	5.88	<10	0.85
29	No EW	38500	4.59	50	1.70	560000	5.75	10	1.00
30	No EW	228000	5.36	20	1.30	1010000	6.00	<10	0.85
31	No EW	44000	4.64	120	2.08	2220000	6.35	20	1.30
32	No EW	92000	4.96	200	2.30	255000	5.41	10	1.00
33	No EW	169000	5.23	300	2.48	3450000	6.54	40	1.60
34	No EW	290000	5.46	220	2.34	1810000	6.26	<10	0.85
35	No EW	800000	5.90	40	1.60	53000000	7.72	<10	0.85
36	No EW	unavailable		80	1.90	119000000	8.08	10	1.00
Mean			**5.20**		**1.92**		**6.04**		**1.09**
S.D			**0.56**		**0.50**		**1.05**		**0.30**
C.I.			**0.20**		**0.17**		**0.36**		**0.10**
N			**32**		**36**		**36**		**36**
n<10					**0**				**15**

Table 11b: Aerobic plate counts and confirmed *Campylobacter* counts on carcasses treated with electrolysed water and microbiologically tested on Days K+1 and K+7 (Electrolysed Water Trial 2)

Sample No.	Treatment	Day K+2				Day K+7			
		Aerobic Plate Count per g	log(APC)	Count of confirmed Campylobacter per g	log(Campy)	Aerobic Plate Count per g	log(APC)	Count of confirmed Campylobacter per g	log(Campy)
37	With EW	232000	5.37	10	1.00	230000	5.36	10	1.00
38	With EW	350000	5.54	240	2.38	35000	4.54	<10	0.85
39	With EW	134000	5.13	10	1.00	12000000	7.08	<10	0.85
40	With EW	800000	5.90	20	1.30	2000000	6.30	<10	0.85
41	With EW	800000	5.90	60	1.78	12000000	7.08	10	1.00
42	With EW	274000	5.44	20	1.30	5500000	6.74	<10	0.85
43	With EW	70000	4.85	670	2.83	1550000	6.19	<10	0.85
44	With EW	47500	4.68	60	1.78	440000	5.64	30	1.48
45	With EW	246000	5.39	20	1.30	165000	5.22	<10	0.85
46	With EW	143000	5.16	80	1.90	40000	4.60	<10	0.85
47	With EW	121000	5.08	190	2.28	15000	4.18	30	1.48
48	With EW	106000	5.03	60	1.78	350000	5.54	<10	0.85
49	With EW	30500	4.48	210	2.32	10000	4.00	<10	0.85
50	With EW	580000	5.76	180	2.26	70000	4.85	<10	0.85
51	With EW	114000	5.06	50	1.70	465000	5.67	40	1.60
52	With EW	380000	5.58	100	2.00	180000	5.26	10	1.00
53	With EW	800000	5.90	180	2.26	11000000	7.04	20	1.30
54	With EW	26500	4.42	60	1.78	1335000	6.13	<10	0.85
55	With EW	101000	5.00	70	1.85	60000	4.78	<10	0.85
56	With EW	23500	4.37	80	1.90	60000	4.78	10	1.00
57	With EW	24500	4.39	80	1.90	20000	4.30	<10	0.85
58	With EW	20000	4.30	30	1.48	35000	4.54	<10	0.85
59	With EW	72000	4.86	110	2.04	145000	5.16	<10	0.85
60	With EW	350000	5.54	90	1.95	10000	4.00	<10	0.85
61	With EW	700000	5.85	70	1.85	2590000	6.41	30	1.48
62	With EW	425000	5.63	180	2.26	505000	5.70	<10	0.85
63	With EW	142000	5.15	220	2.34	425000	5.63	<10	0.85
64	With EW	45500	4.66	280	2.45	120000	5.08	20	1.30
65	With EW	800000	5.90	60	1.78	50000	4.70	<10	0.85
66	With EW	109000	5.04	210	2.32	70000	4.85	<10	0.85
67	With EW	158000	5.20	190	2.28	3780000	6.58	<10	0.85
68	With EW	117000	5.07	210	2.32	5750000	6.76	<10	0.85
69	With EW	331500	5.52	60	1.78	3500000	6.54	<10	0.85
70	With EW	28000	4.45	20	1.30	60000	4.78	<10	0.85
71	With EW	84000	4.92	140	2.15	885000	5.95	40	1.60
72	With EW	132000	5.12	330	2.52	125000	5.10	<10	0.85
Mean			**5.16**		**1.93**		**5.47**		**0.99**
S.D			**0.49**		**0.43**		**0.92**		**0.25**
C.I.			**0.16**		**0.15**		**0.31**		**0.08**
N			**36**		**36**		**36**		**36**
n<10					**0**				**25**

Table 12a: Aerobic plate counts and confirmed *Campylobacter* counts on untreated carcasses on Days K+1 and K+7 (Electrolysed Water Trial 3)

Sample No.	Treatment	Day K+2		Day K+2,3		Day K+7		Day K+8	
		Aerobic Plate Count per g	log(APC)	Count of confirmed Campylobacter per g	log(Campy)	Aerobic Plate Count per g	log(APC)	Count of confirmed Campylobacter per g	log(Campy)
1	Before EW	615000	5.79	1520	3.18	320000	5.51	50	1.70
2	Before EW	213000	5.33	320	2.51	195000	5.29	90	1.95
3	Before EW	35500	4.55	90	1.95	160000	5.20	50	1.70
4	Before EW	74000	4.87	110	2.04	115000	5.06	40	1.60
5	Before EW	66000	4.82	360	2.56	2050000	6.31	140	2.15
6	Before EW	59500	4.77	450	2.65	440000	5.64	70	1.85
7	Before EW	73500	4.87	40	1.60	2715000	6.43	20	1.30
8	Before EW	336000	5.53	840	2.92	300000	5.48	20	1.30
9	Before EW	60000	4.78	110	2.04	720000	5.86	270	2.43
10	Before EW	204000	5.31	670	2.83	235000	5.37	10	1.00
11	Before EW	79500	4.90	400	2.60	1110000	6.05	70	1.85
12	Before EW	342000	5.53	180	2.26	1315000	6.12	3600	3.56
13	Before EW	43000	4.63	1270	3.10	335000	5.53	480	2.68
14	Before EW	261500	5.42	130	2.11	240000	5.38	20	1.30
15	Before EW	244000	5.39	150	2.18	700000	5.85	10	1.00
16	Before EW	74500	4.87	90	1.95	4435000	6.65	80	1.90
17	Before EW	158000	5.20	190	2.28	1050000	6.02	90	1.95
18	Before EW	87000	4.94	280	2.45	215000	5.33	20	1.30
19	Before EW	174000	5.24	90	1.95	235000	5.37	10	1.00
20	Before EW	contaminated		40	1.60	310000	5.49	<10	0.85
21	Before EW	110000	5.04	20	1.30	2315000	6.36	10	1.00
22	Before EW	81000	4.91	500	2.70	200000	5.30	280	2.45
23	Before EW	40000	4.60	330	2.52	1500000	6.18	1300	3.11
24	Before EW	87000	4.94	30000	4.48	1490000	6.17	1180	3.07
25	Before EW	42000	4.62	130	2.11	240000	5.38	80	1.90
26	Before EW	86000	4.93	150	2.18	185000	5.27	<10	0.85
27	Before EW	57500	4.76	190	2.28	360000	5.56	90	1.95
28	Before EW	288000	5.46	120	2.08	1805000	6.26	300	2.48
29	Before EW	201000	5.30	530	2.72	805000	5.91	130	2.11
30	Before EW	310000	5.49	11000	4.04	1580000	6.20	520	2.72
31	Before EW	162000	5.21	66000	4.82	320000	5.51	1520	3.18
32	Before EW	32500	4.51	90	1.95	800000000	8.90	140	2.15
33	Before EW	48500	4.69	360	2.56	625000	5.80	60	1.78
34	Before EW	87000	4.94	650	2.81	695000	5.84	500	2.70
35	Before EW	185000	5.27	1060	3.03	375000	5.57	660	2.82
36	Before EW	79500	4.90	2360	3.37	95000	4.98	880	2.94
Mean			**5.04**		**2.55**		**5.81**		**1.99**
S.D			**0.33**		**0.75**		**0.68**		**0.74**
C.I.			**0.11**		**0.25**		**0.23**		**0.25**
N			**35**		**36**		**36**		**36**
n<10					**0**				**2**

Data highlighted in red might relate to carcasses contaminated by material from the feet

Table 12b: Aerobic plate counts and confirmed *Campylobacter* counts on carcasses treated with electrolysed water and microbiologically tested on Days K+1 and K+7 (Electrolysed Water Trial 3)

Sample No.	Treatment	Day K+2		Day K+2,3		Day K+7		Day K+8	
		Aerobic Plate Count per g	log(APC)	Count of confirmed Campylobacter per g	log(Campy)	Aerobic Plate Count per g	log(APC)	Count of confirmed Campylobacter per g	log(Campy)
37	After EW	9500	3.98	50	1.70	565000	5.75	<10	0.85
38	After EW	106000	5.03	30	1.48	13500000	7.13	50	1.70
39	After EW	367000	5.56	250	2.40	3500000	6.54	10	1.00
40	After EW	374500	5.57	70	1.85	2920000	6.47	<10	0.85
41	After EW	288000	5.46	60	1.78	1330000	6.12	170	2.23
42	After EW	115000	5.06	50	1.70	1475000	6.17	10	1.00
43	After EW	121500	5.08	380	2.58	1865000	6.27	10	1.00
44	After EW	154000	5.19	270	2.43	1210000	6.08	60	1.78
45	After EW	89500	4.95	30	1.48	1330000	6.12	50	1.70
46	After EW	66000	4.82	270	2.43	275000	5.44	60	1.78
47	After EW	64000	4.81	360	2.56	1370000	6.14	10	1.00
48	After EW	148500	5.17	120	2.08	1700000	6.23	130	2.11
49	After EW	68000	4.83	90	1.95	2495000	6.40	<10	0.85
50	After EW	92000	4.96	110	2.04	2350000	6.37	50	1.70
51	After EW	96000	4.98	160	2.20	105000	5.02	100	2.00
52	After EW	285000	5.45	300	2.48	1010000	6.00	710	2.85
53	After EW	650000	5.81	110	2.04	1225000	6.09	100	2.00
54	After EW	380000	5.58	250	2.40	220000	5.34	50	1.70
55	After EW	64000	4.81	130	2.11	2210000	6.34	30	1.48
56	After EW	44000	4.64	20	1.30	1685000	6.23	<10	0.85
57	After EW	13000	4.11	50	1.70	375000	5.57	50	1.70
58	After EW	105000	5.02	220	2.34	35000	4.54	30	1.48
59	After EW	128500	5.11	250	2.40	45000	4.65	60	1.78
60	After EW	2500	3.40	<10	0.85	1140000	6.06	340	2.53
61	After EW	113000	5.05	220	2.34	10000	4.00	140	2.15
62	After EW	42500	4.63	50	1.70	45000	4.65	30	1.48
63	After EW	3500	3.54	60	1.78	125000	5.10	30	1.48
64	After EW	31000	4.49	180	2.26	295000	5.47	50	1.70
65	After EW	62500	4.80	1070	3.03	failed to grow		50	1.70
66	After EW	274000	5.44	630	2.80	20000	4.30	190	2.28
67	After EW	206000	5.31	36000	4.56	40000	4.60	4560	3.66
68	After EW	contaminated		420	2.62	45000	4.65	80	1.90
69	After EW	40500	4.61	590	2.77	130000	5.11	2130	3.33
70	After EW	93000	4.97	410	2.61	175000	5.24	160	2.20
71	After EW	203000	5.31	290	2.46	95000	4.98	70	1.85
72	After EW	66000	4.82	520	2.72	30000	4.48	150	2.18
Mean			**4.92**		**2.22**		**5.59**		**1.77**
S.D			**0.54**		**0.62**		**0.78**		**0.66**
C.I.			**0.18**		**0.21**		**0.27**		**0.22**
N			**35**		**36**		**35**		**36**
n<10					**1**				**4**

Data highlighted in red might relate to carcasses contaminated by material from the feet

Table 13a: Weights of carcasses treated with plain water and the properties of that water (Electrolysed Water Trial 4)

PLAIN WATER

Bird No.	Purpose	Chiller temp, C	Temp of liquid applied, C	pH of liquid applied	ORP of liquid applied, mV	Free chlorine in liquid applied, ppm	Total chlorine in liquid applied, ppm	Bird temp exit chill, C	Weight of carcass, g	Comments
1	Micro	3.2	12.9	7.5	426	0.11	0.33	4.1	1646	Water sample taken from tank before spray
2	Micro	3.1	13.1	7.89	130	0.15	0.46		1822	Water sample taken from washer before spray
3	Micro								1722	
4	Micro								1136	
5	Micro								1681	
6	Micro								1900	
7	Micro								1915	
8	Micro								1634	
9	Micro								1716	
10	Micro								1334	
11	Micro								1825	
12	Micro								1363	
13	Micro								1859	
14	Micro								1546	
15	Micro								1874	
16	Micro								1413	
17	Micro								1643	
18	Micro								1532	
19	Micro	3.1	12.9	7.55	446	0.15	0.2		1818	Water sample taken from tank during spray
20	Micro								1708	
21	Micro								1837	
22	Micro								1723	
23	Micro								1733	
24	Micro								1652	
25	Micro								1165	
26	Micro								2096	
27	Micro								1633	
28	Micro								1631	
29	Micro								1593	
30	Micro								2016	
31	Micro								1261	
32	Micro								1763	
33	Micro								1833	
34	Micro								1351	
35	Micro								1627	
36	Micro	3.3	13.0	7.95	130	0.11	0.37		1790	Water sample taken from washer during spray
S1	Photo*								1712	
S2	Reserve								1706	
Mean									1663	
S.D.									220	

* Photograph beside elec and no water birds on Days 0, 3, and 7

Table 13b: Weights of carcasses treated with electrolysed water and the properties of that water (Electrolysed Water Trial 4)

ELEC WATER										
ORP 735mV measured by priot to trial										
Bird No.	Purpose	Chiller temp, C	Temp of liquid applied, C	pH of liquid applied	ORP of liquid applied, mV	Free chlorine in liquid applied, ppm	Total chlorine in liquid applied, ppm	Bird exit chill, C	Weight of carcass, g	Comments
37	Micro	3.4	12.4	7.72	574	1.4	1.83		1801	Water sample taken from tank before spray
38	Micro	4.1	9.2	7.93	143	0.36	0.56		1630	Water sample taken from washer before spray
39	Micro								1651	
40	Micro								1432	* Breast quite red
41	Micro								1272	
42	Micro								1685	
43	Micro								1435	
44	Micro								2025	
45	Micro								2078	
46	Micro								1357	
47	Micro								1579	
48	Micro								1507	
49	Micro								1519	
50	Micro								1799	
51	Micro								1692	
52	Micro								1755	
53	Micro								1519	
54	Micro								1726	
55	Micro	3.4	12.6	7.71	622	1.4	1.57		1315	Water sample taken from tank during spray
56	Micro	4.2	9.4	7.91	208	0.35	0.85		1911	Water sample taken from washer during spray
57	Micro								1557	
58	Micro								1349	
59	Micro								1186	
60	Micro								1501	
61	Micro								1672	
62	Micro								1311	
63	Micro								1570	
64	Micro								1692	
65	Micro								1629	
66	Micro								1732	
67	Micro								1352	
68	Micro								1780	
69	Micro								1624	
70	Micro								1717	
71	Micro								1838	
72	Micro	3.3	12.5	7.70	697	1.05	1.79		1678	Water sample taken from tank after spray
S3	Photo*				730				1579	Water sample taken from tank after spray
S4	Reserve								2021	
Mean									1618	
S.D.									212	
* Photograph beside plain and no water birds on Days 0, 3, and 7										

Table 13c: Weights carcasses that were not sprayed (Electrolysed Water Trial 4)

NO WATER		
Bird No.	Purpose	Weight of carcass, g
73	Micro	1622
74	Micro	1359
75	Micro	1714
76	Micro	1129
77	Micro	2030
78	Micro	1843
79	Micro	1991
80	Micro	2027
81	Micro	1337
82	Micro	1477
83	Micro	1543
84	Micro	1897
85	Micro	1928
86	Micro	1698
87	Micro	1698
88	Micro	1548
89	Micro	1482
90	Micro	1913
91	Micro	1820
92	Micro	2062
93	Micro	1936
94	Micro	1910
95	Micro	1910
96	Micro	1778
97	Micro	1611
98	Micro	2076
99	Micro	1880
100	Micro	1722
101	Micro	1836
102	Micro	1609
103	Micro	1392
104	Micro	1890
105	Micro	1617
106	Micro	1520
107	Micro	1581
108	Micro	1363
S5	Photo*	1639
S6	Reserve	1875
Mean		1717
S.D.		233

* Photograph beside plain and elec water birds on Days 0, 3, and 7

Table 14a: Aerobic plate counts and confirmed *Campylobacter* counts at Days 1 and 7 on carcasses treated with plain water (Electrolysed Water Trial 4)

Sample No.	Treatment	Day K+2				Day K+7			
		Aerobic Plate Count per g	log(APC)	Count of confirmed Campylobacter per g	log(Campy)	Aerobic Plate Count per g	log(APC)	Count of confirmed Campylobacter per g	log(Campy)
1	No EW	44000	4.64	90	1.95	75000	4.88	<10	0.85
2	No EW	48000	4.68	10	1.00	70000	4.85	<10	0.85
3	No EW	142000	5.15	10	1.00	275000	5.44	80	1.90
4	No EW	700000	5.85	120	2.08	375000	5.57	20	1.30
5	No EW	800000	5.90	80	1.90	22500000	7.35	<10	0.85
6	No EW	900000	5.95	50	1.70	15000000	7.18	<10	0.85
7	No EW	100000	5.00	100	2.00	28000000	7.45	30	1.48
8	No EW	unavailable		80	1.90	76500000	7.88	<10	0.85
9	No EW	800000	5.90	40	1.60	6000000	6.78	10	1.00
10	No EW	580000	5.76	80	1.90	490000	5.69	10	1.00
11	No EW	46000	4.66	130	2.11	385000	5.59	10	1.00
12	No EW	200000	5.30	1670	3.22	95000	4.98	30	1.48
13	No EW	206000	5.31	120	2.08	100000	5.00	10	1.00
14	No EW	6000	3.78	110	2.04	5000	3.70	20	1.30
15	No EW	187000	5.27	100	2.00	450000	5.65	10	1.00
16	No EW	21500	4.33	10	1.00	20000	4.30	<10	0.85
17	No EW	55000	4.74	100	2.00	180000	5.26	<10	0.85
18	No EW	760000	5.88	120	2.08	1055000	6.02	<10	0.85
19	No EW	43500	4.64	190	2.28	570000	5.76	<10	0.85
20	No EW	186000	5.27	50	1.70	60000	4.78	<10	0.85
21	No EW	87000	4.94	330	2.52	330000	5.52	30	1.48
22	No EW	720000	5.86	50	1.70	9500000	6.98	10	1.00
23	No EW	unavailable		20	1.30	100000000	8.00	60	1.78
24	No EW	unavailable		50	1.70	1500000	6.18	10	1.00
25	No EW	600000	5.78	70	1.85	3120000	6.49	<10	0.85
26	No EW	800000	5.90	30	1.48	1570000	6.20	20	1.30
27	No EW	97000	4.99	1650	3.22	925000	5.97	30	1.48
28	No EW	64000	4.81	120	2.08	760000	5.88	<10	0.85
29	No EW	38500	4.59	50	1.70	560000	5.75	10	1.00
30	No EW	228000	5.36	20	1.30	1010000	6.00	<10	0.85
31	No EW	44000	4.64	120	2.08	2220000	6.35	20	1.30
32	No EW	92000	4.96	200	2.30	255000	5.41	10	1.00
33	No EW	169000	5.23	300	2.48	3450000	6.54	40	1.60
34	No EW	290000	5.46	220	2.34	1810000	6.26	<10	0.85
35	No EW	800000	5.90	40	1.60	53000000	7.72	<10	0.85
36	No EW	unavailable		80	1.90	119000000	8.08	10	1.00
Mean			**5.20**		**1.92**		**6.04**		**1.09**
S.D			**0.56**		**0.50**		**1.05**		**0.30**
C.I.			**0.20**		**0.17**		**0.36**		**0.10**
N			**32**		**36**		**36**		**36**
n<10					**0**				**15**

Table 14b: Aerobic plate counts and confirmed *Campylobacter* counts at Days 1 and 7 on carcasses treated with electrolysed water (Electrolysed Water Trial 4)

Sample No.	Treatment	Day 1				Day 7			
		Aerobic Plate Count per g	log(APC)	Count of confirmed Campylobacter per g	log(Campy)	Aerobic Plate Count per g	log(APC)	Count of confirmed Campylobacter per g	log(Campy)
37	**Elec Water**	110,000	5.04	160	2.20	34,000,000	7.53	10	1.00
38	**Elec Water**	99,000	5.00	368	2.57	45,000,000	7.65	<10	0.85
39	**Elec Water**	160,000	5.20	<10	0.85	55,000,000	7.74	<10	0.85
40	**Elec Water**	250,000	5.40	48	1.68	25,000,000	7.40	<10	0.85
41	**Elec Water**	150,000	5.18	48	1.68	29,000,000	7.46	<10	0.85
42	**Elec Water**	66,000	4.82	60	1.78	36,000,000	7.56	352	2.55
43	**Elec Water**	150,000	5.18	20	1.30	20,000,000	7.30	50	1.70
44	**Elec Water**	140,000	5.15	88	1.94	120,000,000	8.08	<10	0.85
45	**Elec Water**	120,000	5.08	<10	0.85	41,000,000	7.61	<10	0.85
46	**Elec Water**	450,000	5.65	240	2.38	100,000,000	8.00	<10	0.85
47	**Elec Water**	470,000	5.67	50	1.70	110,000,000	8.04	10	1.00
48	**Elec Water**	340,000	5.53	<10	0.85	260,000,000	8.41	<10	0.85
49	**Elec Water**	320,000	5.51	66	1.82	200,000,000	8.30	200	2.30
50	**Elec Water**	200,000	5.30	<10	0.85	780,000,000	8.89	10	1.00
51	**Elec Water**	250,000	5.40	10	1.00	4,800,000	6.68	<10	0.85
52	**Elec Water**	120,000	5.08	20	1.30	78,000,000	7.89	<10	0.85
53	**Elec Water**	97,000	4.99	40	1.60	25,000,000	7.40	<10	0.85
54	**Elec Water**	150,000	5.18	200	2.30	2,500,000	6.40	20	1.30
55	**Elec Water**	570,000	5.76	150	2.18	67,000,000	7.83	10	1.00
56	**Elec Water**	89,000	4.95	<10	0.85	160,000,000	8.20	<10	0.85
57	**Elec Water**	290,000	5.46	128	2.11	60,000,000	7.78	20	1.30
58	**Elec Water**	220,000	5.34	54	1.73	76,000,000	7.88	10	1.00
59	**Elec Water**	83,000	4.92	240	2.38	100,000,000	8.00	<10	0.85
60	**Elec Water**	97,000	4.99	10	1.00	44,000,000	7.64	<10	0.85
61	**Elec Water**	560,000	5.75	<10	0.85	110,000,000	8.04	<10	0.85
62	**Elec Water**	53,000	4.72	10	1.00	25,000,000	7.40	<10	0.85
63	**Elec Water**	69,000	4.84	<10	0.85	19,000,000	7.28	<10	0.85
64	**Elec Water**	150,000	5.18	90	1.95	7,600,000	6.88	<10	0.85
65	**Elec Water**	100,000	5.00	80	1.90	41,000,000	7.61	<10	0.85
66	**Elec Water**	110,000	5.04	33	1.52	42,000,000	7.62	<10	0.85
67	**Elec Water**	56,000	4.75	20	1.30	140,000,000	8.15	<10	0.85
68	**Elec Water**	140,000	5.15	60	1.78	180,000,000	8.26	30	1.48
69	**Elec Water**	150,000	5.18	20	1.30	1,000,000,000	9.00	10	1.00
70	**Elec Water**	230,000	5.36	48	1.68	1,000,000,000	9.00	10	1.00
71	**Elec Water**	130,000	5.11	30	1.48	80,000,000	7.90	<10	0.85
72	**Elec Water**	330,000	5.52	144	2.16	92,000,000	7.96	30	1.48
Mean			5.20		1.57		7.80		1.05
S.D.			0.28		0.53		0.56		0.40
C.I.			0.09		0.18		0.19		0.14
N			36		36		36		36
n<10					7				22

Table 14c: Aerobic plate counts and confirmed *Campylobacter* counts at Days 1 and 7 on carcasses that were not treated by spraying (Electrolysed Water Trial 4)

Sample No.	Treatment	Day 1				Day 7			
		Aerobic Plate Count per g	log(APC)	Count of confirmed Campylobacter per g	log(Campy)	Aerobic Plate Count per g	log(APC)	Count of confirmed Campylobacter per g	log(Campy)
73	**No Water**	120,000	5.08	64	1.81	32,000,000	7.51	60	1.78
74	**No Water**	88,000	4.94	48	1.68	520,000,000	8.72	<10	0.85
75	**No Water**	220,000	5.34	90	1.95	42,000,000	7.62	50	1.70
76	**No Water**	190,000	5.28	80	1.90	42,000,000	7.62	60	1.78
77	**No Water**	22,000	4.34	10	1.00	81,000,000	7.91	<10	0.85
78	**No Water**	60,000	4.78	104	2.02	130,000,000	8.11	<10	0.85
79	**No Water**	71,000	4.85	20	1.30	180,000,000	8.26	10	1.00
80	**No Water**	58,000	4.76	40	1.60	190,000,000	8.28	10	1.00
81	**No Water**	53,000	4.72	100	2.00	30,000,000	7.48	<10	0.85
82	**No Water**	50,000	4.70	90	1.95	130,000,000	8.11	<10	0.85
83	**No Water**	50,000	4.70	72	1.86	400,000,000	8.60	10	1.00
84	**No Water**	66,000	4.82	120	2.08	60,000,000	7.78	<10	0.85
85	**No Water**	120,000	5.08	104	2.02	12,000,000	7.08	50	1.70
86	**No Water**	68,000	4.83	72	1.86	13,000,000	7.11	<10	0.85
87	**No Water**	120,000	5.08	<10	0.85	12,000,000	7.08	<10	0.85
88	**No Water**	74,000	4.87	180	2.26	94,000,000	7.97	10	1.00
89	**No Water**	110,000	5.04	240	2.38	140,000	5.15	30	1.48
90	**No Water**	71,000	4.85	30	1.48	450,000,000	8.65	10	1.00
91	**No Water**	150,000	5.18	<10	0.85	30,000,000	7.48	<10	0.85
92	**No Water**	47,000	4.67	50	1.70	41,000,000	7.61	<10	0.85
93	**No Water**	140,000	5.15	120	2.08	28,000,000	7.45	30	1.48
94	**No Water**	120,000	5.08	<10	0.85	230,000,000	8.36	<10	0.85
95	**No Water**	250,000	5.40	50	1.70	110,000,000	8.04	<10	0.85
96	**No Water**	160,000	5.20	72	1.86	34,000,000	7.53	<10	0.85
97	**No Water**	120,000	5.08	<10	0.85	52,000,000	7.72	30	1.48
98	**No Water**	85,000	4.93	10	1.00	9,300,000	6.97	<10	0.85
99	**No Water**	120,000	5.08	20	1.30	16,000,000	7.20	<10	0.85
100	**No Water**	110,000	5.04	<10	0.85	25,000,000	7.40	<10	0.85
101	**No Water**	78,000	4.89	10	1.00	2,300,000	6.36	<10	0.85
102	**No Water**	33,000	4.52	<10	0.85	1,800,000	6.26	<10	0.85
103	**No Water**	59,000	4.77	<10	0.85	27,000,000	7.43	<10	0.85
104	**No Water**	69,000	4.84	<10	0.85	20,000,000	7.30	<10	0.85
105	**No Water**	56,000	4.75	<10	0.85	27,000,000	7.43	10	1.00
106	**No Water**	45,000	4.65	<10	0.85	150,000,000	8.18	<10	0.85
107	**No Water**	45,000	4.65	10	1.00	180,000,000	8.26	40	1.60
108	**No Water**	41,000	4.61	<10	0.85	25,000,000	7.40	10	1.00
Mean			4.90		1.45		7.59		1.05
S.D.			0.24		0.52		0.71		0.32
C.I.			0.08		0.18		0.24		0.11
N			36		36		36		36
n<10					11		0		21

Table 15: Summary of the results from the trials with electrolysed water

Trial	Bird	Chemical	Free Cl ppm	Best Campylobacter Reduction
1	Chicken	Plain water	0.1	None
1	Chicken	NaCl	0.2	None
1	Chicken	Na_2CO_3	0.2	0.2-log
2	Chicken	NaCl	16.7 and 18.4	0.1-log
3	Turkey	NaCl	7.0	0.3-log
4	Chicken	Plain water	0.1	None
4	Chicken	NaCL	1.2	None

Table 16: Published data on the efficacy of chlorine/chlorine dioxide for reducing the microbial counts on poultry

Approach	Microbial Reduction log CFU(means unless otherwise stated)		Method eg Spraying	Application Point eg post-EV	Sampling point eg post-chill	Material			Conditions						Quality Acceptance	Comments	Reference	Refereed
	Organisms	Campylobacter				Type eg chicken	Portion eg whole	Contamination, sample	Temp, ^{o}C	Time, s	Conc, ppm	pH	ORP, mv	Pressure, psi	Y/N			Y/N
Chlorinated water	N/A	C.jejuni=2.6 to 3 log CFU g^{-1} with little effect of temp or time	Stomacher	Lab	Lab	Chicken	Wing	Artificial, wing skin	4 or 23	600 or 1800	26 or 53 ppm chlorine	2.97 to 3.22	990 to 1046	?	?	7-log CFU ml^{-1} reduction in liquid sample in 10 s	Park et al., 2002	Y
	Psychrotrophs (relative to water spray)= 0.55 to 2.41 log cfu ml^{-1} depending on storage time. Yeast (rel to water spray)=0.27 to 0.78 log cfu ml^{-1}	N/A	I/O washer	Pilot plant	post-I/O	Chicken (cold)	Whole bird	Natural, rinse	?	5	50 ppm chlorine	8.2		80	?	Carcasses stored for 0 to 14 days at $4^{o}C$	Hinton et al., 2007	Y
	E.coli0157:H7=9 log cfu ml^{-1}		Tipping	Lab	Lab	Liquid	Liquid	Artificial, liquid	24	30	13 or 60	3.9 or 2.9	1160 or 998	N/A	N/A	Tests on liquid alone	Kim, Hung and Brackett (2000)	Y
			Water in chiller	Water chiller	post-chiller											Tests chiller water show that 7 times more chlorine is required than ClO_2 for the same bactericidal effect	Lillard (1979)	Y
	APC=No reduction achieved by washing relative to natural control but it did remove artificial contamination	Campy=No reduction achieved by washing relative to natural control but it did remove artificial contamination.	Spraying	Pilot I/O washer		Chicken	Whole	Natural and artificial, rinse	21 to 54	5	0 or 50	7.4 to 7.6 (0.5ppm); 8.2 to 8.3 (50ppm)		80 psi	No effect of chlorine or temperature on colour		Northcutt et al., 2005	Y
	Salmonella not irradicated by any of the treatments		Immersion	Lab	Post-treatment	Turkey	Drumsticks	Artificial, broth	21	10800s (1487 to 3400ppm); 32400s (2125 to 3400ppm); 86400 (1700 to 2125 ppm)	1487 to 3400				Less than 2550 ppm for 3 hours did not change the colour of the skin but, after 9 hours, drumsticks were yellow, with a greasy film, and soft		Teoria, Miller, 1975	Y
	APC=0.7 log cfu ml^{-1}; Ecoli=1.5 log; Salmonella=2.4 log	Campy=1.6 log cfu ml^{-1}	Spray	pre-I/Owasher	Pilot plant	Chicken	Whole bird	Artificial, rinse	?	5,10,15	50mg/l sodium hypochlorite	8		5	Increasing time from 5 to 15 s increased log reduction by 0.3 to 1.0 log		Northcutt et al., 2007	Y

	APC=1.17 log (immersion, Day0), 1.1 (not sig, immersion Day7); Salmonella=no diff at Day 0 or 7 (immersion); APC = no diff (spray, Dauy0 and 7), Salmonella = 0.83 and 1.36 (Days 0 and 7, spray)		Immersion or spray	Lab	After chilling and Day 7	Chicken	Whole bird	Artificial, rinse	4°C (immersion), 25°C (spray, 85psi)	2700s (immersion), 15s spray)	20ppm	9.0 reducing to 6.7 post-treatment					Fabrizio et al., 2002	Y
		Average for all plant: Campy=0.5 log cfu ml^{-1}	Washers, sprays, chill tanks	Washers, sprays, chill tanks	Before and after 3 carcass washers and chill tank; or post-ev, after washer, after antimicrobial, after chill tank	Chicken	Whole bird	Natural, rinse			25 to 35 ppm					Looked at birds from four processing plants using chlorinated water in the post-ev washers. Concluded that carcass wash systems with multiple washers have minimal effect on Campy populations when using chlorinated water.	Bashor et al., 2004	Y
	APC=2.4 log cfu ml^{-1}; Coliforms=2.8 log; E.coli=2.9 log; 79% reduced incidence of Salmonella		New York wash, post ev wash, 2x I/O wash, ClO2 wash, ClO2 wash+chlorine chiller, chiller exit spray, post chiller wash			Chicken	Whole and parts	Natural, rinse			20 to 50ppm in NY wash, post ev wash, I/O washes; 50 to 150ppm sodium chlorite and 20 to 50ppm chlorine in CLO2-Cl2 chiller					Commercial plant. Included here to show effect of multiple applications of chlorinated water.	Stopforth et al., 2007	Y
Chlorine dioxide		C.jejuni=0.7-log using ClO_2 and 0.35-log using water									4.25 ppm ClO_2						Bolder et al., 2007	Y

		Campy=0.99 to 1.21 log								600s	50 to 100 ppm ClO_2						Hong et al., 2007	Y
		No significant effect on Campylobacter numbers															Corry et al., 2008	N

Table 17a: Weights of birds and properties of the water when no chlorine dioxide was added to the holding tank (Chlorine Dioxide Trial)

Bird No.	Room temp, C	Temp of liquid applied, C	pH of liquid applied	Free Chlorine in liquid applied, ppm	Total Chlorine in liquid applied, ppm	Chlorine dioxide residual, mg/l chlorine	Chlorine dioxide residual, mg/l ClO2	Bird temp after spray, C	Weight with tag after chiller, g
37	17.4	10.9	7.52	0.50	0.71	3.15	1.197	2.0	1566
38									1617
39									1490
40									1730
41									1524
42									1264
43									1669
44									1464
45									1488
46									1546
47									1688
48									1281
49									1779
50									1395
51									1646
52									1739
53									1419
54									1708
55	18.4	12.1	7.56	0.52	0.72	3.65	1.387	2.1	1245
56									1359
57									1229
58									1589
59									1649
60									1561
61									1629
62									1838
63									1245
64									1654
65									1691
66									1509
67									1635
68									1476
69									1643
70									1419
71									1386
72	18.2	12.0	7.34	0.45	0.69	2.40	0.91	2.3	1833
Average	18.0	11.7	7.47	0.49	0.71	3.07	1.17	2.1	1545
Min	17.4	10.9	7.34	0.45	0.69	2.40	0.91	2.0	1229
Max	18.4	12.1	7.56	0.52	0.72	3.65	1.39	2.3	1838
S.D.	0.5	0.7	0.12	0.04	0.02	0.63	0.239078	0.2	170

Table 17b: Weights of birds and properties of the water when chlorine dioxide was added to the holding tank (Chlorine Dioxide Trial)

Bird No.	Room temp, C	Temp of liquid applied, C	pH of liquid applied	ORP of liquid applied, mV	Free Chlorine in liquid applied, ppm	Total Chlorine in liquid applied, ppm	Chlorine dioxide residual, mg/l chlorine	Chlorine dioxide residual, mg/l ClO_2	Bird temp after spray, C	Weight of bird after chiller, g
1	19.5	11.5	7.18	6.0	0.47	0.67	2.95	1.121	2.3	1306
2										1320
3										1980
4										1625
5										1521
6										1370
7										1364
8										1191
9										1786
10										1584
11										2010
12										1930
13										2079
14										1722
15										1702
16										1754
17										1778
18										1956
19	19.6	11.7	7.21	5	0.47	0.72	2.7	1.026		1602
20										1872
21										1492
22										1792
23										1799
24										1568
25										1603
26										1331
27										1557
28										1528
29										1745
30										1712
31										1464
32										1688
33										1961
34										1783
35										1286
36	19.6	11.8	7.49	8.0	0.52	0.71	2.65	1.01	2.2	1349
Average	19.6	11.7	7.29	6.3	0.49	0.70	2.77	1.05	2.3	1642
Min	19.5	11.5	7.18	5.0	0.47	0.67	2.65	1.01	2.2	1191
Max	19.6	11.8	7.49	8.0	0.52	0.72	2.95	1.12	2.3	2079
S.D.	0.1	0.2	0.17	1.5	0.03	0.03	0.16	0.06	0.1	233

Table 18a: Aerobic plate counts and confirmed *Campylobacter* counts on untreated carcasses on Days K+1 and K+7 (Chlorine Dioxide Trial)

Bird No.	Treatment	Day K+1				Day K+7			
		Aerobic plate count per g	log(APC)	Count of confirmed Campylobacter per g	log(Campy)	Aerobic plate count per g	log(APC)	Count of confirmed Campylobacter per g	log(Campy)
37	Untreated	240000	5.38	30	1.48	1172000000	9.07	60	1.78
38	Untreated	460000	5.66	150	2.18	1800000000	9.26	30	1.48
39	Untreated	375000	5.57	160	2.20	1020000000	9.01	20	1.30
40	Untreated	195000	5.29	120	2.08	464000000	8.67	30	1.48
41	Untreated	135000	5.13	520	2.72	1310000000	9.12	40	1.60
42	Untreated	280000	5.45	210	2.32	1352000000	9.13	40	1.60
43	Untreated	90000	4.95	200	2.30	1356000000	9.13	90	1.95
44	Untreated	200000	5.30	590	2.77	1432000000	9.16	870	2.94
45	Untreated	250000	5.40	320	2.51	1720000000	9.24	60	1.78
46	Untreated	50000	4.70	340	2.53	1718000000	9.24	730	2.86
47	Untreated	35000	4.54	230	2.36	1410000000	9.15	50	1.70
48	Untreated	355000	5.55	260	2.41	1748000000	9.24	160	2.20
49	Untreated	55000	4.74	240	2.38	500000000	8.70	60	1.78
50	Untreated	70000	4.85	1840	3.26	1520000000	9.18	490	2.69
51	Untreated	245000	5.39	380	2.58	1162000000	9.07	260	2.41
52	Untreated	180000	5.26	220	2.34	608000000	8.78	90	1.95
53	Untreated	485000	5.69	630	2.80	1160000000	9.06	30	1.48
54	Untreated	255000	5.41	6900	3.84	591000000	8.77	1040	3.02
55	Untreated	125000	5.10	190	2.28	804000000	8.91	110	2.04
56	Untreated	60000	4.78	170	2.23	1200000000	9.08	30	1.48
57	Untreated	105000	5.02	210	2.32	1680000000	9.23	100	2.00
58	Untreated	55000	4.74	50	1.70	1230000000	9.09	40	1.60
59	Untreated	185000	5.27	370	2.57	1230000000	9.09	40	1.60
60	Untreated	70000	4.85	990	3.00	1328000000	9.12	540	2.73
61	Untreated	425000	5.63	120	2.08	1096000000	9.04	20	1.30
62	Untreated	775000	5.89	270	2.43	1960000000	9.29	70	1.85
63	Untreated	410000	5.61	290	2.46	1372000000	9.14	380	2.58
64	Untreated	750000	5.88	170	2.23	948000000	8.98	60	1.78
65	Untreated	190000	5.28	80	1.90	1500000000	9.18	100	2.00
66	Untreated	385000	5.59	60	1.78	852000000	8.93	130	2.11
67	Untreated	45000	4.65	10	1.00	1320000000	9.12	50	1.70
68	Untreated	135000	5.13	4960	3.70	1440000000	9.16	50	1.70
69	Untreated	55000	4.74	260	2.41	1440000000	9.16	40	1.60
70	Untreated	110000	5.04	210	2.32	1960000000	9.29	20	1.30
71	Untreated	115000	5.06	420	2.62	1620000000	9.21	230	2.36
72	Untreated	95000	4.98	150	2.18	1990000000	9.30	30	1.48
Average			5.21		2.40		9.09		1.92
S.D.			0.36		0.53		0.16		0.49
C.I.			0.12		0.18		0.05		0.16
N			36		36		36		36
n<10					0				0

Table 18b: Aerobic plate counts and confirmed *Campylobacter* counts on carcasses treated with electrolysed water and microbiologically tested on Days K+1 and K+7 (Chlorine Dioxide Trial)

Bird No.	Treatment	Day K+1				Day K+7			
		Aerobic plate count per g	log(APC)	Count of confirmed Campylobacter per g	log(Campy)	Aerobic plate count per g	log(APC)	Count of confirmed Campylobacter per g	log(Campy)
1	Treated	85000	4.93	430	2.63	522000000	8.72	40	1.60
2	Treated	50000	4.70	390	2.59	1920000000	9.28	30	1.48
3	Treated	55000	4.74	660	2.82	1204000000	9.08	30	1.48
4	Treated	145000	5.16	350	2.54	1580000000	9.20	60	1.78
5	Treated	150000	5.18	270	2.43	528000000	8.72	90	1.95
6	Treated	280000	5.45	730	2.86	1850000000	9.27	160	2.20
7	Treated	105000	5.02	200	2.30	908000000	8.96	50	1.70
8	Treated	135000	5.13	450	2.65	1270000000	9.10	40	1.60
9	Treated	310000	5.49	490	2.69	1168000000	9.07	300	2.48
10	Treated	110000	5.04	760	2.88	1024000000	9.01	40	1.60
11	Treated	65000	4.81	500	2.70	1330000000	9.12	90	1.95
12	Treated	70000	4.85	430	2.63	908000000	8.96	230	2.36
13	Treated	160000	5.20	470	2.67	1348000000	9.13	70	1.85
14	Treated	130000	5.11	430	2.63	1309000000	9.12	70	1.85
15	Treated	180000	5.26	620	2.79	1640000000	9.21	50	1.70
16	Treated	115000	5.06	350	2.54	1660000000	9.22	40	1.60
17	Treated	140000	5.15	160	2.20	1234000000	9.09	310	2.49
18	Treated	145000	5.16	190	2.28	1482000000	9.17	200	2.30
19	Treated	45000	4.65	840	2.92	1144000000	9.06	1010	3.00
20	Treated	20000	4.30	590	2.77	1560000000	9.19	20	1.30
21	Treated	175000	5.24	160	2.20	816000000	8.91	40	1.60
22	Treated	270000	5.43	400	2.60	2210000000	9.34	150	2.18
23	Treated	90000	4.95	290	2.46	1506000000	9.18	210	2.32
24	Treated	1000000	6.00	390	2.59	1200000000	9.08	130	2.11
25	Treated	110000	5.04	190	2.28	1810000000	9.26	60	1.78
26	Treated	185000	5.27	210	2.32	2000000000	9.30	170	2.23
27	Treated	125000	5.10	110	2.04	746000000	8.87	50	1.70
28	Treated	230000	5.36	400	2.60	1132000000	9.05	60	1.78
29	Treated	470000	5.67	130	2.11	1770000000	9.25	60	1.78
30	Treated	75000	4.88	400	2.60	1860000000	9.27	30	1.48
31	Treated	85000	4.93	170	2.23	1600000000	9.20	<10	0.85
32	Treated	70000	4.85	1370	3.14	730000000	8.86	10	1.00
33	Treated	85000	4.93	310	2.49	1520000000	9.18	190	2.28
34	Treated	170000	5.23	680	2.83	1600000000	9.20	130	2.11
35	Treated	180000	5.26	1720	3.24	1388000000	9.14	620	2.79
36	Treated	255000	5.41	350	2.54	1690000000	9.23	20	1.30
Average			5.11		2.58		9.11		1.88
S.D.			0.31		0.27		0.15		0.46
C.I.			0.10		0.09		0.05		0.16
N			36		36		36		36
n<10					0				1

Table 19: Published data on the efficacy of electro-oxidation of process water for reducing the microbial counts on poultry

Approach	Microbial Reduction log CFU(means unless otherwise stated)		Method eg Spraying	Application Point eg post-EV	Sampling point eg post-chill	Material			Conditions						Quality Acceptance	Comments	Reference	Refereed
	Organisms	Campylobacter				Type eg chicken	Portion eg whole	Contamination, sample	Temp, °C	Time, s	Conc, ppm	pH	ORP, mv	Presure, psi	Y/N			Y/N
Electro-oxidation of chiller water		Campy=0.5, 1.2, 1.4 log with 0.1,0.2, and 0.3% solutions and 600s treatment. 1-log reduction achieved in 16, 10, 8 min with solution concs of 0.1,0.2, and 0.3% salt.	Pulsed electrical treatment of salted chiller water	Chiller	Liquid from chiller	Chiller liquid	Liquid	Liquid	2 to 5	Up to 1200	0.1, 0.2, 0.3% NaCl	7.1 to 7.3				Campy added to chiller water that was then treated. 10mA cm^{-2}, 1 kHz,	Li et al., 1995	Y

Table 20: Published data on the efficacy of ultra-violet radiation for reducing the microbial counts on poultry

Approach	Microbial Reduction log CFU(means unless otherwise stated)		Method eg Tunnel	Application Point eg post-EV	Sampling point eg post-chill	Material			Conditions				Quality Acceptance	Comments	Reference	Refereed
	Organisms	Campylobacter				Type eg chicken	Portion eg whole	Contamination, sample	Temp, °C	Time, s	Wavelength	Dose				Y/N
UV	No effect on Psychrotrophs. 0.5 log reduction in Salmonella		Cabinet	Chilled birds	After treatment and after 10d	Chicken	Halves	Artificial Salmonella, Natural Psychrotrophs, rinse		60s	254 nm	82560 to 86400 µWs cm^{-2}	Slight effect on colour of legs at days 0 and 10. TBA levels (rancidity) reduced by the treatment.	UV not recommended as the sole method of reducing carcass contamination.	Wallner_Pendleton et al., 1994	Y
		Campy = 7-log to undetectable in liquid (0.192 J cm^{-2}) ; 0.76-log reduction on breast meat and 0.58-log reduction on skin (0.192 J cm^{-2})	Cabinet	Laboratory	Laboratory	Chicken	Breast meat or skin	Artificial, meat or skin		2 to 36s		4000 to 6000 µW cm^{-2} (says J cm^{-2} in the paper)	Deliberately ensured temperature below 50°C. Overall, colour not affected.	Effect of UV on C. Jejuni in liquid and on chicken. Micro reductions vary with Campy isolate.	Haughton et al., 2011	Y
		Campy=0.7 (meat); 0.8 (skin); 0.4 (carcasses); 6.3 (on agar plates)	Cabinet	Chilled birds	Post treatment	Chicken	Meat, skin, whole	Artificial, swabbed or rinsed		4 to 18 s	254nm	9400 to 32900 µW/s	No significant effect on colour or sensory quality or fatty acid concent.	Use of UV along or in combination with activated oxygen is not recommended.	Isohanni, Lyhs, 2009	Y

Table 21a: Microbial counts on untreated chicken breast skin when tested at Day K+1 (UVC)

Sample No.	Bird No.	Side	Treatment	Temperature, °C	Flux, mW/cm^2	Aerobic Plate Count per g	log(APC)	Campylobacter count per g	log(Campy)
21	1	Left	Untreated			3540000	6.55	105	2.02
22	2	Right	Untreated			7100000	6.85	290	2.46
23	3	Left	Untreated			2680000	6.43	585	2.77
24	4	Right	Untreated			6820000	6.83	85	1.93
25	5	Left	Untreated			4160000	6.62	140	2.15
26	6	Right	Untreated			6240000	6.80	295	2.47
27	7	Left	Untreated			3800000	6.58	270	2.43
28	8	Right	Untreated			4180000	6.62	85	1.93
29	9	Left	Untreated			4020000	6.60	225	2.35
30	10	Right	Untreated			10240000	7.01	325	2.51
31	11	Left	Untreated			3990000	6.60	95	1.98
32	12	Right	Untreated			4660000	6.67	130	2.11
33	13	Left	Untreated			3920000	6.59	170	2.23
34	14	Right	Untreated			6200000	6.79	150	2.18
35	15	Left	Untreated			4940000	6.69	335	2.53
36	16	Right	Untreated			6200000	6.79	160	2.20
37	17	Left	Untreated			5880000	6.77	240	2.38
38	18	Right	Untreated			6320000	6.80	525	2.72
39	19	Left	Untreated			4290000	6.63	130	2.11
40	20	Right	Untreated			6340000	6.80	115	2.06
Average							6.70		2.28
S.D.							0.14		0.25
C.I.							0.06		0.12
N							20		20
n<1									0

Table 21b: Microbial counts on chicken breast skin treated with UVC and then tested at Day K+1 and flux and temperatures measured in the UVC tunnel.

Sample No.	Bird No.	Side	Treatment	Temperature, °C	Flux, mW/cm^2	Aerobic Plate Count per g	log(APC)	Campylobacter count per g	log(Campy)
1	1	Right	UVC	34.0	11.92	2000000	6.30	105	2.02
2	2	Left	UVC	31.7	11.8	5400000	6.73	185	2.27
3	3	Right	UVC	37.6	12.05	1650000	6.22	175	2.24
4	4	Left	UVC	37.6	11.91	2240000	6.35	40	1.60
5	5	Right	UVC	40.5	11.97	3110000	6.49	60	1.78
6	6	Left	UVC	39.3	11.75	1560000	6.19	65	1.81
7	7	Right	UVC	39.1	11.53	1940000	6.29	1550	3.19
8	8	Left	UVC	39.5	11.56	1310000	6.12	100	2.00
9	9	Right	UVC	39.3	11.5	4550000	6.66	535	2.73
10	10	Left	UVC	38.8	11.34	2400000	6.38	120	2.08
11	11	Right	UVC	38.9	11.88	1030000	6.01	135	2.13
12	12	Left	UVC	38.1	12	1400000	6.15	110	2.04
13	13	Right	UVC	42.5	12.12	1850000	6.27	170	2.23
14	14	Left	UVC	37.1	12.1	950000	5.98	130	2.11
15	15	Right	UVC	40.8	12.2	2520000	6.40	500	2.70
16	16	Left	UVC	40.8	12.11	1930000	6.29	45	1.65
17	17	Right	UVC	40.9	11.99	1630000	6.21	350	2.54
18	18	Left	UVC	41.0	12.53	2320000	6.37	240	2.38
19	19	Right	UVC	37.6	12.51	3720000	6.57	250	2.40
20	20	Left	UVC	37.0	12.23	1910000	6.28	40	1.60
Average				38.6	12.0		6.31		2.18
S.D.				2.5	0.3		0.19		0.41
C.I.				1.2	0.1		0.09		0.19
N				20	20		20		20
n<1									0

Figure 1: Photograph of the superheated steam chamber supported on wooden pallets at the poultry processing plant

Figure 2a: Photograph of a chicken with a small section of skin removed prior to a treatment with superheated steam (150°C for 1 minute). The skin section was removed to demonstrate the effect of the treatment on exposed flesh.

Figure 2b: Photograph of the chicken after treatment with superheated steam (150°C for 1 minute) showing the change in colour of the exposed flesh

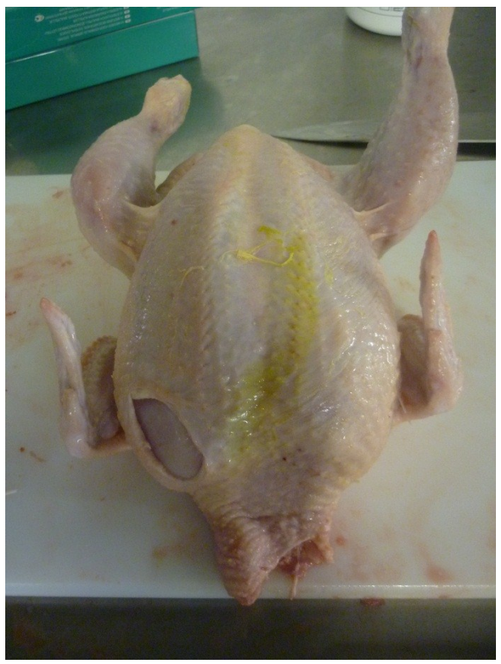
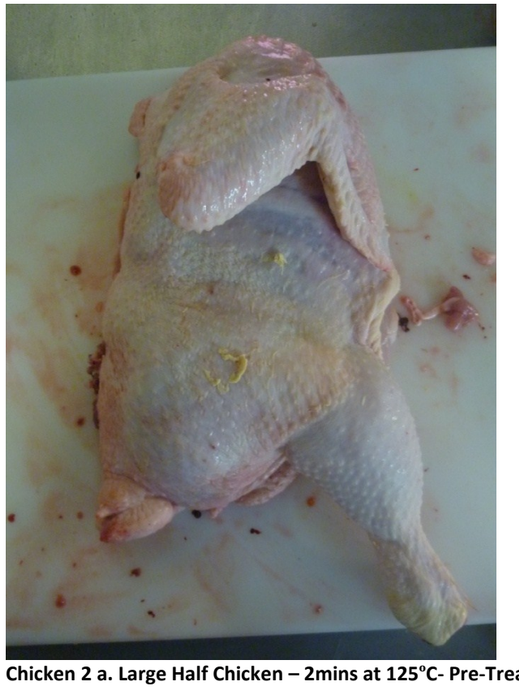
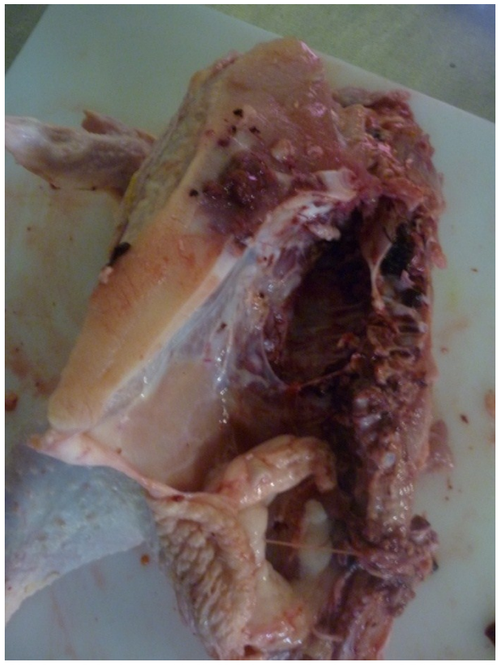


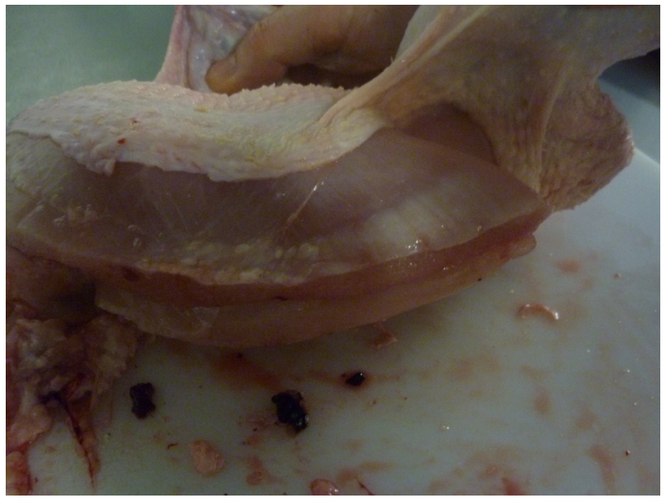
Figure 3: Photographs showing chicken samples before and after various treatments with superheated steam. Chicken numbers refer to the bird numbers shown in Table 7.



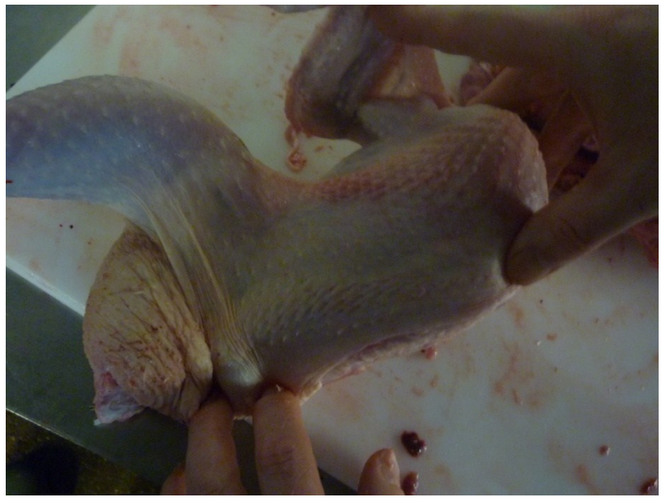
Chicken 2 a. Large Half Chicken – 2mins at 125°C- Pre-Treatment (1)



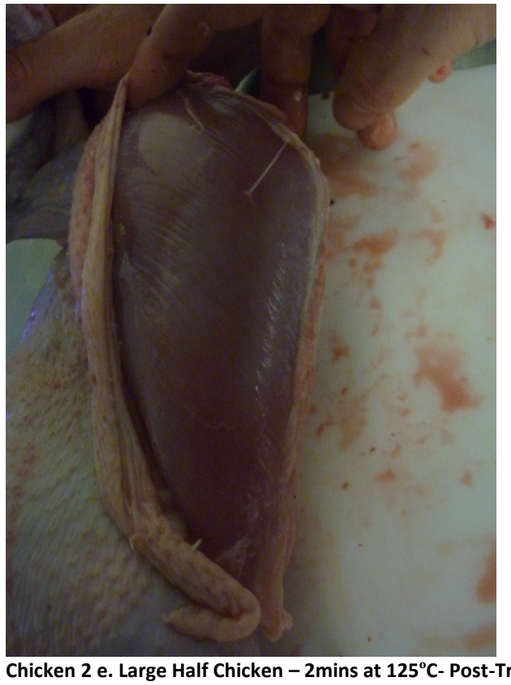
Chicken 2 b. Large Half Chicken – 2mins at 125°C- Pre-Treatment (2)



Chicken 2 c. Large Half Chicken – 2mins at 125°C- Post-Treatment (showing denaturing of breast meat)

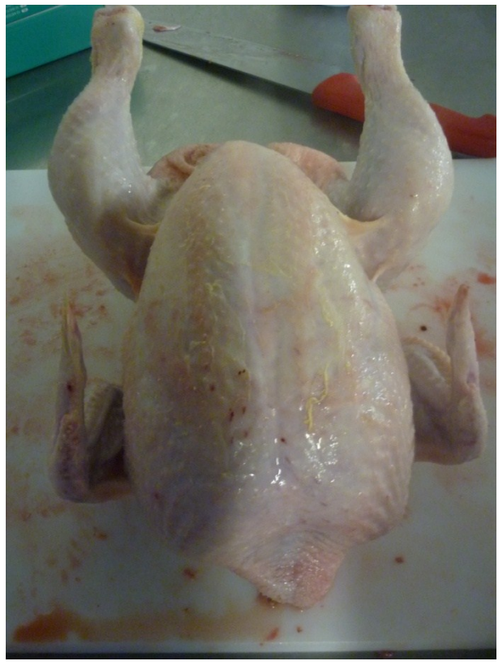


Chicken 2 d. Large Half Chicken – 2mins at 125°C- Post-Treatment

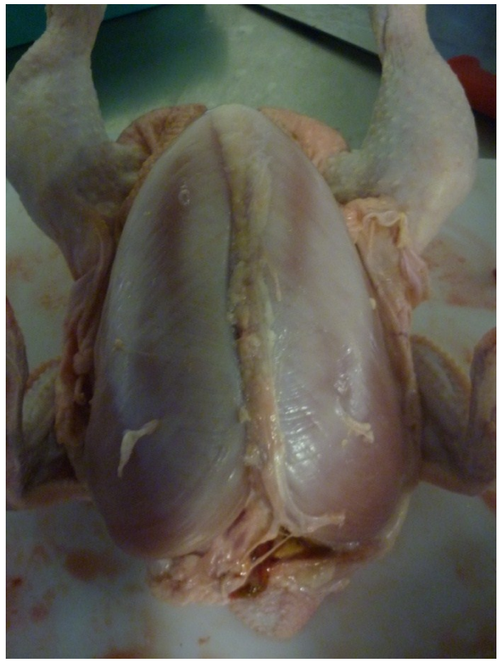


Chicken 2 e. Large Half Chicken – 2mins at 125°C- Post-Treatment (showing denaturing on breast meat and hot-spot)

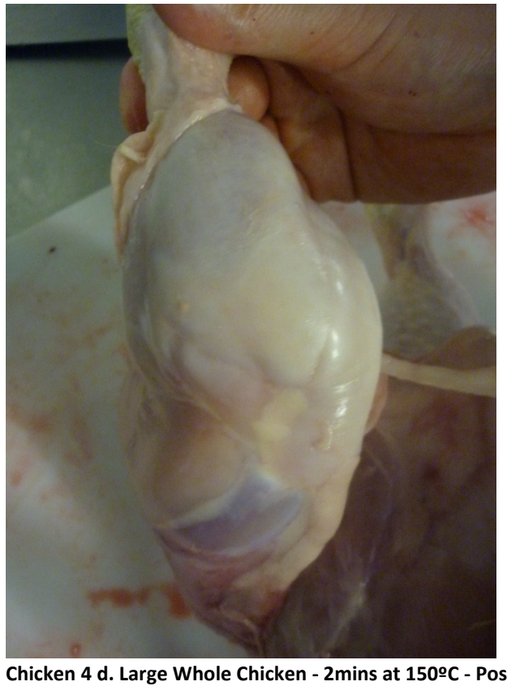
Chicken 4 a. Large Whole Chicken - 2mins at 150°C - Pre-Treatment



Chicken 4 b. Large Whole Chicken - 2mins at 150ºC - Post-Treatment

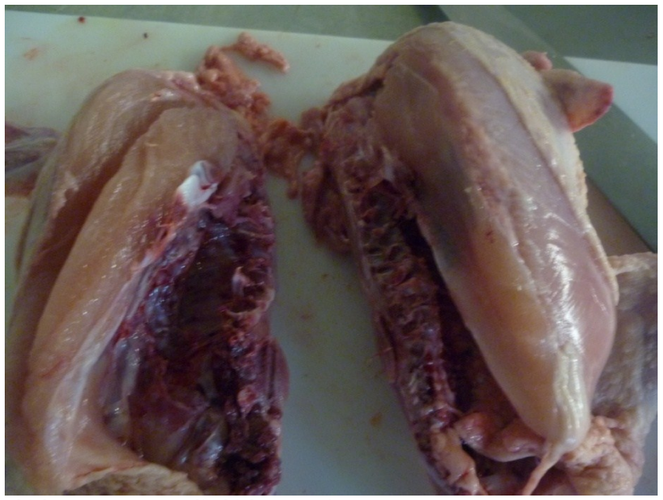


Chicken 4 c. Large Whole Chicken - 2mins at 150ºC - Post-Treatment (widespread denaturing on breasts)



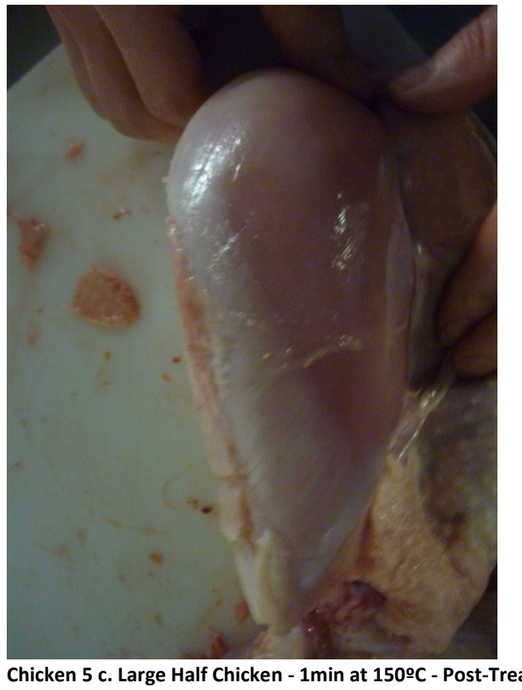
Chicken 4 d. Large Whole Chicken - 2mins at 150ºC - Post-Treatment (showing denaturing on leg meat)

Chicken 4 e. Large Whole Chicken - 2mins at 150ºC - Post Treatment (showing depth of denatured meat in breast)



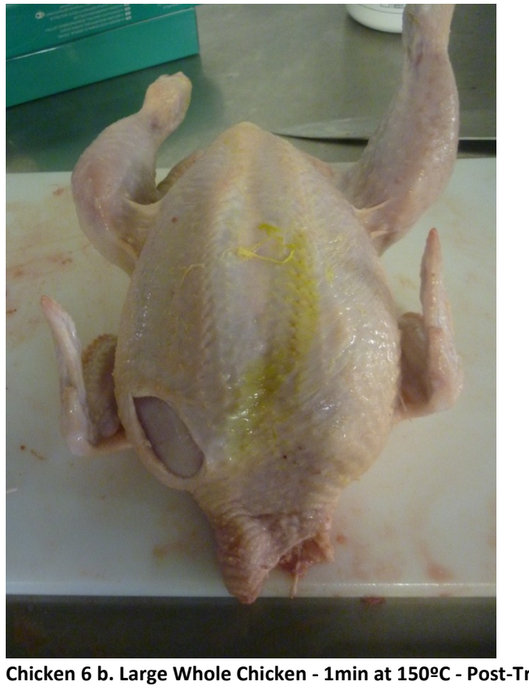
Chicken 5 a. Large Half Chicken - 1min at 150ºC - Pre-Treatment

Chicken 5 b. Large Half Chicken - 1min at 150ºC - Post-Treatment

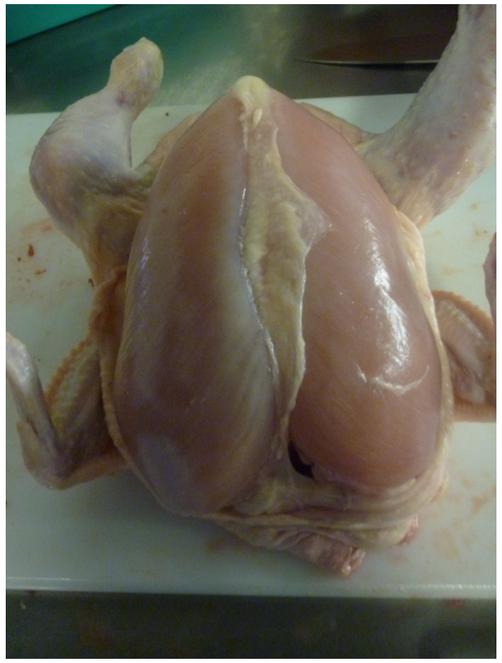


Chicken 5 c. Large Half Chicken - 1min at 150ºC - Post-Treatment (showing denatured breast meat)

Chicken 6 a. Large Whole Chicken - 1min at 150ºC -Pre-Treatment (with skin incision)



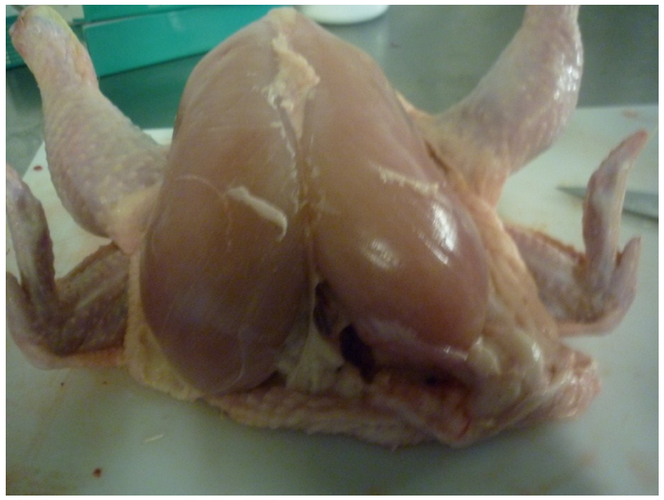
Chicken 6 b. Large Whole Chicken - 1min at 150ºC - Post-Treatment (with skin incision)



Chicken 6 c. Large Whole Chicken - 1min at 150ºC - Post-Treatment (showing denaturing of breast meat and hot-spot)

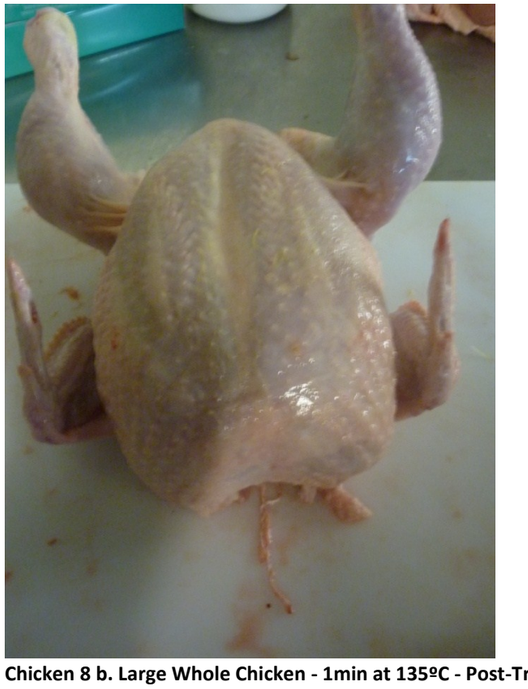
Chicken 7 a. Large Whole Chicken - 1min at 130ºC - Pre-Treatment (with skin incision)

Chicken 7 b. Large Whole Chicken - 1min at 130ºC - Post-Treatment (with skin incision)



Chicken 7 c. Large Whole Chicken - 1min at 130ºC - Post-Treatment (showing slight denaturing with hot-spot)

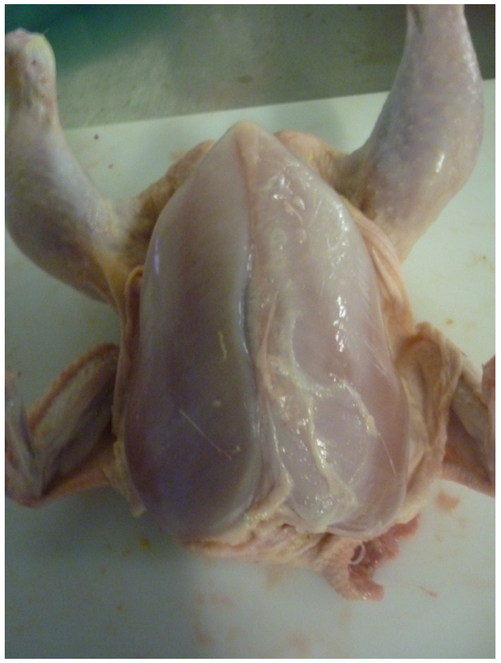
Chicken 8 a. Large Whole Chicken - 1min at 135ºC - Pre-Treatment



Chicken 8 b. Large Whole Chicken - 1min at 135ºC - Post-Treatment

Chicken 9 a. Small Whole Chicken - 1min at 135ºC – Pre-Treatment (with skin incision)

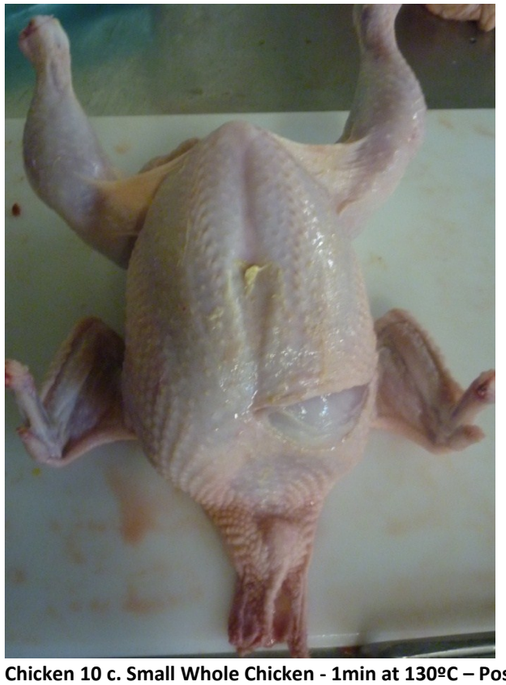
Chicken 9 b. Small Whole Chicken - 1min at 135ºC – Post-Treatment (with skin incision)



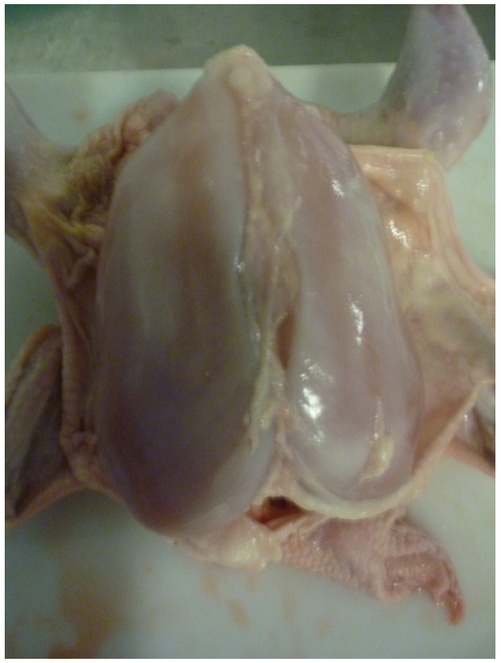
Chicken 9 c. Small Whole Chicken - 1min at 135ºC – Post-Treatment (showing widespread denaturing of breast meat)

Chicken 10 a. Small Whole Chicken - 1min at 130ºC – Pre-Treatment

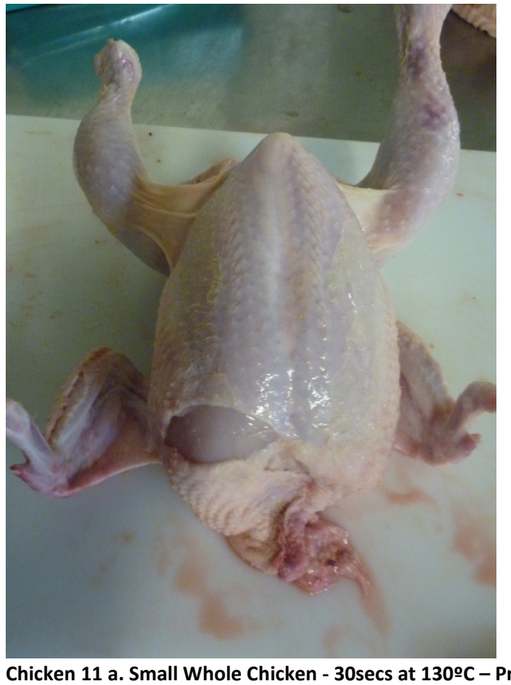
Chicken 10 b. Small Whole Chicken - 1min at 130ºC – Pre-Treatment (with skin incision)



Chicken 10 c. Small Whole Chicken - 1min at 130ºC – Post-Treatment (with skin incision)

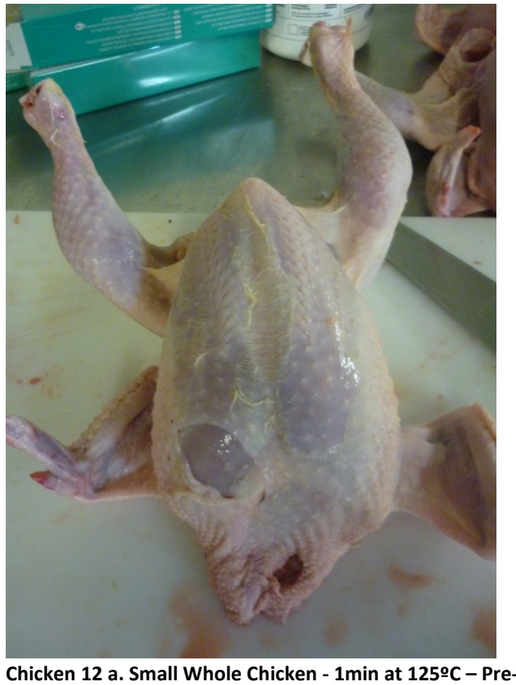


Chicken 10 d. Small Whole Chicken - 1min at 130ºC – Post-Treatment (showing breast meat denaturing and hot-spot)

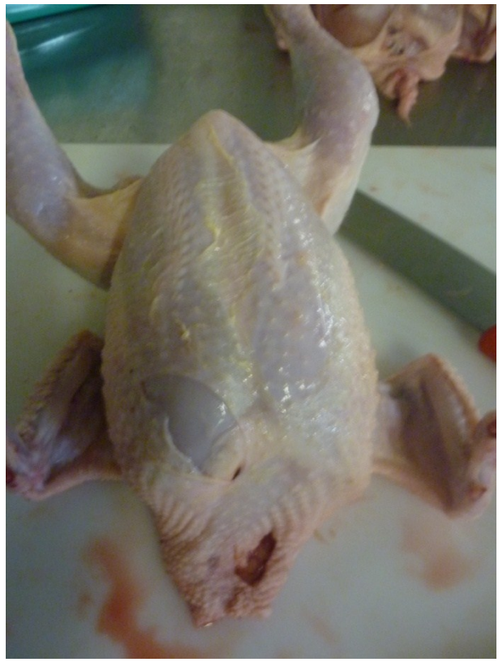


Chicken 11 a. Small Whole Chicken - 30secs at 130ºC – Pre-Treatment (with skin incision)

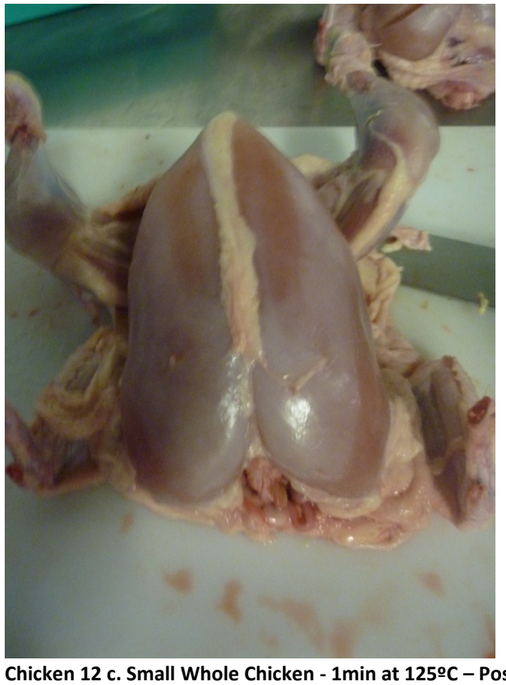
Chicken 11 b. Small Whole Chicken - 30secs at 130ºC – Post-Treatment (showing hot-spot on breast meat)



Chicken 12 a. Small Whole Chicken - 1min at 125ºC – Pre-Treatment (with skin incision)



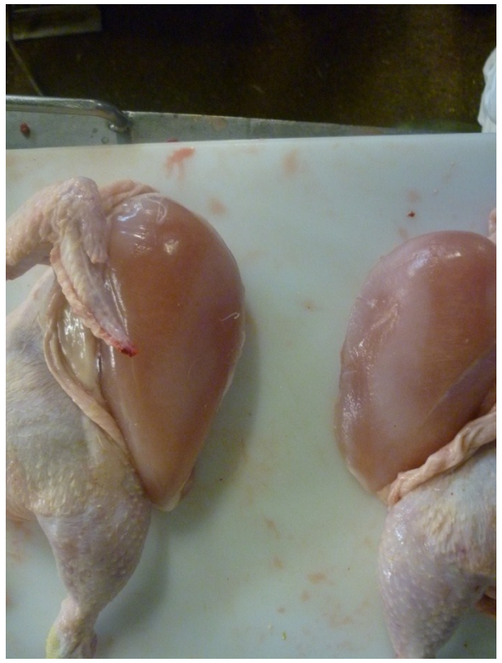
Chicken 12 b. Small Whole Chicken - 1min at 125ºC – Post-Treatment (with skin incision)



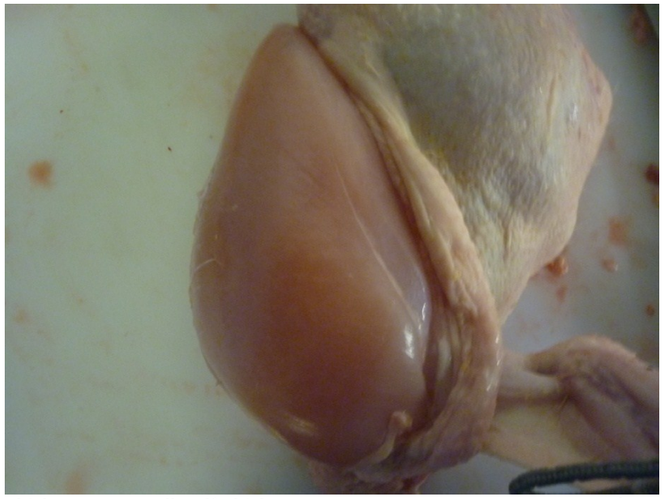
Chicken 12 c. Small Whole Chicken - 1min at 125ºC – Post-Treatment (showing denaturing of breast meat)

Chicken 13 a. Small Whole Chicken - 30secs at 125ºC – Pre-treatment (with skin incision)

Chicken 15 a. Small Half Chicken - 20secs at 125ºC – Pre-Treatment



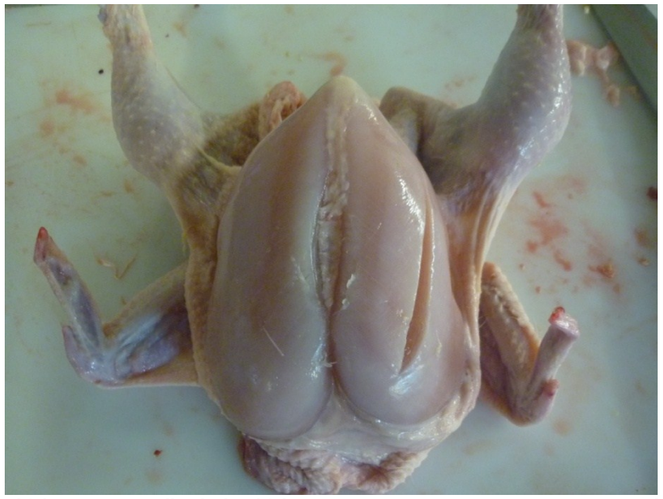
Chicken 15 b. Small Half Chicken - 20secs at 125ºC – Post-Treatment (treated on the right, breast meat denaturing)



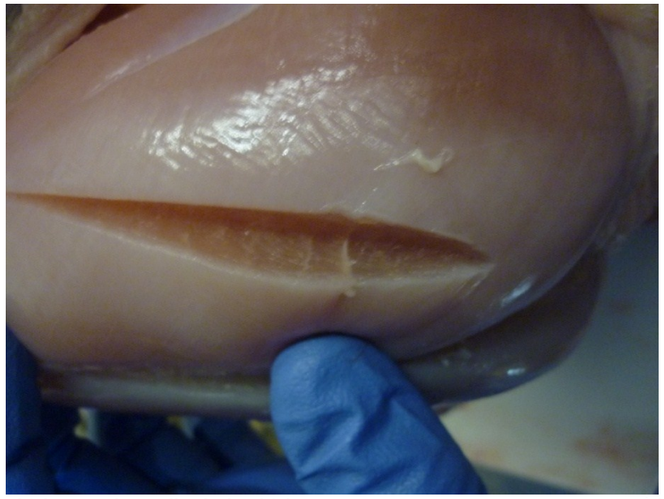
Chicken 15 c. Small Half Chicken - 20secs at 125ºC – Post-Treatment (treated on the right, breast meat denaturing)

Chicken 16 a Small Whole Chicken - 20secs at 125ºC – Pre-Treatment

Chicken 16 b. Small Whole Chicken - 20secs at 125ºC – Post-Treatment

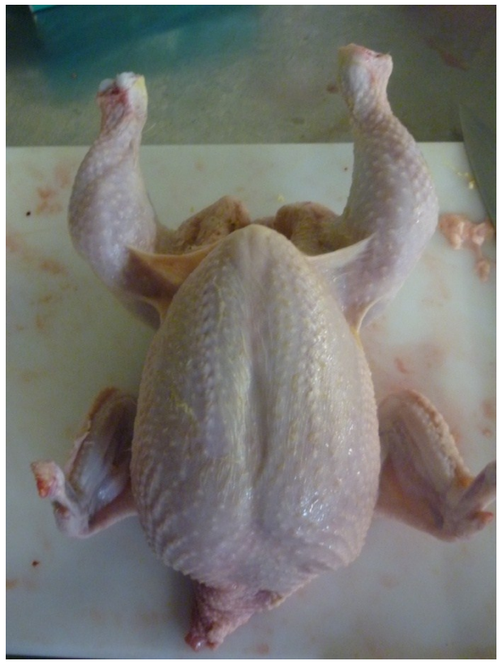


Chicken 16 c. Small Whole Chicken - 20secs at 125ºC – Post-Treatment (showing skin removed and breast meat denaturing)

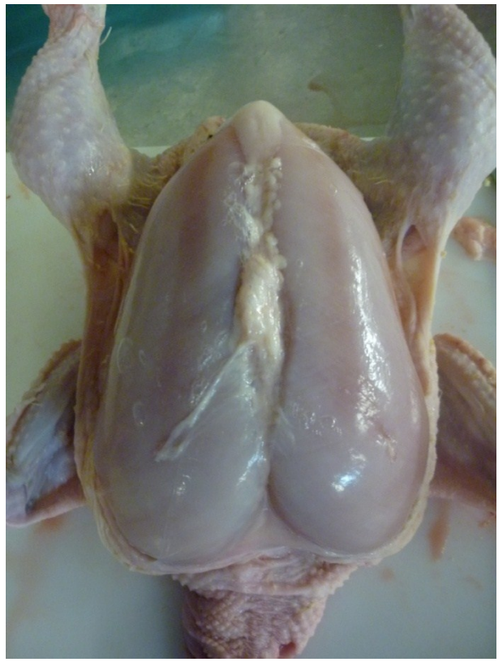


Chicken 16 d. Small Whole Chicken - 20secs at 125ºC – Post-Treatment (showing depth of breast meat denaturing from incision)

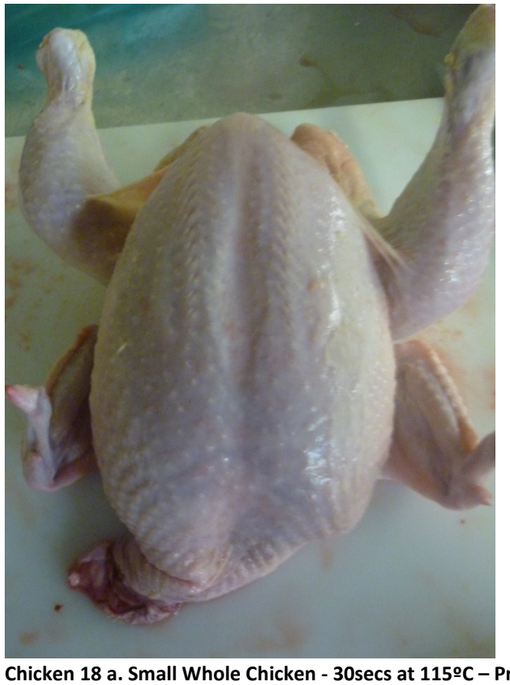
Chicken 17 a. Small Whole Chicken - 1min at 115ºC – Pre-Treatment



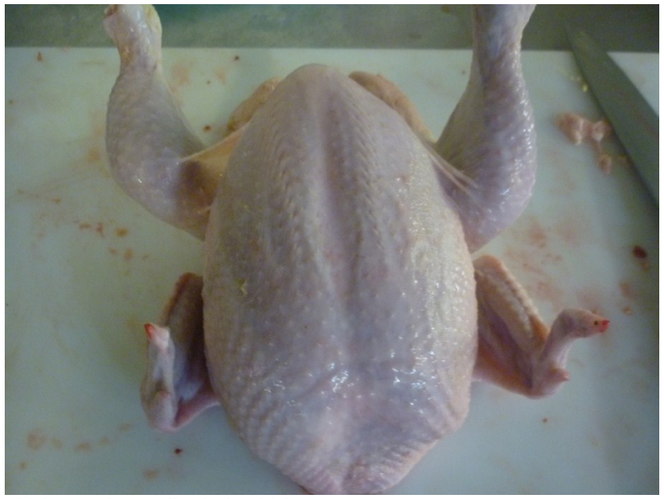
Chicken 17 b. Small Whole Chicken - 1min at 115ºC – Post-Treatment



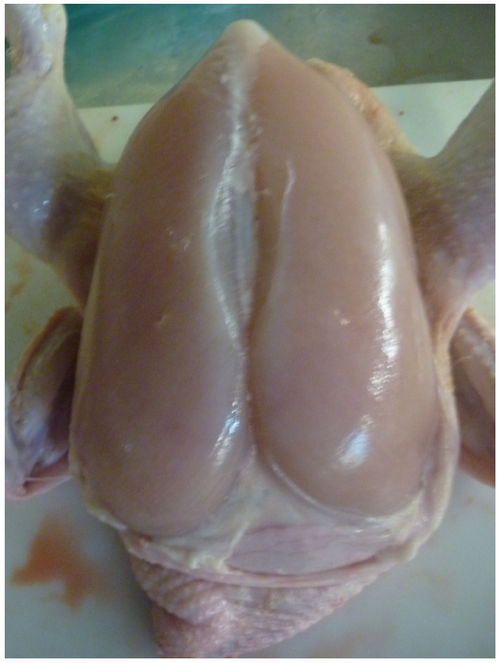
Chicken 17 c. Small Whole Chicken - 1min at 115ºC – Post-Treatment (showing breast meat denaturing)



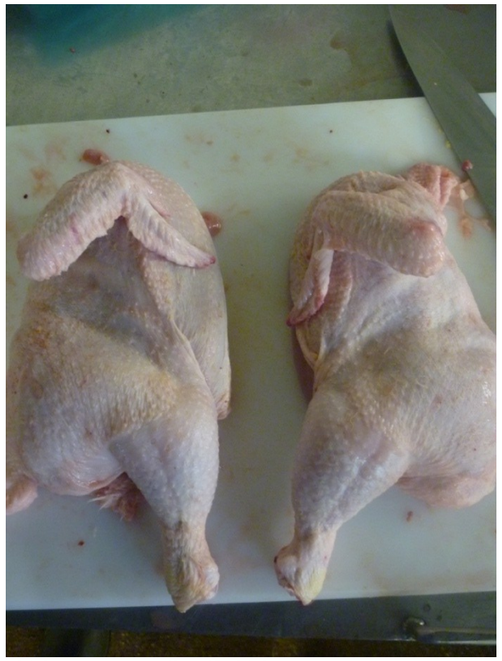
Chicken 18 a. Small Whole Chicken - 30secs at 115ºC – Pre-Treatment



Chicken 18 b. Small Whole Chicken - 30secs at 115ºC – Post-Treatment

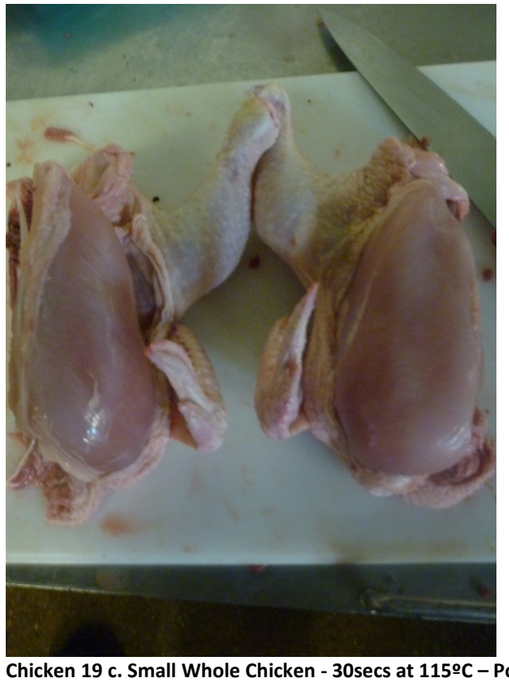


Chicken 18 c.Small Whole Chicken - 30secs at 115ºC – Post-Treatment (showing an acceptable quality of meat)



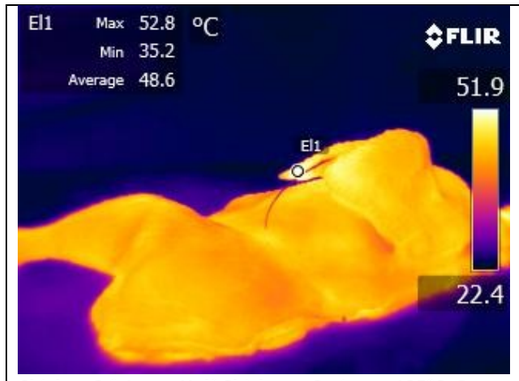
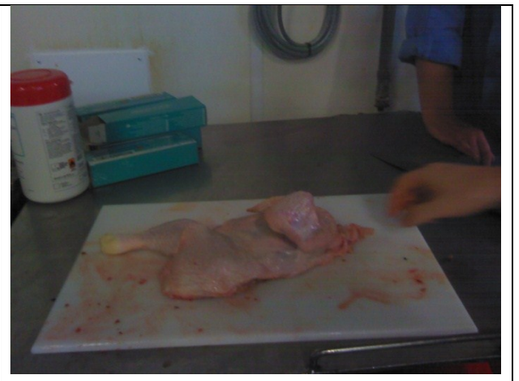
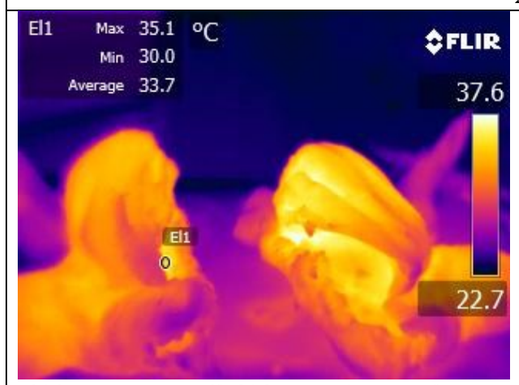
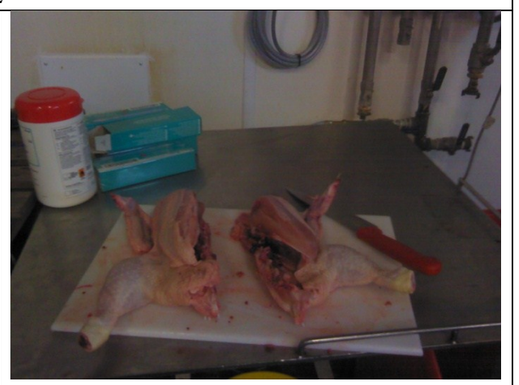
Chicken 19 a. Small Half Chicken - 30secs at 115ºC – Pre-Treatment

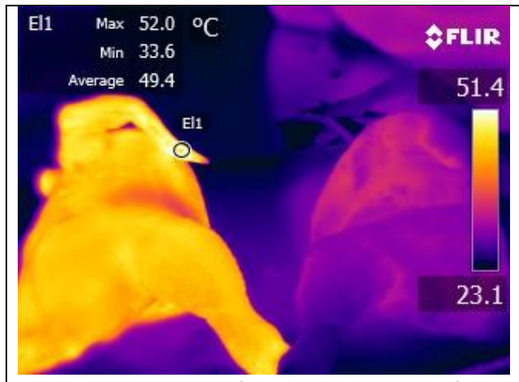
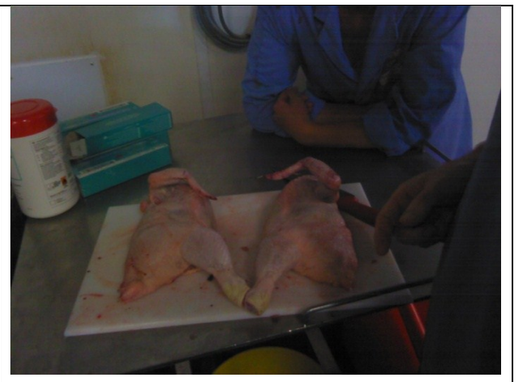
Chicken 19 b. Small Whole Chicken - 30secs at 115ºC – Post-Treatment (showing treated half on the left



Chicken 19 c. Small Whole Chicken - 30secs at 115ºC – Post-Treatment (showing comparison between treated (L) and untreated (R)

Figure 4 Thermal images and photographs of chicken samples before and after various treatments with superheated steam. Chicken numbers refer to the bird numbers shown in Table 7.

	
Chicken 2 f. Large Half Chicken – 2mins at 125°C- Post-Treatment	
2	
	
Chicken 3 a. Large Half Chicken – 2mins at 125°C – Pre-Treatment	
3	

 **Chicken 3 b. Large Half Chicken – 2mins at 125°C – Post-Treatment (treated on left)**	
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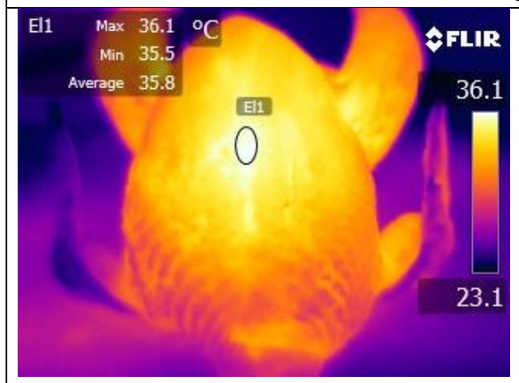
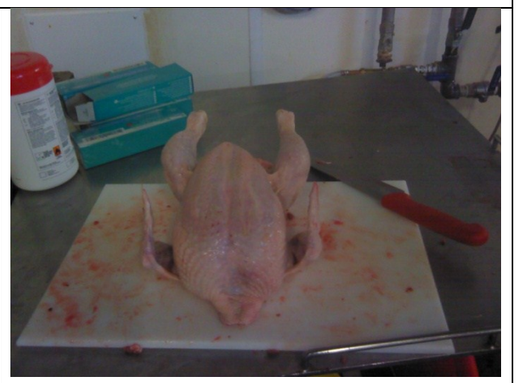
 **Chicken 4 f. Large Whole Chicken - 2mins at 150°C - Pre-Treatment**	
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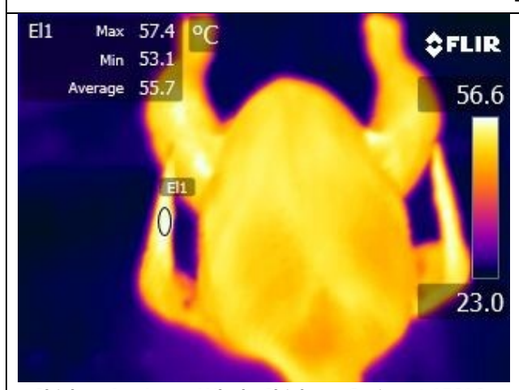
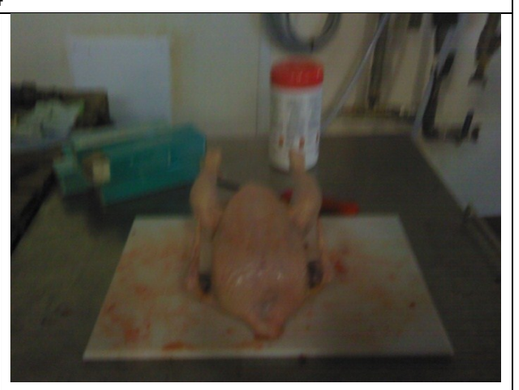
 **Chicken 4 g. Large Whole Chicken - 2mins at 150ºC - Post-Treatment**	
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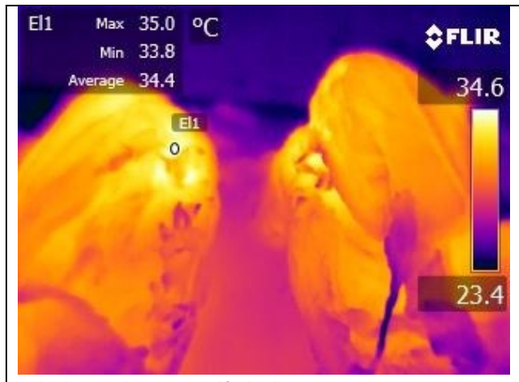
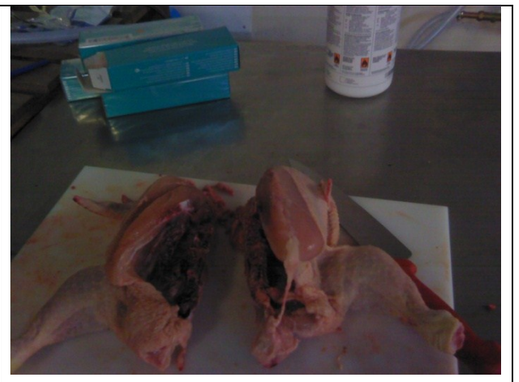
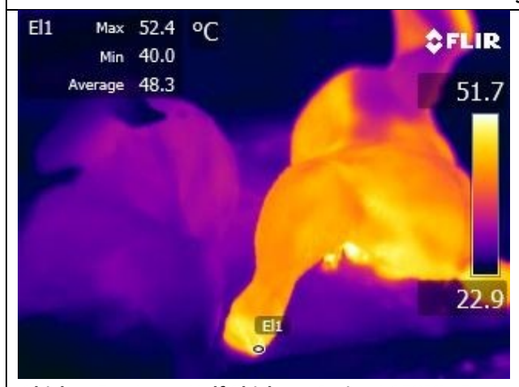
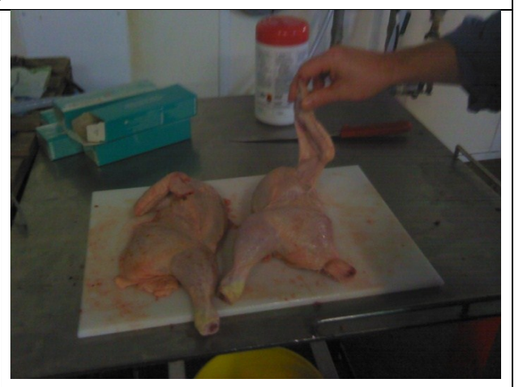
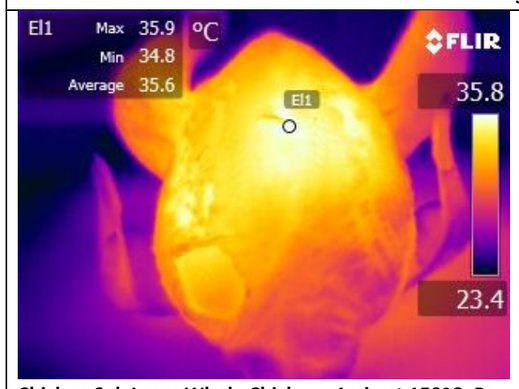
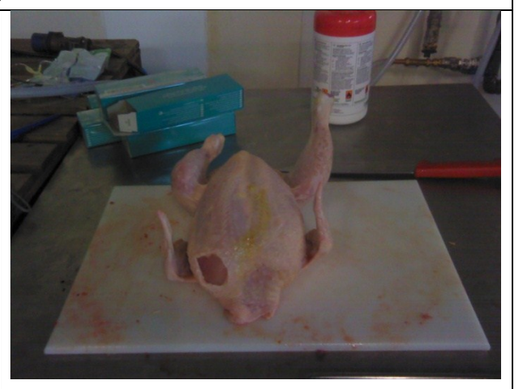
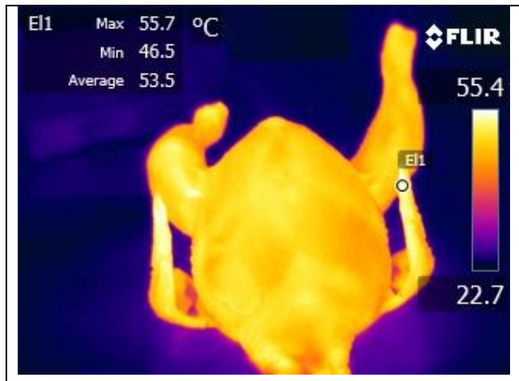
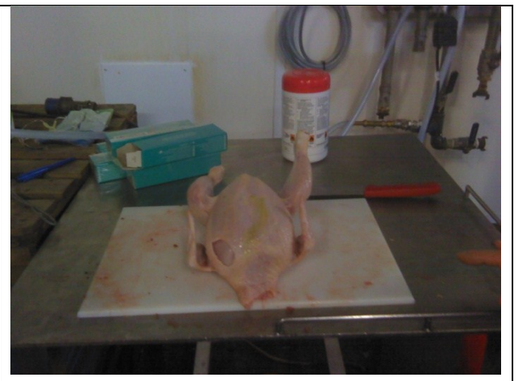
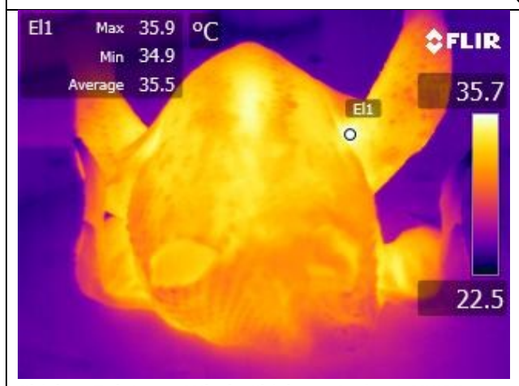
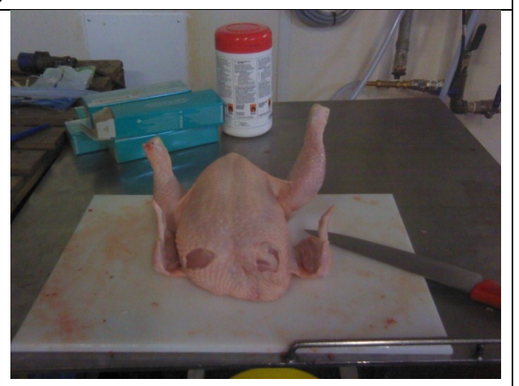
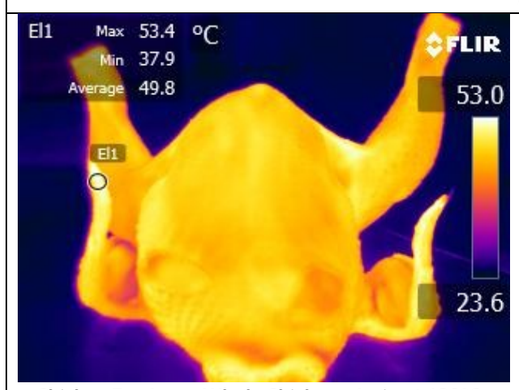
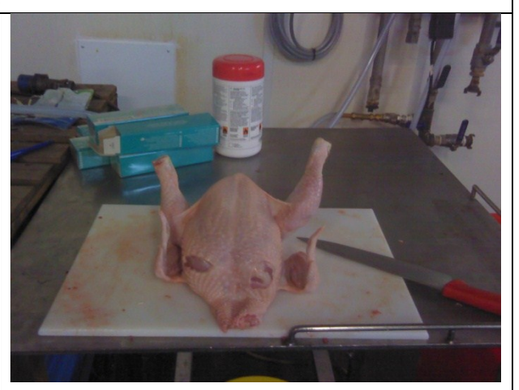
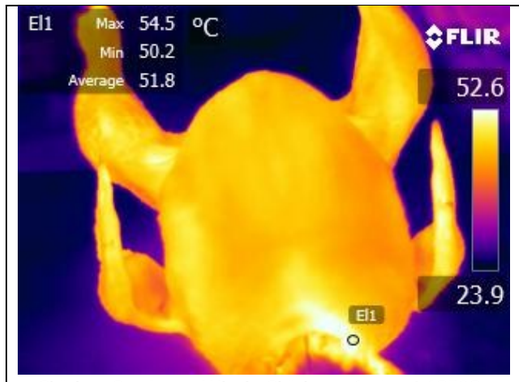
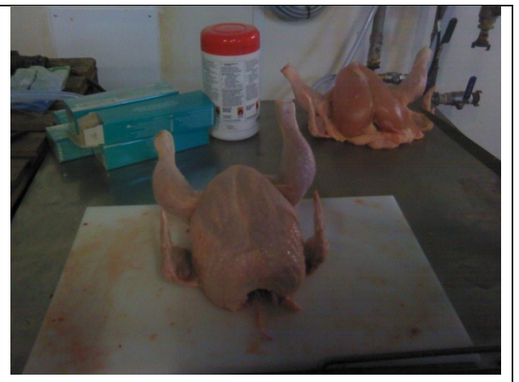
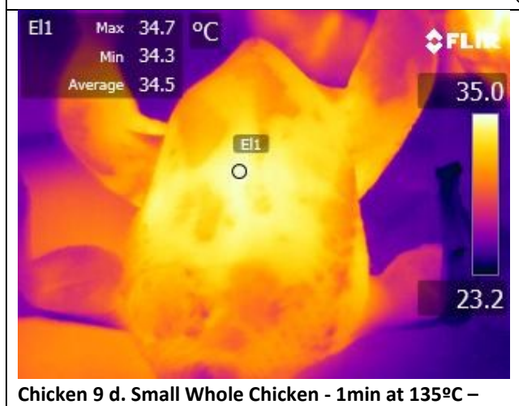
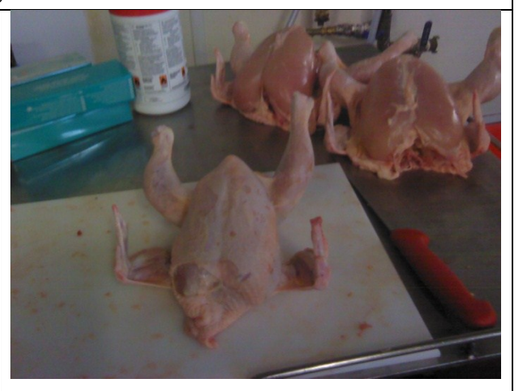
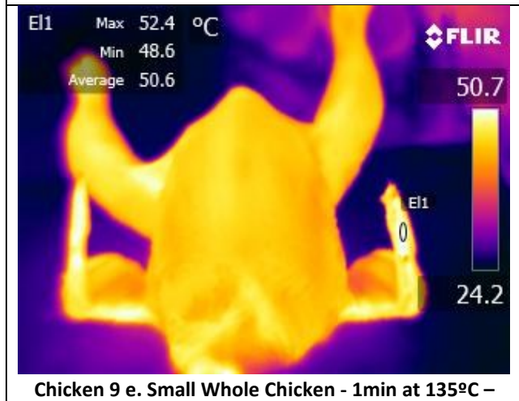
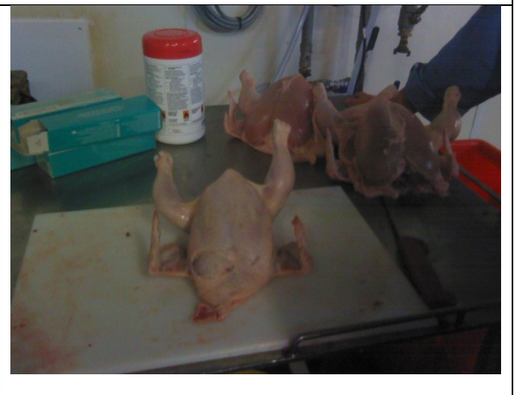
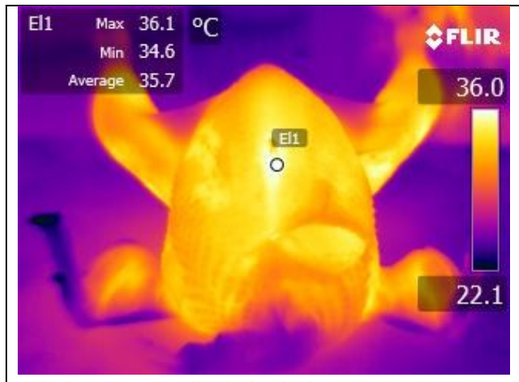
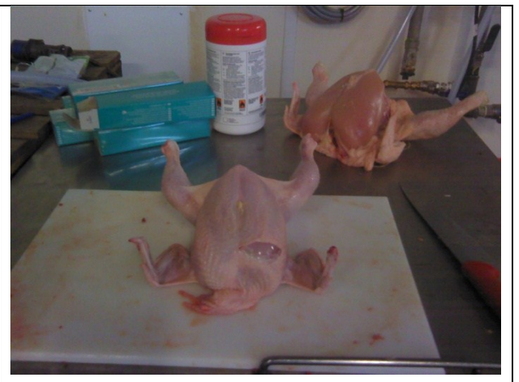
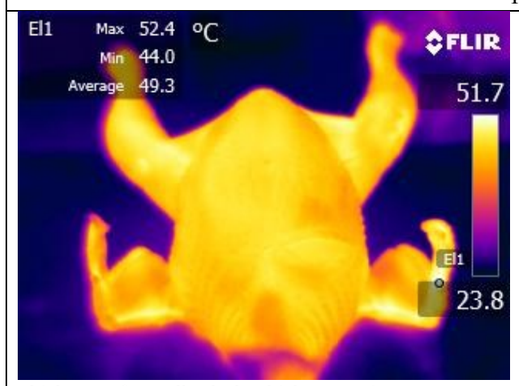
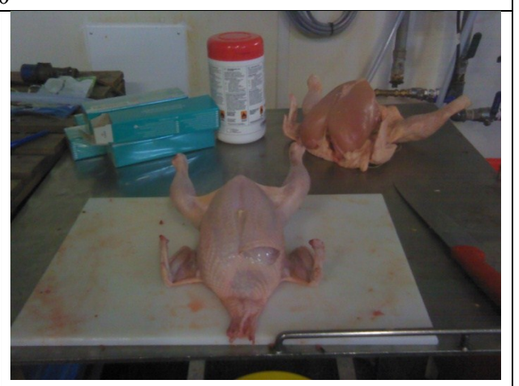
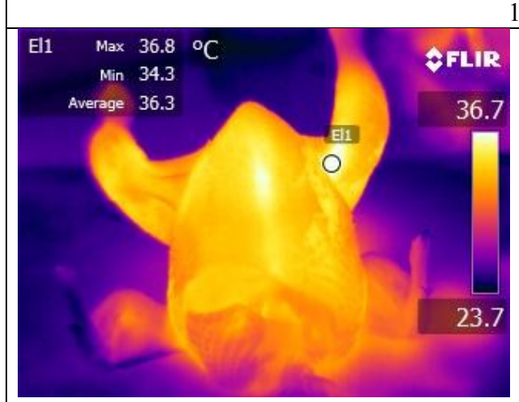
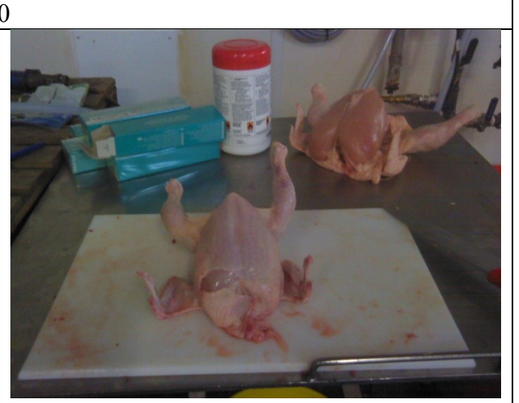
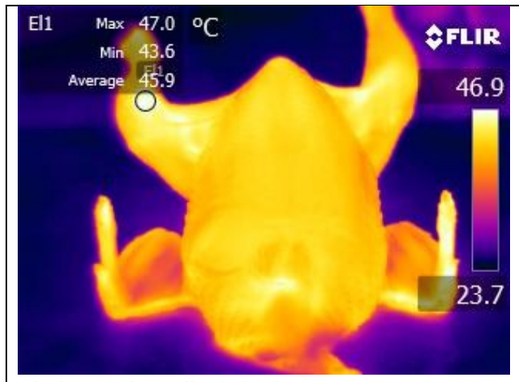
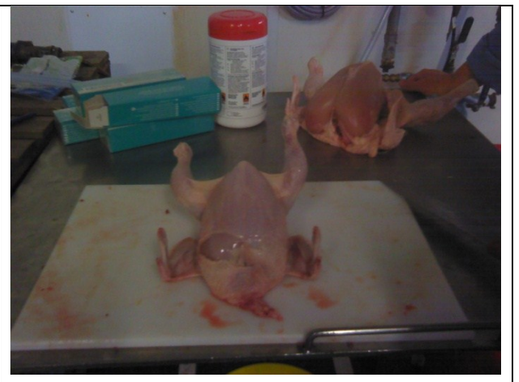
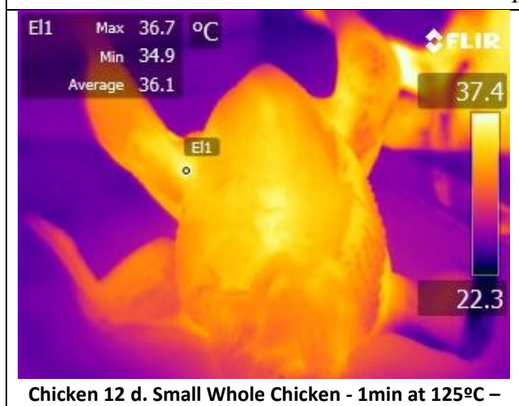
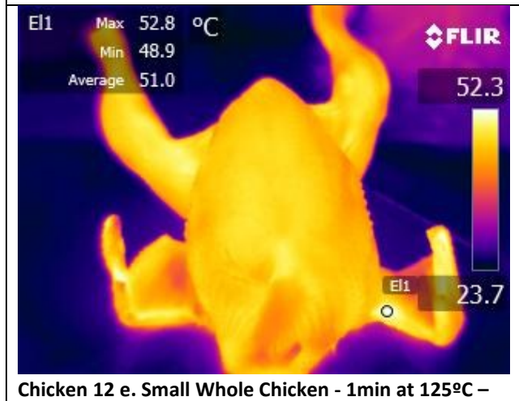
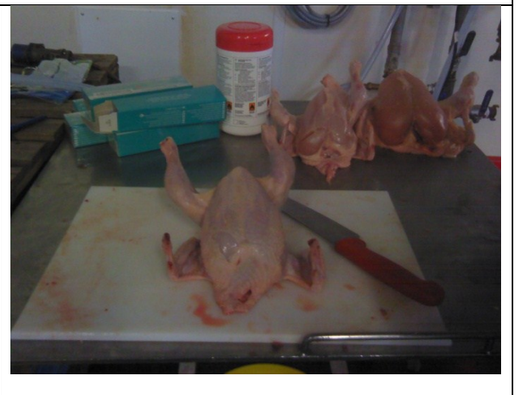
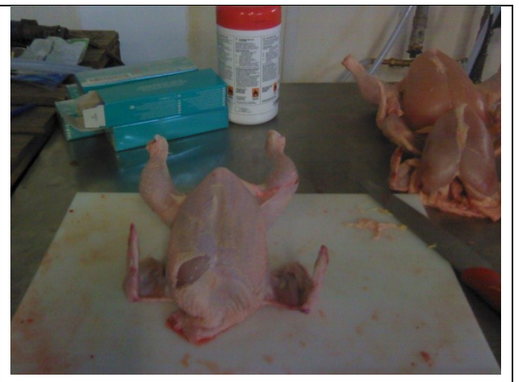
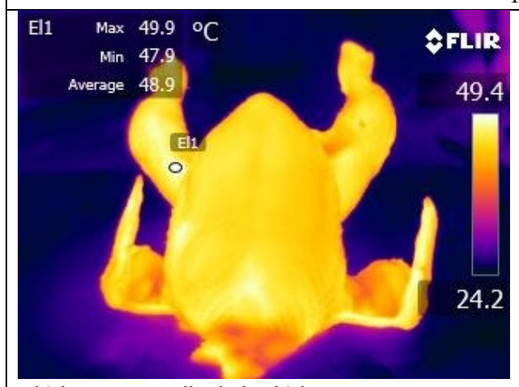
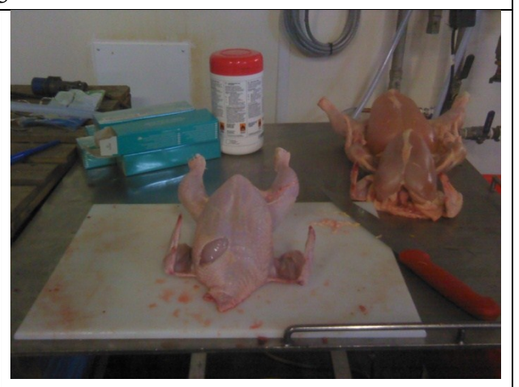
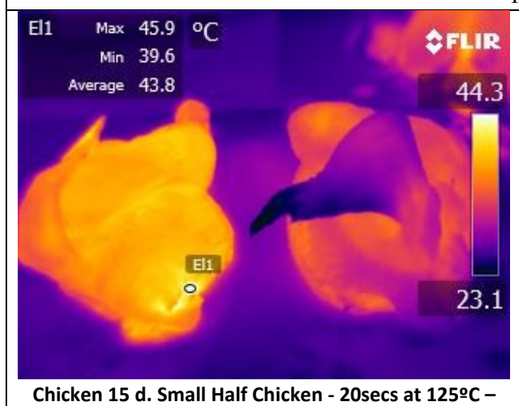
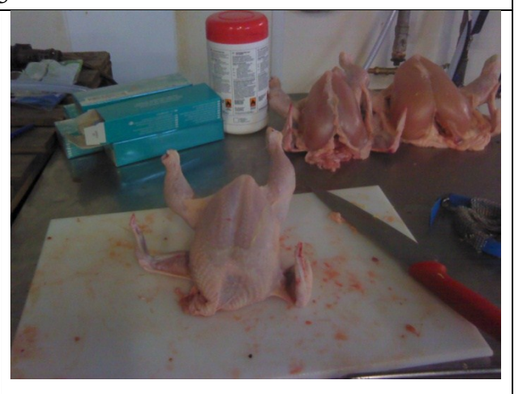
	
Chicken 5 d. Large Half Chicken - 1min at 150ºC - Pre-Treatment	
5	
	
Chicken 5 e. Large Half Chicken - 1min at 150ºC - Post-Treatment	
5	
	
Chicken 6 d. Large Whole Chicken - 1min at 150ºC -Pre-Treatment (with skin incision)	
6	

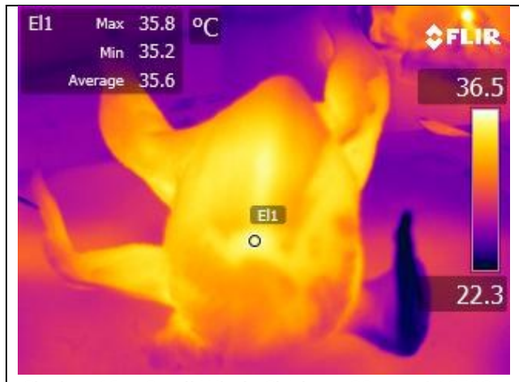
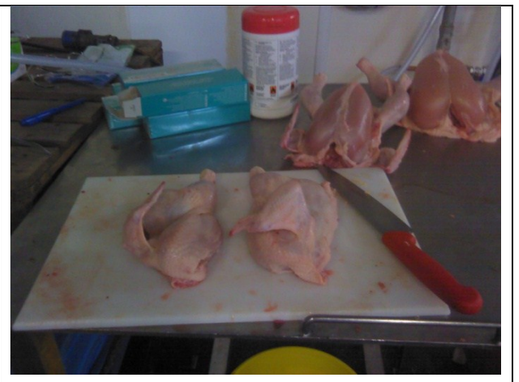
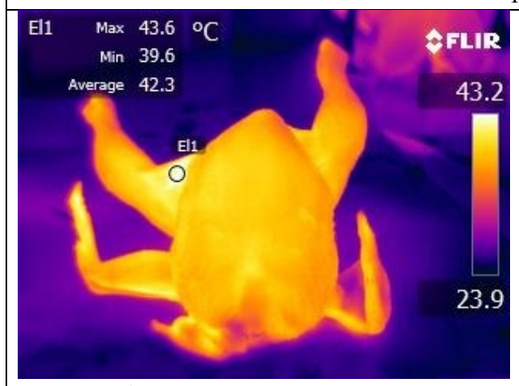
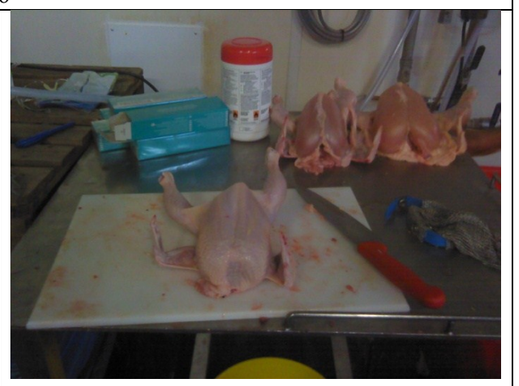
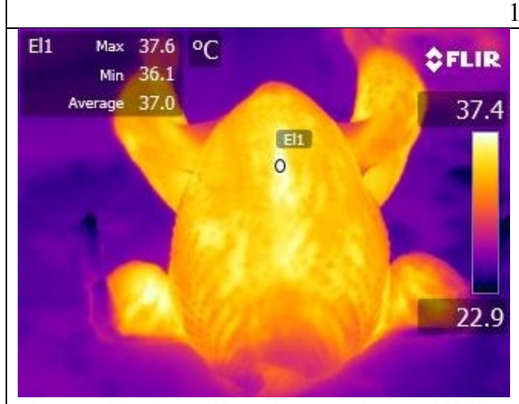
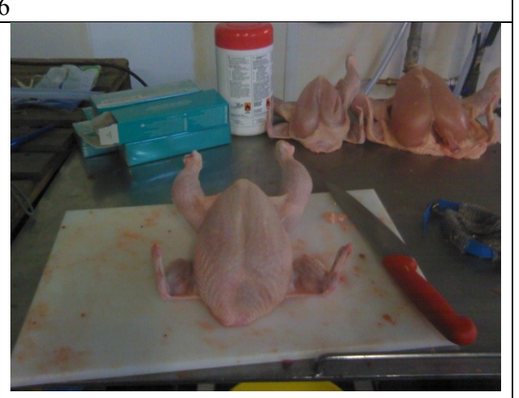
	
Chicken 6 e. Large Whole Chicken - 1min at 150ºC - Post-Treatment (with skin incision)	
6	
	
Chicken 7 d. Large Whole Chicken - 1min at 130ºC - Pre-Treatment (with skin incision)	
7	
	
Chicken 7 e. Large Whole Chicken - 1min at 130ºC - Post-Treatment (with skin incision)	
7	

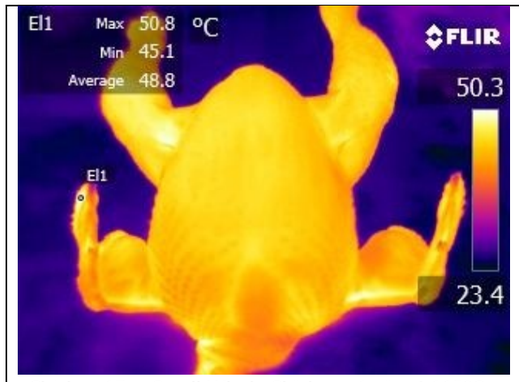
	
Chicken 8 c. Large Whole Chicken - 1min at 135ºC - Post-Treatment	
8	
	
Chicken 9 d. Small Whole Chicken - 1min at 135ºC – Pre-Treatment (with skin incision)	
9	
	
Chicken 9 e. Small Whole Chicken - 1min at 135ºC – Post-Treatment (with skin incision)	
9	

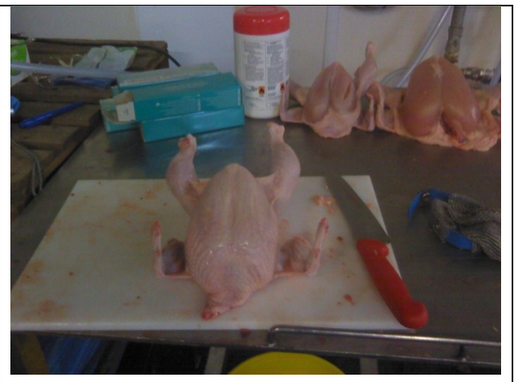
	
Chicken 10 e. Small Whole Chicken - 1min at 130ºC – Pre-Treatment (with skin incision)	
10	
	
Chicken 10 f. Small Whole Chicken - 1min at 130ºC – Post-Treatment (with skin incision)	
10	
	
Chicken 11 c. Small Whole Chicken - 30secs at 130ºC – Pre-Treatment (with skin incision)	
11	

	
Chicken 11 d. Small Whole Chicken - 30secs at 130ºC – Post-Treatment (showing hot-spot on breast meat)	
11	
	
Chicken 12 d. Small Whole Chicken - 1min at 125ºC – Pre-Treatment (with skin incision)	
12	
	
Chicken 12 e. Small Whole Chicken - 1min at 125ºC – Post-Treatment (with skin incision)	
12	

	
Chicken 13 b. Small Whole Chicken - 30secs at 125ºC – Pre-treatment (with skin incision)	
13	
	
Chicken 13 c. Small Whole Chicken - 30secs at 125ºC – Post-treatment (with skin incision)	
13	
	
Chicken 15 d. Small Half Chicken - 20secs at 125ºC – Post-Treatment	
15	

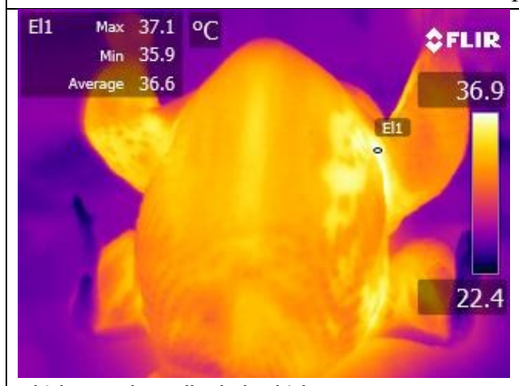
	
Chicken 16 e. Small Whole Chicken - 20secs at 125ºC – Pre-Treatment	
16	
	
Chicken 16 f. Small Whole Chicken - 20secs at 125ºC – Post-Treatment	
16	
	
Chicken 17 d. Small Whole Chicken - 1min at 115ºC – Pre-Treatment	
17	

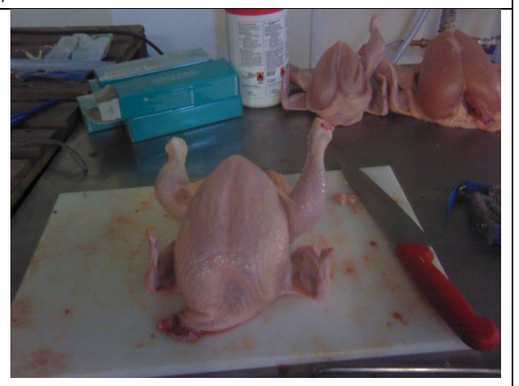




Chicken 17 e. Small Whole Chicken - 1min at 115ºC – Post-Treatment

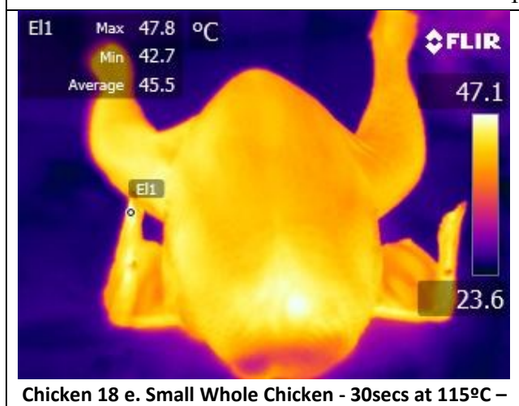
17

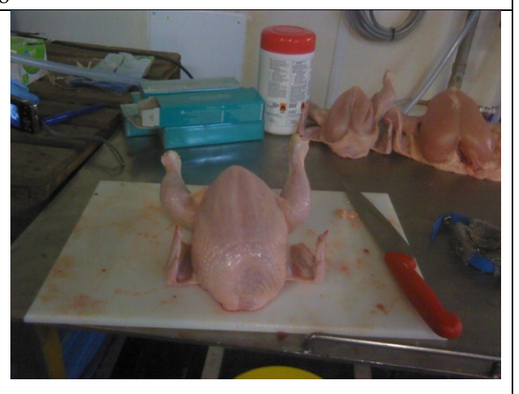




Chicken 18 d. Small Whole Chicken - 30secs at 115ºC – Pre-Treatment

18





Chicken 18 e. Small Whole Chicken - 30secs at 115ºC – Post-Treatment

18

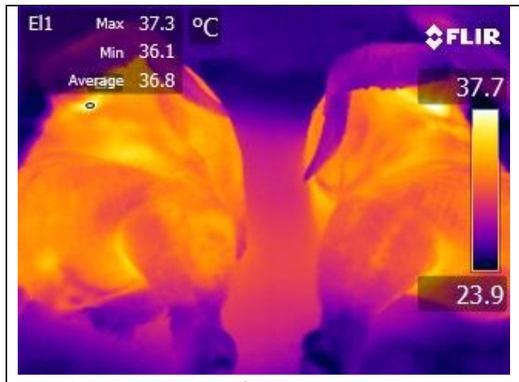
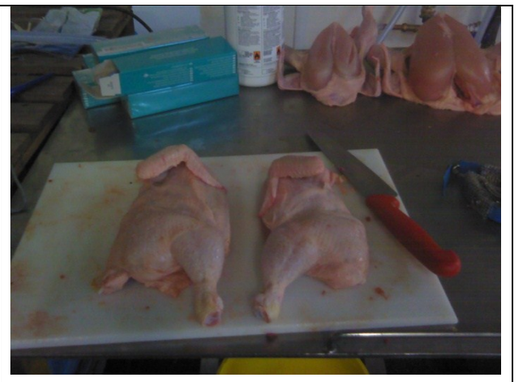
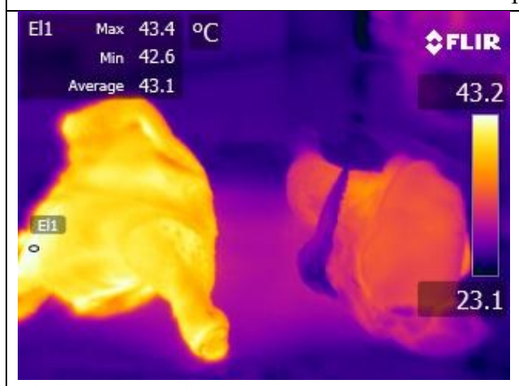
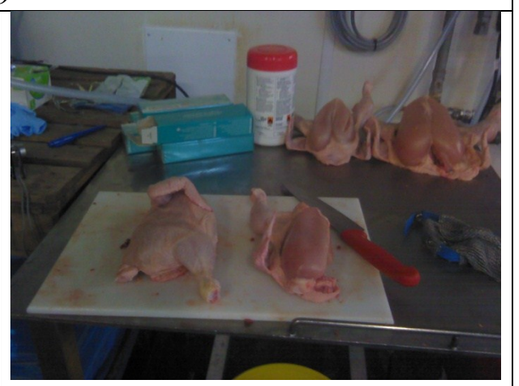
	
Chicken 19 d. Small Half Chicken - 30secs at 115ºC – Pre-Treatment	
19	
	
Chicken 19 e. Small Whole Chicken - 30secs at 115ºC – Post-Treatment (showing treated half on the left)	
19	

Figure 5: Aerobic plate counts from chicken breast skin samples after storage for 1 or 7 days after treatment with plain water, electrolysed water, or no water. (Error bars are 95% confidence intervals).

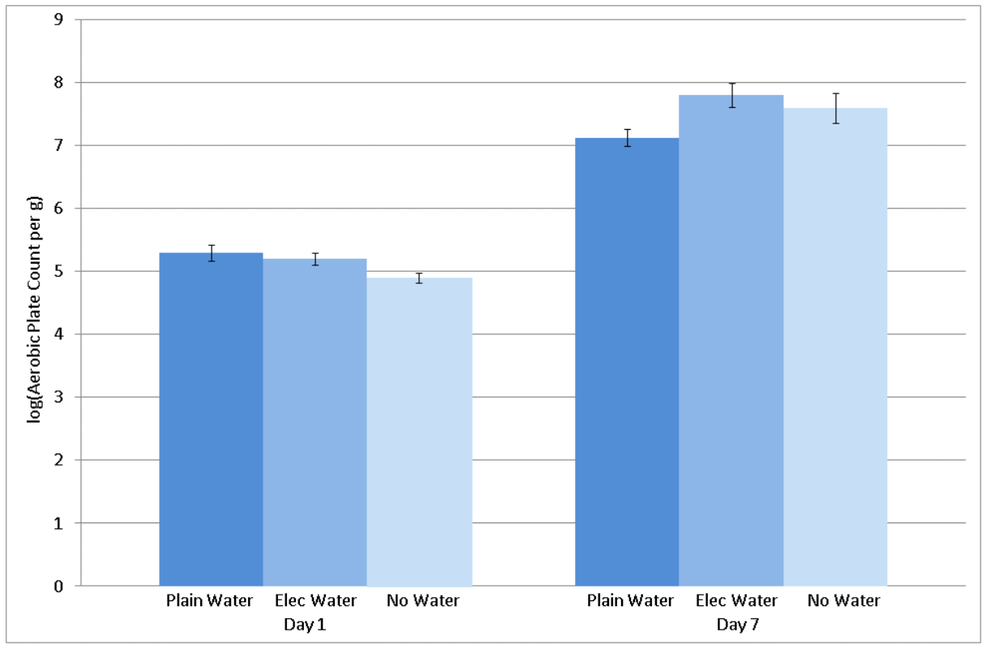


Figure 6: Confirmed counts of *Campylobacter* from chicken breast skin samples after storage for 1 or 7 days after treatment with plain water, electrolysed water, or no water. (Error bars are 95% confidence intervals).

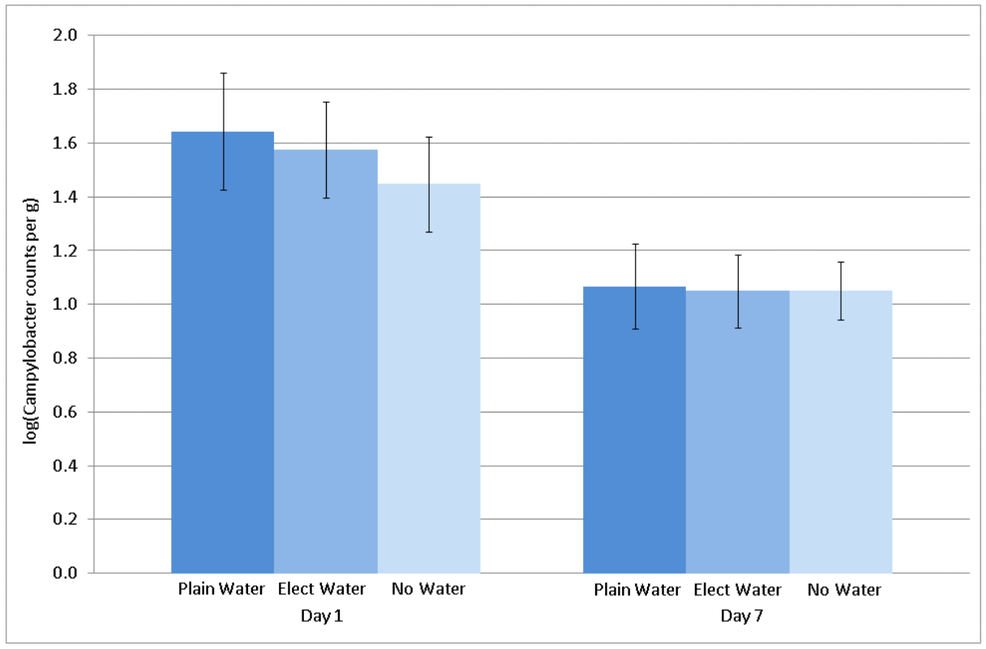


Figure 7: Aerobic plate counts on breast skin samples at Days K+1 and K+7 taken from untreated samples and those treated with chlorine dioxide. (Error bars are 95% confidence intervals).

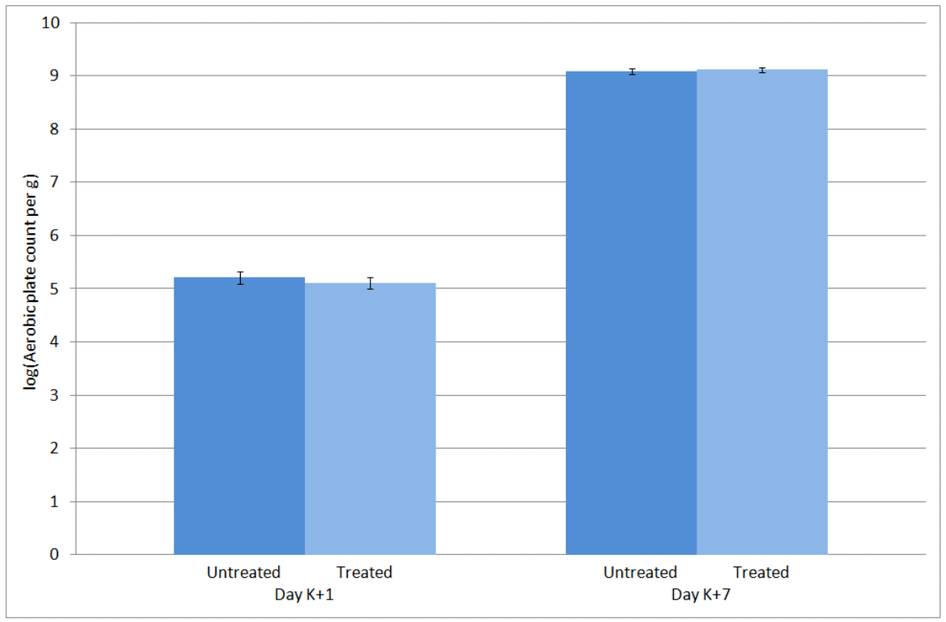


Figure 8: *Campylobacter* counts on breast skin samples at Days K+1 and K+7 taken from untreated samples and those treated with chlorine dioxide. (Error bars are 95% confidence intervals).

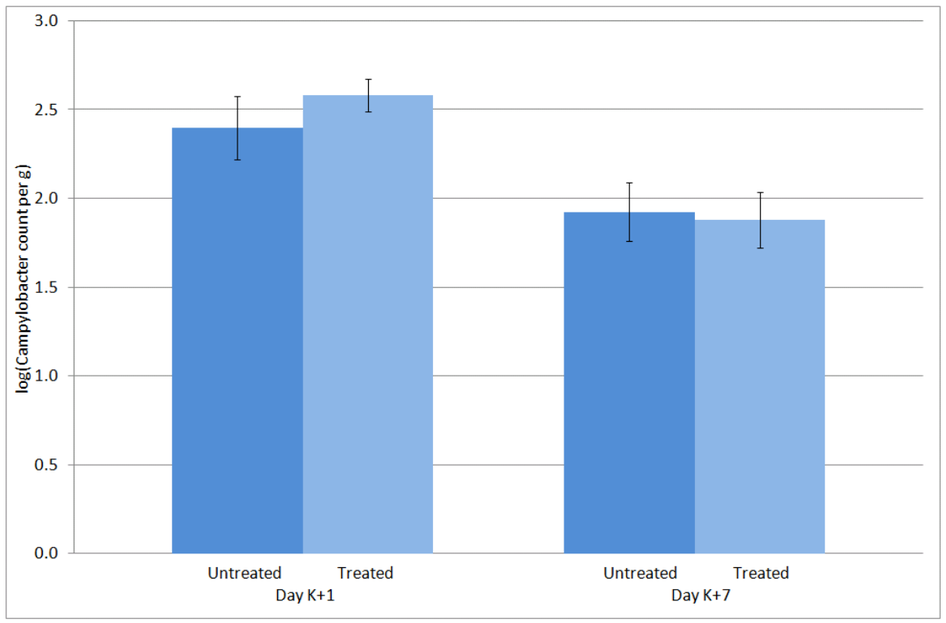
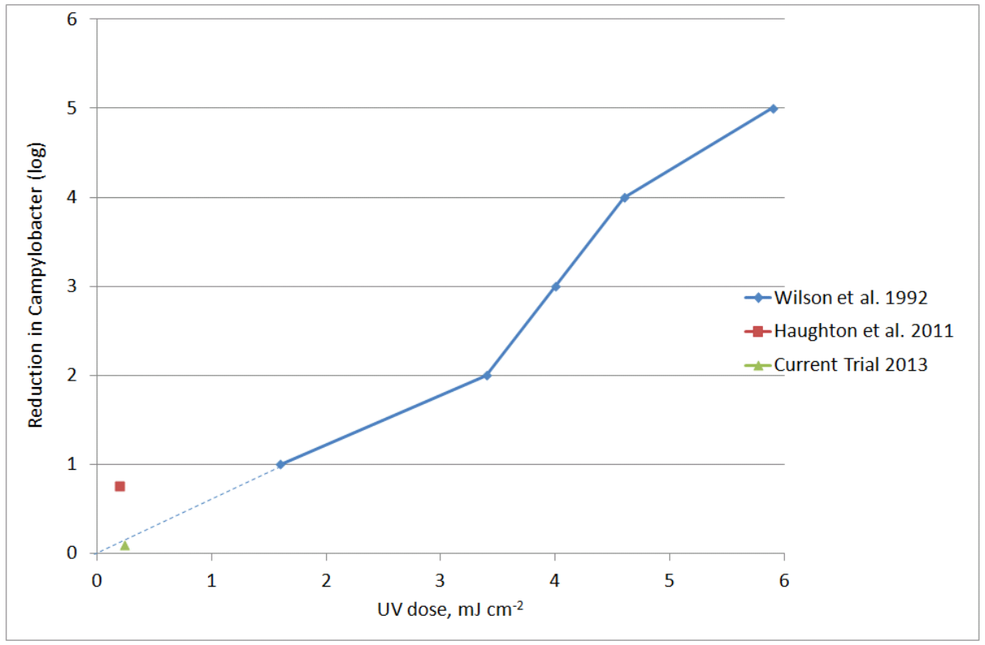


Figure 9: Comparison of reductions in numbers of *Campylobacter* found in previous studies and the current trial



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