Consumer preferences of poultry decontamination methods on the island of Ireland

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Executive summary

Campylobacter is the leading cause of bacterial food poisoning on the island of Ireland (IOI) with 3,772 cases reported in 2015 (Health Protection Surveillance Centre [HPSC] 2016, Public Health Agency [PHA] provisional, unpublished data, 2016). Poultry – domestic fowl, such as chickens, turkeys, ducks and geese – is the main food associated with *Campylobacter* food poisoning.

In 2010, the UK Food Standards Agency's *Campylobacter* citizens' forums surveyed consumers to determine: the awareness of *Campylobacter*; purchasing habits; and the acceptability of interventions, or actions taken, to control *Campylobacter* at farm, processing and retail level. There was little awareness about *Campylobacter* and its effects. In relation to potential slaughterhouse decontamination treatments, there was concern that processing interventions affect the taste, smell and texture of meat. Respondents felt that these changes would be unpopular.

Forum respondents recognised that *Campylobacter* presented a significant public health risk. They supported interventions designed to reduce the level of the bacteria on chicken sold to the public, which they felt would be reassuring to consumers. However, they felt it would be important to promote hygienic handling of chicken to ensure that the public do not become complacent about their responsibility to protect themselves (Food Standards Agency [FSA], 2013).

This *safe*food-funded study builds on previous research (such as that carried out by the FSA) but it is designed for the IOI's needs, market structure and resources. The study, led by University College Dublin (UCD), aims to gain an understanding of the acceptability of poultry decontamination methods to consumers on the IOI, as this will influence their practical application in the poultry industry.

The project had 4 objectives:

1. To identify new and existing decontamination methods in poultry processing. These include methods currently in use and authorised for use in the European Union (EU). The reported efficacy of the decontamination methods was also looked at, through data gathering in focus groups with industry stakeholders and a review of academic and "grey" literature and reports from governments and other organisations. (Grey literature means information produced by people and organisations that are not academic or traditional publishers.)

2. To ascertain consumers' understanding of the problem of *Campylobacter* contamination in poultry, through a "mixed method" approach. Consumers participated in both focus groups and telephone surveys.

3. To determine consumers' attitudes to present and potential interventions. These include the most and least acceptable. This objective was also achieved through a mixed method approach. Consumers participated in both focus groups and telephone surveys.

4. To identify barriers to consumer acceptance of interventions and how acceptability might be improved, for example, by the provision of additional information or improved communication with consumers, again through a mixed method approach. Consumers participated in both focus groups and telephone surveys. The interventions included in the quantitative survey were identified through the focus groups. The final results should help to inform policy makers of the challenges faced by both industry and consumers regarding *Campylobacter* decontamination methods for poultry.

Several aspects of poultry decontamination were considered, including <u>but not limited to</u>

- Biosecurity (methods to protect against infection)

- Water treatment

- Thinning (removing some of the flock)

- Transportation

- Vaccination against infection

- "Competitive exclusion" (CE), that is, introducing other bacteria that will make it impossible for *Campylobacter* to exist

- Processing

- In-feed additives.

There were several key findings of this project. It identified that

- There is little awareness of *Campylobacter* among consumers.

- Consumers have no knowledge of how bacteria enter the poultry supply chain, or of potential interventions to control bacteria.

- Consumers on the IOI place their trust in retailers to sell them safe food.

- A consumer's reaction to any decontamination process is strongly influenced by the vocabulary used to describe it.

- Consumers from the IOI show a preference for what they perceive as "natural" and non-invasive decontamination processes.
- Irradiation and organic and chemical washes are considered invasive.
- Forced air chilling ranks as the most acceptable intervention followed by crust freezing, steam ultrasound, cold plasma and organic acid washes.
- Chemical washes are the least acceptable decontamination method.
- 67% of respondents would like to see information on the product label about treatments used in the processing plant to kill bacteria.

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Abbreviations

AGP	antiobiotic growth promoter
AMP	antimicrobial peptide
ASC	acidified sodium chlorite
BEUC	Bureau Européen des Unions de Consommateurs
BWG	body weight gain
CAP-Pen	cold atmospheric plasma pen
CE	competitive exclusion
CF	crust freezing
CFU	colony-forming units
CO_2	carbon dioxide
CP	capric acid sodium salt
CPC	cetylpyridinium chloride
CSO	Central Statistics Office
DAFM	Department of Agriculture, Food and The Marine
DBD	dielectric barrier discharge
DNA	deoxyribonucleic acid
EFSA	European Food Safety Authority
EO	Electrolysed oxidising (water)
EU	European Union
FA	fatty acid
FSA	Food Standards Agency
FSAI	Food Safety Authority of Ireland
GTP	guanosine triphosphate
He	helium

HPSC	Health Protection Surveillance Centre
IOI	island of Ireland
MAP	modified atmosphere packaging
MCFA	medium-chain fatty acid
MG	monoglycerides
N_2	nitrogen
NI	Northern Ireland
NUV−Vis	near ultraviolet−visible
O_2	oxygen
O_3	ozone
PAA	peracetic, or peroxyacetic, acid
PFGE	pulsed-field gel electrophoresis
PFU	plaque-forming units
PHA	Public Health Agency
ppm	parts per million
ROI	Republic of Ireland
RT−qPCR	Reverse Transcriptase − quantitative Polymerase Chain Reaction
SCFA	short-chain fatty acid
TSP	trisodium phosphate
TVC	total viable count
UCD	University College Dublin
UK	United Kingdom
USA	United States of America
USDA FSIS	United States Department of Agriculture Food Safety and Inspection Service
UV	ultraviolet
UVC	ultraviolet-C
WHO	World Health Organisation

Acknowledgements

The research team then designed a telephone questionnaire, with reference to the focus group findings.

The findings of this research are presented throughout the document. Considerable acknowledgement must go to all industry stakeholders named individually, along with Ipsos, UCD and Devenish Nutrition.

1 Introduction

Campylobacter is the leading cause of bacterial food poisoning on the IOI with 3,772 cases reported in 2015 (HPSC, 2016, PHA provisional, unpublished data, 2016). *Campylobacter* infections are generally mild but can be fatal among very young children, the elderly and immunosuppressed individuals. The bacteria normally inhabit the intestinal tract of warm-blooded animals, such as poultry and cattle, and are frequently detected in foods derived from these animals. The main food associated with *Campylobacter* food poisoning is poultry – domestic fowl, such as chickens, turkeys, ducks and geese.

Reducing levels of *Campylobacter* on poultry products by 1 $\log_{10}$ has been estimated to decrease human risk by between 50% and 90% (European Food Safety Authority [EFSA], 2011).[1] There are a number of processing methods that can be applied to poultry to reduce the overall level of *Campylobacter* contamination, however, the overall consumer acceptability of these methods is unknown.

***safe*food** commissioned this research project (an investigation of customer acceptance of processing interventions) as part of their *Campylobacter* strategy. This is in order to produce a quantitative (measurable) assessment of consumers' attitudes towards potential decontamination treatments and processes to reduce the level of bacteria, in particular *Campylobacter*, on raw meat on the IOI.

The research was proposed in August 2015 and discussed by the *Campylobacter* Stakeholders Group. It was commissioned by ***safe*food** in December 2015, with results to be delivered in late autumn 2016.

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[1] "Log reduction" describes the relative number of live microorganisms eliminated from a surface by decontamination processes. A 5-log reduction means lowering the number of microbes by 100,000-fold; if the surface has 100,000 microbes on it, a 5-log reduction would reduce that number to one.

2 Research methodology and objectives

Literature review

The range of academic literature available on *Campylobacter* prevention is vast. The literature review includes a mix of grey literature, academic literature and case studies. Effective strategies for reducing *Campylobacter* in poultry were taken from the literature. They include both a reduction of the levels of the organism in the live birds and a continuation of the control strategies through to the slaughterhouse, processing plant, retail setting and the domestic kitchen.

Therefore, several aspects of poultry decontamination will be considered in this project. These include (but are not limited to) biosecurity, water treatment, thinning, transportation hygiene, vaccination, competitive exclusion, processing and in-feed additives.

The consumer engagement component of the project specifically targeted factory interventions and their acceptability by consumers.

Qualitative focus groups with consumers

Before the quantitative phase began, qualitative work was conducted with a general audience to gain an initial understanding about how consumers react to the various types of possible meat decontamination treatments.[2] There is a range of possible interventions; this study has focussed on a few.

This exercise attempted to engage with consumers and seek their views. If an intervention is to be successful, it will have to be acceptable to consumers. How to achieve this presents a challenge for stakeholders in the future.

The focus groups enabled us to understand how consumers perceive the interventions, and to identify the six most likely to be acceptable to include in the subsequent quantitative research. The decision on which treatments to include in the surveys was also influenced by the view of the Republic of Ireland (ROI*) Campylobacter* Stakeholder Group. This is because consumers would not know which treatments are possible, and practical, to use.

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[2] "Qualitative" research relies on observations and insights drawn, for example, from focus group discussions. "Quantitative" study is measurable data, such as that recorded in a survey or questionnaire.

While the main objective was to present the various interventions and understand how they are perceived by the audience, the five focus groups conducted across the ROI and Northern Ireland (NI) also included discussion on topics such as:

- Meat preparation and consumption
- Precautions taken during storage, defrosting and cooking
- Awareness of *Campylobacter* and other bacteria that cause food poisoning
- Attitudes towards origin of meat.

Quantitative surveys with consumers

The quantitative element of this research consisted of two "omnibus surveys" across the ROI and NI. (In omnibus surveys data is collected on a range of topics for several organisations or companies at once.) Each survey interviewed a representative sample of around 1,000 respondents.

The most important objective of the surveys was to assess the level of acceptability of each of the six meat decontamination treatments investigated. Other objectives were to

- Identify respondents' cooking responsibilities in the household as well as the frequency of chicken preparation and consumption
- Understand what the most prevalent cause of food poisoning is perceived to be
- Assess consumers' levels of awareness of bacteria that cause food poisoning, and of *Campylobacter* in particular
- Identify where consumers typically buy raw meat and whether they show any preference for seeing information on the label about the decontamination treatment used on the product
- Gathering information on the proportion of households that include someone under the age of four or over 65 years old, or with diabetes or other long-term illness; and whether any special measures are taken when preparing food for these family members.

3 Literature review

This literature review focussed on both the existing and new methods of reducing *Campylobacter* contamination in the poultry industry.

Campylobacter is a Gram-negative, thermophilic, obligate microaerophilic bacteria that is ubiquitous in temperate environments (Newell & Fearnley, 2003).

- "Gram-negative" means the bacteria does not retain the crystal violet coloured stain as applied in Gram's Method but instead turns pink or red. This indicates that the bacteria has a particular type of cell wall. "Gram-positive" organisms will appear dark blue or violet, and have a different type of cell wall.

- "Thermophilic" bacteria thrive at high temperatures.

- "Obligate" organisms require a specific condition, such as the presence of a particular element or environment, in order to survive.

- "Microaerophilic" bacteria need oxygen in order to survive but the oxygen must be at a lower concentration than is found in the atmosphere. Microaerophiles often also require carbon dioxide, and at a higher concentration than is normally present in the atmosphere.

The two main strains of *Campylobacter* that are associated with illness in people are *Campylobacter jejuni* and *Campylobacter coli.* The favoured environment of *C. jejuni* appears to be the intestines of all avian (bird) species, in which they generally colonise as a "commensal organism" – meaning the bacteria thrive in their host organism without affecting it. In contrast, in humans the infection is associated with acute enteritis, that is, inflammation of the small intestine (Hermans et al., 2011a).

Campylobacter contamination of retailed chicken is a global phenomenon. It is reported that *Campylobacter* is responsible for the majority of intestinal infectious diseases worldwide (World Health Organisation [WHO], 2002; Allos, 2001), affecting 1.1% and 1.0% of populations in the United Kingdom (UK) and United States of America (USA), respectively, each year (Snelling et al., 2005a). However, due to under-reporting, the true public incidence is estimated to be up to 10 times higher than documented case numbers (Allos, 2001).

Both the incidence and prevalence of campylobacteriosis – infection caused by *Campylobacter* – have increased in developed and developing countries over the last 10 years (Kaakoush et al., 2015). In the ROI during 2015, 2,452 cases were reported to the Health Protection Surveillance Centre

(HPSC, 2016). In NI in 2015, *Campylobacter* remained the most common bacterial gastrointestinal infection with 1,320 laboratory reported cases (PHA, unpublished, provisional data, 2016).

The chicken "reservoir" – the infected chicken population – as a whole is estimated to be responsible for up to 80% of human campylobacteriosis cases (EFSA, 2010), with most *C. jejuni* infections acquired by the consumption and handling of poultry (Allos, 2001). "Broiler" chickens are bred and raised for meat production. The proportion of broiler flocks colonised with *Campylobacter* varies among countries. In the United States, a survey (Stern et al., 2001b) indicated that nearly 90% of flocks were colonised. In Europe, this prevalence varies from 18% to over 90%, with the northernmost countries having substantially lower figures than southern European countries (Newell & Fearnley, 2003).

In 2016, the FSA UK *Campylobacter* retail survey showed that 11% of chickens tested positive for the highest level of contamination (over 1,000 colony-forming units per gram [CFU/g]). Although this result was down from the previous result of 19% in the period between October and December 2014, *Campylobacter* prevalence still remains too high.

As a result of campylobacteriosis, substantial worldwide losses are accumulated annually because of clinical costs and lost working hours. For example, in the USA the annual cost of campylobacteriosis interventions to reduce the level of *Campylobacter* contamination in the poultry industry is $1.3 billion to $6.2 billion (Forsythe, 2000). In the UK, the median estimated costs to patients and the health service of *Campylobacter* during the 2008–2009 period was £50 million (Tam & O'Brien, 2016). In addition, the cost of *Campylobacter*-related Guillain–Barré syndrome hospitalisation was £1.26 million (Tam & O'Brien, 2016).

Campylobacter colonisation

Most studies indicate that "horizontal" transmission from environmental sources is the main route of flock colonisation by *Campylobacter* (Newell & Fearnley, 2003). ("Horizontal transmission" occurs between individuals of the same generation. In "vertical transmission", the infection passes from one generation to the next.)

The factors commonly associated with *Campylobacter* colonisation in broiler flocks include

- Reduced level of biosecurity on farms

- Presence of other animals close to poultry houses (including other poultry species, livestock, pets and wildlife)

- Age and number of houses on a poultry farm

- Slaughter age

- Size of flocks

- Practice of partial depopulation (thinning)

- Seasonal and climate changes

- Use of ventilators

- Fly population (and lack of fly screens)

- Use of old litter

- Farm equipment

- Transport vehicles and

- Farm workers

(Pattison, 2001; Hald et al., 2001; Newell et al., 2001; Slader et al., 2002).

Feed, fresh litter and water are rarely the sources of the initial introduction of *Campylobacter* into poultry flocks (Berndtson et al., 1996). Even so, they can be contaminated by the organism once in a poultry house where the birds are already colonised and thus can facilitate the spread of *Campylobacter* within production facilities.

On-farm interventions

On-farm interventions include decontamination methods that are incorporated pre-slaughter. The only intervention that has consistently been shown to be truly effective in commercial settings in preventing the introduction of *Campylobacter* is the application of strict biosecurity measures (Gibbons et al., 2001; WHO, 2012). However, other specific pre-slaughter interventions that have also been successful in research include water treatment, "no thinning" practices, transport hygiene and breeding for genetic resistance.

Farm biosecurity

Farm biosecurity is a set of measures designed to protect a property from the entry and spread of pests and diseases. Biosecurity adaptation on poultry farms can be variable.

It is estimated that human incursions (entries) into broiler houses can occur between 50 and 150 times over the life of a flock and constitute a significant risk for *Campylobacter* introduction (Wagenaar et al., 2006). The implementation of personnel hygiene and broiler house disinfection protocols were found to decrease the prevalence of *Campylobacter* from 80% to at most 40% (Gibbons et al., 2001). Rodent, wild bird and fly control have all been associated with reduced risks of *Campylobacter* colonisation (Allain et al., 2014; Hald et al., 2001, 2015).

In Nordic countries (Sweden, Denmark, Norway, Finland and Iceland), the use of fly screens as a biosecurity measure is common practice, with 50% to 90% risk reduction achievable in combination with strict biosecurity measures (EFSA, 2011). A reduction of *Campylobacter*-positive flocks from 41.4% (2003 to 2005, before fly screens) to 10.3% (2006 to 2009, with fly screens) has been reported in Denmark (Bahrndorff et al., 2013) (Figure 1). However, it must be noted that the use of fly screens may have a significant impact on the ventilation control within houses and so their implementation to date has been minimal.

Figure 1: *Campylobacter* prevalence before and after fly screen installation
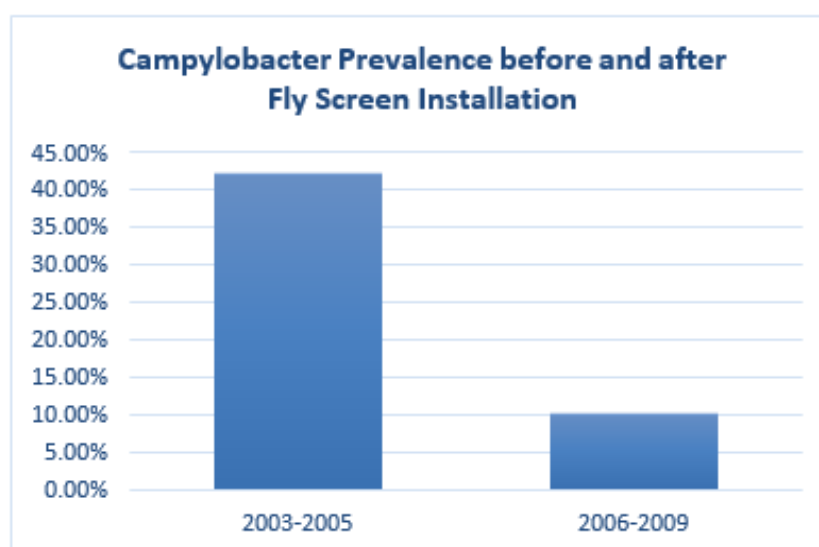
Biosecurity on a poultry farm must ultimately encompass appropriate decontamination methods pre-entry to the poultry house. This includes keeping certain standards within the house itself and meeting the guidelines of terminal hygiene upon bird removal at the end of the crop lifecycle.

Foot dips, footwear change, step-over barriers, handwashing facilities, drinker and feeder hygiene, optimal in-house and bird management (such as litter, water, temperature and humidity), poultry house boundary maintenance and traffic management and hygiene all are highlighted as key factors in the biosecurity protocol for preventing *Campylobacter* contamination. The protocol also clearly sets out contamination risks, and clearly defines them into primary, secondary and tertiary risk groups.

For terminal hygiene, a guide sets out with appropriate standards and recommendations at each phase – dry clean-out, wet clean or wash, disinfection, drying out and dis-infesting.

Even the most stringent biosecurity measures do not always deliver *Campylobacter*-free flocks but the probability of being *Campylobacter*-free is greater if the biosecurity is good. Strict biosecurity measures can be potentially cost-prohibitive and hard to maintain, with variable effectiveness in different production systems (Newell et al., 2011; English, 2015; Dale et al., 2015). For example, a

study conducted on Finnish poultry farms concluded that biosecurity costs around 3.55 eurocents per bird and accounts for 8% of the total work time on broiler farms (Siekkinen et al., 2012).

However, biosecurity interventions should be considered an investment, not a cost to production, due to reduced cases of *Campylobacter*-positive flocks and the control of other infections that impact on the performance of the flock. Motivating growers is a challenge, and a change of historic practice often requires incentives or sanctions to achieve the desired behavioural change.

Water treatment

It has been suggested that there is an association between the sanitisation of water systems in commercially reared poultry flocks and a reduction in the prevalence of *Campylobacter* (WHO, 2012; Hansson et al., 2007a). *Campylobacter* contamination of a flock may occur through contaminated water coming onto the farm, or by on-farm contamination of the water or water delivery system. Bore-well water could be a risk (Newell & Fearnley, 2003), especially if draining local pasture land.

Isolate typing studies have not demonstrated that bacterial isolates from poultry house water supplies have gone on to cause colonisation in flocks (Zimmer et al., 2003), even in sequential or following flocks. In addition, the evidence for drinking water as a source of flock colonisation is largely circumstantial, with many studies failing to isolate *Campylobacter* from water supplies in poultry houses (Gregory et al., 1997). However, it is known that *Campylobacter* is notoriously difficult to recover from water (Pearson et al., 1993). Importantly, the frequency of disinfection of water lines is a statistically significant risk reduction factor in some (but not all) risk factor studies.

The ability of *Campylobacter* to form biofilms, in which microorganisms stick to each other and often to surfaces, makes water treatment and water system hygiene all the more important. Biofilms can protect bacteria in aquatic environments and have been shown to significantly improve the ability of *Campylobacter* to survive environmental stresses, such as desiccation (drying out), antimicrobial treatments, and so on (Reuter et al., 2007).

Methods to reduce the level of flock contamination through drinking water include chlorination and acidification of the water (disinfection by adding chlorine or organic acids). They also include the addition of glycerol monocaprate (monocaprin, which is an anitmicrobial treatment) and probiotic treatments that support beneficial or "good" bacteria. However, the reported efficacy of such treatments is variable in the literature.

Water chlorination (0.2–0.4 parts per million [ppm] free chlorine) combined with effective cleaning of the drinking system was found to reduce the proportion of *Campylobacter*-positive birds in a flock from 81% to 7% (Pearson et al., 1993). In addition, the treatment gave a 10^3- to 10^4-fold reduction in contamination levels on the carcass post–slaughter. Other studies have shown no improvement from chlorination of water (Stern et al., 2002). This may be because, although *Campylobacter* are sensitive to chlorine treatment when in free suspension, they appear to derive

some protection when present in mixed populations with other organisms, such as protozoa − single-celled organisms that live in water or as parasites (Snelling et al., 2005b; Vieria et al., 2015).

The acidification of drinking water has been reported to decrease the risk of *Campylobacter* colonisation in broiler flocks, with reported reductions of 4.25 $\log_{10}$ CFU in broiler ceca (a pouch found at the junction of the large and small intestine) compared with a control group at slaughter age (Allain et al., 2014; Jansen et al., 2014). Lactic acid addition to water during feed withdrawal has been shown to significantly reduce the isolation incidence of *Campylobacter* (62.3% in treatment as against 85.1% in the control groups) recovered from crop samples (Byrd et al., 2001).

A commercially available product, containing formic acid, acetic acid, lactic acid and propionic acid, was shown to significantly decrease *Campylobacter* transmission between infected and susceptible broilers that were spatially separated, i.e separated from other birds (Van Bunnik et al., 2012). However, when the spatial separation was eliminated, water acidification did not have an impact.

The addition of 5 mm and 10 mm of monocaprin emulsions to *Campylobacter*-spiked chicken feed significantly reduced the bacterial contamination of the feed (Thormar et al., 2006). In addition, it was found that monocaprin emulsions were active against *C. jejuni* in 160- to 200-fold final dilutions in tap water, and they caused a > 6- to 7-$\log_{10}$ reduction in viable bacterial count in one minute at room temperature.

In another study, the addition of emulsions of glycerol monocaprate (monocaprin) to drinking water and feed was found not to prevent the spread of *Campylobacter* from artificially infected to non-infected 24-day-old chickens. However, *Campylobacter* counts in cloacal swabs were significantly reduced, particularly during the first two treatment days (Hilmarsson et al., 2006).[3]

Interestingly, in the kitchen environment glycerol monocaprate (monocaprin) has also been found to reduce the contamination of hard surfaces by *Escherichia coli* and *Salmonella enteritidis*, killing *S. enteritidis* in chicken meat juice on plastic cutting boards. It also reduced the number of viable *E. coli* and *S. enteritidis* by more than 5 $\log_{10}$ in two minutes on a laminated plastic kitchen counter contaminated with nutrient broth (Thormar & Hilmarrson, 2011).

Probiotic supplements have also been administered through water with effect. The application of 2 mg per bird per day of PoultryStar® sol (a probiotic product that contains *Enterococcus faecium*, *Pediococcus acidilactici*, *Bifidobacterium animalis*, *Lactobacillus salivarius* and *Lactobacillus reuteri*) through drinking water to challenged birds significantly reduced the cecal colonisation of *Campylobacter*. At day 15, all *Campylobacter*-positive control birds had counts > 8 $\log_{10}$ CFU/g,

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[3] "Cloacal swabs" are samples of material taken from the cloaca, a cavity at the end of the bird's digestive system into which the intestinal and urinary fluids empty before being excreted. In female birds semen is also collected in this cavity.

whereas the PoultryStar® group's maximum count was 4.1 $\log_{10}$ CFU/g, and half the birds had counts < 2 $\log_{10}$ CFU/g (Abdelrahman, 2014).

In a second experiment it was found that the application of 2 mg or 20 mg per bird per day of PoultryStar® sol through the water significantly reduced *Campylobacter* cecal colonisation, with PoultryStar® groups showing a 6-$\log_{10}$ reduction compared with the positive control.

Thinning

"Thinning" is the early removal of a portion of birds that are at the correct market weight. This creates space for the rest of flock for continued growth. The thinning process requires the entry of personnel and catching equipment into broiler houses. Such incursions can increase the risk of *Campylobacter* transmission within and between flocks, with reports of thinning leading to the contamination of 50% of flocks that were previously *Campylobacter*-free (Hermans et al., 2011b, 2012; Allen et al., 2008). In a recent study, *Campylobacter* prevalence was found to increase to > 85% in both high- and low-performance farms across all seasons at final depopulation, suggesting that *Campylobacter* was introduced during thinning (Smith et al., 2016).

Studies have shown that farm driveways, transport vehicles, equipment and personnel can be contaminated with *Campylobacter* before thinning. Pulsed-field gel electrophoresis (PFGE) typing indicated a spread of particular strains from one farm to another during thinning by transport vehicles, equipment and personnel (Allen et al., 2008).[4]

In addition to the enhanced stress the thinning process places on the birds that remain, the withholding of water and feed for up to 12 hours prior to thinning is a further cause of stress. This is a common industry practice carried out to decrease intestinal content and intestinal rupture, thereby decreasing the probability of carcass contamination. Unfortunately, feed withdrawal can be associated with increased pecking of manure-contaminated litter, which may increase the amount of pathogens in the intestine of the chickens (Thompson & Applegate, 2006). Stressed birds are more likely to be susceptible to any infectious agents, including *Campylobacter.*

The discontinuation of thinning (a "zero thinning" or "no thinning" system) has been shown to have a positive effect on *Campylobacter* reduction in broiler flocks. For example, after thinning ceased in Iceland, the number of *Campylobacter*-positive flocks reduced from 40% to 15% per year (Strydom, 2014).

Zero thinning is an option that is being considered by retailers. However, this would impact on the cost of production. The industry claims it would need additional payments for poultry farmers who

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[4] "Pulsed-field gel electrophoresis" (PFGE) typing is a highly accurate means of detecting the presence of organisms by applying a changing electrical current to a gel "matrix". This matrix is the substance in which the organisms are held and subsequenty separated for identification during the test.

do not thin their flocks, to make up for their lost performance due to reduced bird numbers. It has been estimated that it would cost up to 10p per bird to introduce the measure (Food Safety News, 2015).

Some researchers believe that the stocking density in the UK should be reviewed (Strydom, 2014). Under the Red Tractor Farm and Food Assurance scheme, broiler farms are not allowed to exceed 38 kg of weight per square metre, while European legislation states that farms can stock up to 42 kg/m^2 provided defined welfare outcomes are met. The UK could increase the permitted stocking density for broilers reared in "no thinning" systems, which would help to reduce the cost implication that would be associated with a no-thinning policy.

Another measure that could be introduced to allow for the discontinuation of thinning is restricting the slaughter age of indoor birds to a maximum of 28 days. This would achieve up to 50% risk reduction (EFSA, 2011), compared with the 25% risk reduction achieved by discontinuing thinning. However, such control solutions, although technically advisable, interfere strongly with current industrial practices and lead to a reduced range of bird weights on offer to the consumer.

Transportation

After catching, the birds are transported to the processing plant in transport crates. Increased stress during the catching process causes increased defecation. In addition, crate design allows for the spread of faeces between birds. Feed withdrawal is practiced to try to minimise faecal spread but significant opportunity still exists to spread *Campylobacter* within a flock.

This type of inter-bird contamination tends to give an increase in *Campylobacter* numbers on the outer surfaces of the bird, particularly the feathers, and this increases the contamination load entering the slaughterhouse. Flocks that are contaminated just prior to slaughter cause a lower level of carcass contamination than birds that had been colonised on-farm, presumably because contamination was restricted to external surfaces and the *Campylobacter* has not the opportunity to multiply inside the birds (Hansson et al., 2007b).

The recycling of contaminated crates between the processing plant and the rearing farms poses a risk of flock–to–flock transmission of *Campylobacter,* particularly if depopulation takes place over an extended period. It is reported that, over a two-year period, 23.5% of empty crates used during thinning were contaminated with *Campylobacter* (Allen et al., 2008). *Campylobacter* can survive on transport cages in faeces dried at ambient temperature (18 to 31 °C) for up to eight hours, and levels only reduce by a half after 24 hours (Berrang et al., 2004).

It is recommended that both modules and crates should be washed and disinfected thoroughly after each use. This is in order to reduce cross-contamination between *Campylobacter*-positive and -negative flocks and decrease the amount of contamination introduced in the slaughter facility (Allen et al., 2008).

However, a number of studies have shown that many crates can still be contaminated with *Campylobacter* or *Salmonella* after cleaning because they are very difficult to clean and sanitise (Corry et al., 2002; Hansson et al., 2005; Stern et al., 2001b).

It has been found that *Campylobacter* counts on crates before and after cleaning were 5.6 to 6.9 and 2.9 to 5.7 CFU per crate base, respectively (Allen et al., 2008). Studies suggest the use of ultrasound during crate cleaning to aid sanitisation (Allen et al., 2008), as it was found to improve cleaning by loosening attached soil. It was also found to have a synergistic effect with heat in killing microbes, meaning the two systems were more effective when used together than separately.

Modifications made to the washing system, which removed the soaking tank and introduced a high-performance washer fitted with high volume and high pressure nozzles, and a greatly improved filtration system, increased the reduction in *Campylobacter* counts by 1 to 2 $\log_{10}$. Increasing the water temperature to 60 °C, in combination with a detergent and followed by a disinfectant spray, resulted in a further significant reduction in numbers, and all trays were visually clean (Allen et al., 2008b).

Another modification in crate washing systems could be the inclusion of brushes in the soaking tank in order to enhance removal of faeces through mechanical action. More frequent replacement of crate washing water would also reduce the level of organic material present but additional detergent would be needed.

Examples of other modifications that have been tried include the use of biodegradable crates, the use of disposable crate liners and drying of cleaned crates before re-use (Berrang & Northcutt, 2005).

A big challenge is to maintain farmers' motivation to adhere to strict biosecurity. The arrival of crates that are not spotless, or thinning equipment that appears dirty, undermines farmers' motivation. Therefore, everyone has to pay attention to detail if good work early in the chain is not to be undermined at a later stage.

Vaccination

Some recent work has shown that the vaccination of chickens with recombinant *Campylobacter* peptides resulted in a reduction in the number of *Campylobacter jejuni* in the ceca compared with the non-vaccinated *Campylobacter*-challenged group (Neal McKinney et al., 2014). However, further work is needed, with research ongoing to find a successful and suitable vaccination policy.

Therefore, in spite of being widely used against other pathogens, no effective vaccine is available for *Campylobacter*. That *Campylobacter* is believed to be a commensal organism and is therefore not pathogenic or problematic to birds may influence their immune response.

Genetic Resistance

Some chickens have been reported to demonstrate resistance to *Campylobacter,* associated with the inhibition of a small GTPase–mediated signal transduction as well as the tumour necrosis factor receptor superfamily genes (Li et al., 2011).

Broilers have been intensively selected for "food conversion efficiency" (that is, the rate at which bird feed is converted to meat) and weight gain, and the strains of poultry used now are very different to those used a decade ago. The length of time required to reach a marketable weight has been reduced dramatically. If the same genetic selection techniques are used to seek out disease resistance perhaps varieties will emerge that are resistant to colonisation with *Campylobacter.*

Currently the breed of broiler affects the disease manifestation, with the slower-growing breeds being more robust. Humphry and co-workers argue that *Campylobacter* is a commensal organism in some breeds but can cause disease in other breeds (certain faster-growing breeds of broiler chicken) (Humphrey et al., 2014).

Selective breeding may be able to produce chickens that are resistant to *Campylobacter* and would be useful, provided it does not harm production traits. It should not increase the susceptibility of the birds to ailments or other pathogens (Sahin et al., 2015).

In-feed interventions

Competitive exclusion

Competitive exclusion (CE) has long been known to reduce *Salmonella* colonisation in chickens (Erickson & Doyle, 2008). The focus of CE is to colonise the gut with "good" bacteria rather than "bad" bacteria. This is usually achieved through the use of probiotics (microorganisms with beneficial qualities) or by encouraging the growth of "good" bacteria through the provision of the nutrients that they require (prebiotics).

The mechanism by which CE reduces *Salmonella* has been a matter of scientific speculation. Some explanations include

1. The antagonising or introduced bacteria preferentially occupy *Salmonella* intestinal colonisation niches (therefore leaving less room for *Salmonella*), or preferentially consume required substrates (using up the material on or from which the organisms grow).

2. The probiotic organisms have a shorter replication (self-reproduction) time than *Salmonella*, and so they outgrow the pathogen.

3. The antagonists produce volatile fatty acids associated with *Salmonella* lysis (that is, the process of *Salmonella* cell walls dissolving and releasing the particles contained inside).

4. Probiotic organisms elicit an immune modulation response in the host to clear *Salmonella*.

5. The CE bacteria produce metabolites (by-products of metabolism) that interfere with or kill the target organism.

As mentioned earlier, the multispecies probiotic product PoultryStar®, which contains *Enterococcus faecium*, *Pediococcus acidilactici*, *Bifidobacterium animalis*, *Lactobacillus salivarius* and *Lactobacillus reuteri*, has been found to significantly reduce *Campylobacter* loads in the ceca of broilers (up to more than 5 $\log_{10}$ CFU) at 8 and 15 days post–challenge (that is, following exposure to infection) when supplemented through the drinking water at 2 mg per bird per day (Ghareeb et al., 2012).

Feed additives

Prebiotics and probiotics

Many studies highlight the benefits of prebiotics and probiotics in poultry diets, with recent attention focussing on their use as antibiotic growth promoter (AGP) replacements. The increasing publicity associated with antibiotic-resistant pathogens, and the calls to reduce the amounts of antibiotics being used in livestock production, have put the spotlight on alternative approaches to keeping the livestock healthy.

In poultry, the probiotic product GalliPro® and prebiotic product TechnoMos® have been shown to serve as alternatives to AGPs (neoxyval) (Abudabos et al., 2015). This is due to the enhancement of broiler performance (Abudabos et al., 2015) through the improvement in the bird's intestinal morphology, or structure, in addition to the microbial balance associated with the modulation (the indirect influence) of intestinal microflora and the inhibition of pathogens.

There is reason to believe that these types of additives could contribute to a reduction in *Campylobacter* colonisation, with probiotics already reported to prevent pathogenic bacteria such as *C. perfringens* and *Salmonella* from colonising the gut (Abudabos et al., 2013).

To date, the use of probiotics in competitive exclusion trials to reduce the level of *Campylobacter* colonisation in the chicken gut have had inconsistent results (Stern et al., 2008). It was found that directly feeding prophylactic (that is, preventative) probiotic treatments was only effective when very low challenge levels were used. Otherwise, probiotic treatments failed to reduce *Campylobacter* colonisation. However, newer commercial products are becoming available that show more promise, as shown in Table 1 (Guyard–Nicodème et al., 2015).

The administration of *Bifidobacterium longum* PCB 133 in feed has been found to reduce *Campylobacter* by approximately 1 $\log_{10}$ in the faeces of experimentally infected chickens (Santini et al., 2010). When *B. longum* PCB 133 was combined with a prebiotic (galacto-oligosaccharide) no noticeable increase in effectiveness against *Campylobacter* colonisation was observed (Baffoni et al., 2012).

A study evaluating the effect of 12 different feed additives on *Campylobacter* cecal colonisation in live broilers found that, at 14 days, eight of the dietary treatments (Lactobutyrin BRC, Biotronic® Top3, PoultryStar®, Excential Alliin Plus, Excential Butycoat, Adimix® Precision, Anta®Phyt products and Campylostat) significantly decreased the colonisation by *Campylobacter* compared with the control group (Guyard−Nicodème et al., 2015). At 35 days of age, three of these dietary treatments (Lactobutyrin, PoultryStar® and Adimix® Precision) were still having a significant effect on *Campylobacter* counts. However, at 42 days Adimix® Precision was the only treatment that remained significantly efficient and showed an average reduction of more than 2 $\log_{10}$ CFU/g (Guyard−Nicodème et al., 2015).

Table 1: Effect of feed additives on *Campylobacter* cecal colonisation

Product	Dose (wt/wt)	Composition	Day 14	Day 35	Day 42
Control	––	––	8.23	7.50	6.29
Lactobutyrin	0.600%	Monoglyceride mixture	7.50*	6.44*	5.67
Biotronic® Top3	0.100%	Short-chain fatty acid (SCFA) mixture	7.17*	7.66	6.77
Campylostat	4.500%	SCFA + monoglycerides	6.20*	7.53	6.99
Adimix® Precision	0.300%	SCFA (butyrate coated on microbeads)	7.11*	6.59*	4.16*
Excential Butycoat	0.100%	SCFA (butyrate coated on microbeads)	7.78*	7.31	5.72
Power-Protexion®	0.150% starter 0.100% grower 0.100% finisher	SCFA + plant extract	7.79	7.00	5.99
Excential Alliin Plus	100%	Plant extract	7.27*	7.19	6.23
Anta®Phyt	0.100%	Plant extract	7.09*	7.50	6.92
Calsporin®	0.010%	Probiotic	7.98	7.57	4.59*
Ecobiol®	0.100%	Probiotic	8.42	6.38	5.01
PoultryStar®	0.100%	Multispecies probiotic	7.69*	5.62*	6.70
Original XPC™	0.125%	Prebiotic–type compound	8.18	7.93	3.13*

*Significant log 10 reduction

In a sister study using a further 12 different feed additives, which included plant extracts, monoglycerides (MGs), medium-chain fatty acids (MCFAs), essential oils, and so-on, it was found that the MCFA and MG–MCFA treatments were effective in reducing *Campylobacter* counts when

supplemented in-feed (Gracia et al., 2015). However, no significant results were observed when they were included in the drinking water (Table 2).

Table 2: Effect of feed additives on *Campylobacter* cecal colonisation including plant extracts, monoglycerides, medium-chain fatty acids and essential oils

Trial number	Feed additive	$\log_{10}$ CFU/g 21 days post–challenge	$\log_{10}$ CFU/g 21 days post–challenge
Trial 1	TI Control	8.66 a	8.4 a
	C8 and C10 mixture (50%)	7.75 a	8.33 a
	Monoglycerides of C8 and C10 (50%)	7.72 b	7.52 b
Trial 2	T2 Control	7.36	6.30
	Bacillis subtilis DSM 17299	7.54	6.72
Trial 3	T3 Control	7.38	7.71
	Essential oil components including thymol, eugenol and piperine + benzoic acid	7.26	7.65
	Herbal substances and essential oils mixture (containing thymol and anethole, spices and	7.77	6.91
	Saccharomyces cerevisiae boulardii	7.13	7.44
	Propionic acid glycerol esters and oregano	7.03	7.83
Trial 4	T4 Control	7.66	7.53

	Monoglycerides of C3, C4, C8, C10 and C12 (in water)	7.22	6.87
	Monoglycerides of C3, C4, C8, C10 and C12, formic acid, ammonium formate, sodium formate and sodium sorbate (in water)	5.36	5.80
	Calcium propionate, sorbic acid and flavouring compounds	8.48	8.07
	Coated source of formic acid and citric acid and encapsulated blend of essential oils including thyme, oregano, capsicum and citrus extract	7.51	6.81

Organic acids

Similar to their use in water, organic acids also have been used for the acidification of chicken feed. This is based on the premise that ingested organic acids might lower the pH in the chicken gut, rendering it more hostile to *Campylobacter* colonisation, as *Campylobacter* prefers a pH of between 6.5 and 7.5.[5]

Although in-vitro (laboratory-based) studies have demonstrated that organic acids, medium-chain fatty acids or monoglycerides of MCFAs have a strong bactericidal effect on *Campylobacter* spp. ("spp." means more than one species), inconsistent results have been reported in in-vivo trials (trials conducted on live animals).

The use of butyrate, acetate, propionate and L-lactate for the control of *Campylobacter* infections in broilers has been investigated (Van Deun et al., 2008a). Butyrate-coated micro-beads were found

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[5] "pH" stands for "the potential of hydrogen" and is used to measure how acid or alkaline a substance is. On a scale of 0 to 14, pH below 7 is acid, pH above 7 is alkaline and pH 7 is neutral – not acid or alkaline.

not to protect broilers from cecal colonisation with *Campylobacter*, despite the marked bactericidal effect of butyrate towards *Campylobacter* in vitro. This is possibly due to the protective effect of mucous and the rapid absorption of butyrate by the enterocytes (intestinal cells). However, butyrate is able to protect Caco-2 intestinal cells from two major "virulence mechanisms" that increase the effectiveness of *Campylobacter* colonisation – invasion and translocation – but not from a decline in transepithelial resistance (Van Deun et al., 2008b).

A 0.7% dose of caprylic acid can consistently reduce the *Campylobacter* counts compared with the positive control in 10-day-old chicks (Solis de los Santos et al., 2008). In addition, caprylic acid at 0.35% and 0.70% has been shown to consistently decrease the colonisation of *C. jejuni* in the chicken ceca of 42-day-old chickens compared with a positive control (Solis de las Santos et al., 2010). When these treatments were evaluated after a 12-hour feed withdrawal period, 0.7% caprylic acid decreased *Campylobacter* colonisation in the three-day treatment supplementation. Caprylic acid's ability to reduce *Campylobacter* does not appear to be due to changes in cecal microflora (Solis de los Santos et al., 2009).

Figure 2: Cecal *Campylobacter jejuni* counts in 42-day-old broiler chickens fed caprylic acid for three days (trials 1 and 2) or seven days (trials 3 and 4) before necropsy or autopsy
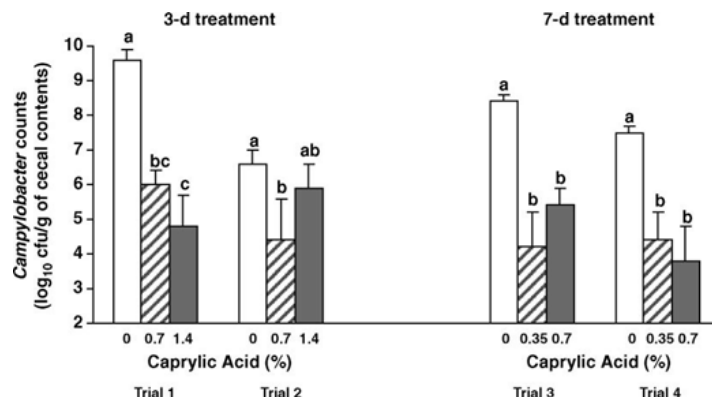
Source: Solis de los Santos et al., 2009.

Medium-chain fatty acids (caproic, caprylic and capric acid), fed from three days before kill, were not capable of reducing cecal *Campylobacter* colonisation in 27-day-old broilers that had been experimentally infected with *Campylobacter* at 15 days of age (Hermans et al., 2010).

However, other studies found positive effects of MCFA supplementation (Van Gerwe et al., 2010; Nutriad, 2015). A mixture of medium-chain fatty acids (C8 to C12) was found to influence *Campylobacter* colonisation and body weight gain (BWG). This was shown through beta-binomial dose response modelling of the colonisation status at 14 days post–inoculation with *Campylobacter*. The *Campylobacter* dose necessary to colonise 50% of inoculated broilers was

estimated to be 200 times higher in broilers fed with supplemented feed ($\log_{10}$ 4.8 CFU) than in control broilers ($\log_{10}$ 2.5 CFU). In addition, feed conversion was not affected, while body weight gain was 49 g higher in supplemented broilers.

Treatment with mono mix powder (monoglycerides of butyric, caprylic and capric acid) in-feed in the first 10 days of the life of the bird (before the experimental challenge of infection) has been found to exert a protective effect against *Campylobacter jejuni* colonisation (Tosi & Massi). In addition, a further treatment with mono mix in the drinking water during the last five days of life (pre–slaughtering treatment from 32 to 37 days) resulted in a further reduction of 2 $\log_{10}$ compared with the CFU determined at day 17.

Adimix® (a coated sodium butyrate) supplementation has had positive effects on *Campylobacter* reduction (Nutriad, 2015). Feeding Adimix® at 5 kg/t can reduce *Campylobacter* counts to below the detection limit of 2 $\log_{10}$ at day 29. Both the 3 kg/t and 5 kg/t inclusions can reduce counts to below the detection limit at day 39 (Figure 3).

Figure 3: Effect of Adimix® on *Campylobacter* growth
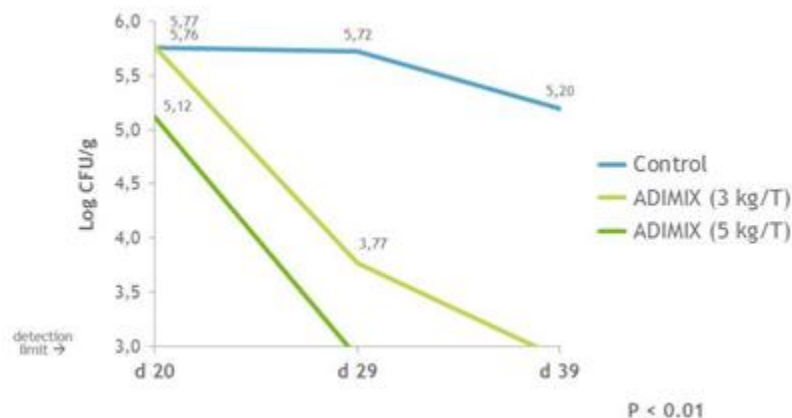
Source: Nutriad, 2015

After broilers were orally infected with *Campylobacter* at day 18, the addition of 3 kg/t of Adimix® reduced cecal *Campylobacter* by a minimum of 2 $\log_{10}$ units by day 39 when included in the feed from the moment of infection onwards (Nutriad, 2015).

In contrast, Adimix® 30 C (30 per cent coated) at 3 kg/t and 5 kg/t was shown not to have a significant effect on *Campylobacter* spp. counts in caeca, and that the effect of the sodium butyrate additive on *Campylobacter* infection was not conclusive (Tello–Velamazán et al., 2015).

The use of formic acid has had positive results, with a combination of 1.5% formic acid and 0.1% sorbate reducing the colonisation of *Campylobacter* significantly. A concentration of 2.0% formic

acid in combination with 0.1% sorbate has been shown to prevent *Campylobacter* colonisation in chickens (Skånseng et al., 2010). In addition, the use of a probiotic preparation containing *Pediococcus acidilactici* and *Saccharomyces boulardii* followed by acidifiers, such as formic and lactic acids, resulted in a significant reduction in the *Campylobacter* rate of shedding and re-isolation (by which the pathogen replicates or reproduces itself) (Abd El-Ghany et al., 2015).

Plant extracts

A wide range of plant extracts and compounds have demonstrated strong bactericidal activity against *Campylobacter* spp. in vitro (Hermans et al., 2011; Sirirak and Voravuthikunchai, 2011; Robyn et al., 2013). However, when evaluating in-vivo results, the data is not conclusive.

Natural plant extracts, such as thymol and carvacrol, have been shown to have efficacy against other enteric pathogens (diseases that can affect the intestines). Treatments with 0.25% thymol, 1.00% carvacrol or 2.00% thymol treatments, or a combination of both thymol and carvacrol at 0.50% were found to reduce *Campylobacter* counts (Arsi et al., 2014) in a study using day-old broiler chicks.

Epps et al. (2015) compared the bactericidal activities of free thymol and the conjugated, or combined, form, thymol-beta-D-glucopyranoside (which is more resistant to absorption), on *Campylobacter jejuni* and *Campylobacter coli*. This was carried out during pure culture tests and during "co-culture" tests with a beta-glycoside–hydrolysing gut bacterium, *Parabacteroides distasonis*, as well as during culture with mixed populations of porcine (swine, or pig) and bovine (cow) gut bacteria.

When treated with 1 mM thymol, *Campylobacter coli* and *jejuni* were reduced during pure or co-culture with *Parabacteroides distasonis*. Thymol beta-D-glucopyranoside treatment (1 mM) did not reduce *C. coli* and *C. jejuni* during pure culture but did during co-culture with *P. distasonis* or during mixed culture with porcine or bovine faecal microbes possessing beta-glycoside–hydrolysing activity. The results suggest that thymol-beta-D-glucopyranoside or similar beta-glycosides may be able to escape absorption within the proximal gut and become activated by bacterial beta-glycosidases in the distal gut.

Seafood by-products

Chitosan is a natural by-product derived from the deacetylation of chitin and is obtained from crab and shrimp shell waste. The exact mode of action of chitosan is not completely understood. However, researchers have previously determined that chitosan is capable of interacting with the outer cell membrane of bacterial pathogens, altering its permeability (that is, whether substances can pass through its cell walls), disrupting cellular physiology and causing cell death.

A dose of 0.5% of the medium molecular weight chitosan was found to reduce cecal *Campylobacter* counts in broiler chickens (Arambel et al., 2015). In addition, Reverse Transcriptase – quantitative Polymerase Chain Reaction (RT–qPCR) analysis revealed that chitosan down-regulated, or suppressed, the expression of chicken colonisation genes as compared with the control. This suggests that chitosan supplementation could be a potential strategy to reduce the enteric colonisation of *Campylobacter* in pre-harvest chickens.

Bacteriocins

Bacteriocins are a group of antimicrobial peptides (AMPs) produced by bacteria with narrow or broad "host ranges" – the number of different cell types a bacteria can infect. Significant progress has been made for the discovery of potent anti–*Campylobacter* bacteriocins from commensal bacteria isolated from the chicken intestinal tract (Lin, 2009). Although bacteriocins, such as defensins and cathelicidins produced by the chicken host, have shown to dramatically reduce *Campylobacter* colonisation in poultry, practical applications of this approach for on-farm control of *Campylobacter* have not been evaluated, likely due to the production cost of bacteriocins (Hoang et al., 2012).

Results have shown that when 250 mg of purified bacteriocins per kilo of feed, produced from *Lactobacillus salivarius* NRRL B-30514 and *Paenibacillus polymyxa* NRRL B-30509, were fed therapeutically (that is, as a treatment post–infection) to chickens colonised with *Campylobacter*, colonisation was reduced by at least one million-fold (Stern et al., 2008) (Table 3).

Table: 3 Effect of bacteriocins on *Campylobacter jejuni*

Bacteriocin	$\log_{10}$ CFU *Campylobacter jejuni*/g
Positive Control	9.08 ±* 0.38
Bacteriocin from *P. polymyxa* NRRL B-30509	Not detected
Bacteriocin from *L. salivarius* NRRL B-30514	0.34 ± 1.00

*The "±" sign indicates "standard deviation". This is the amount of possible variation or inaccuracy in the test results.

Dietary modulation of the synthesis of endogenous chicken antimicrobial proteins (that is, AMPs originating from inside the chicken) has emerged as a novel antibiotic–alternative approach to antimicrobial therapy (Zhang & Sunkara, 2014). A group of short-chain fatty acids (for example, butyrate) displayed a strong ability to increase the expression of nearly all 14 chicken endogenous AMPs. Oral administration of butyrate significantly reduced colonisation of *Salmonella enteritidis* (nearly a 10-fold reduction in the bacterial count) in the chicken cecum (Sunkara et al., 2011). These findings suggest the potential of dietary compounds to boost both poultry immunity and clearance of foodborne pathogens including *Campylobacter.*

Bacteriophages

Bacteriophages are viruses of bacteria that can be applied as pre-harvest and post-harvest interventions in food to reduce foodborne pathogens (Tan et al., 2014). Bacteriophages invade bacterial cells and, in the case of lytic phages, disrupt bacterial metabolism and cause the bacterium to "lyse" – their cell walls dissolve and particles inside are released (Figure 4). This approach is well documented in the literature.

Figure 4: Bacteriophage lifecycle
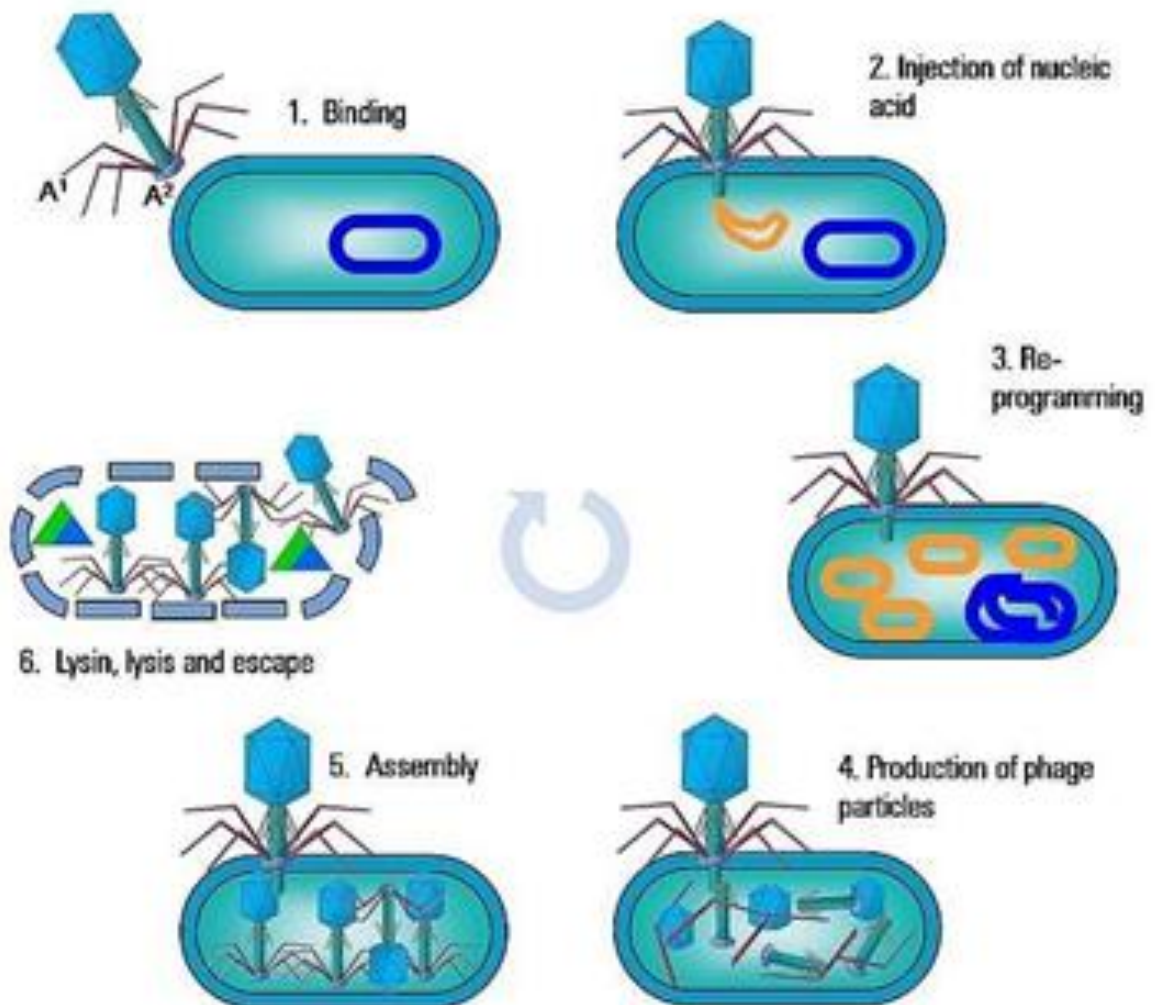
In pre–harvest interventions, the phages are usually administered directly to the live animal before being processed into meat. The purpose of such an approach is that bacteriophages may eliminate, or reduce, the colonisation of the pathogenic bacteria on the livestock prior to slaughter and carcass processing to ensure that the processed meat is free from those pathogens.

Phage–based technologies in the control of foodborne pathogens in post-harvest foods appears to be more successful than those phage therapies trialled pre-harvest. The post-harvest intervention is to improve the food safety by applying phages on the surface of foods. This eliminates or reduces the contamination of foods with foodborne bacterial pathogens, making the foods safe to consume.

Loc Carrillo and co-workers (2005) were the first to perform bacteriophage treatment of live chickens. They discovered effective reduction of *Campylobacter* counts in cecal contents in the treated broiler chickens using the pre-harvest technique. Using a combination of phages can provide a greater decrease in *Campylobacter* level in the cecal contents of infected broiler chickens than the single-

phage approach (Wagenaar et al., 2005). These observations are in agreement with others that showed the colonisation of both *Campylobacter jejuni* and *Campylobacter coli* in chickens were successfully reduced upon exposure to virulent bacteriophages (El-Shibiny, 2009; Carvalho, 2010).

Several studies on post-harvest interventions of bacteriophages against *Campylobacter* were conducted to control pathogen contamination on food surfaces such as chicken skin (Goode et al., 2003; Atterbury et al., 2003). Although the studies showed a small reduction of *Campylobacter* levels on the chicken skin, the reduction was greater when freezing at -20 °C was used in combination with the bacteriophage treatment (Atterbury et al., 2003).

In addition, inoculated chicken portions (log_{10} 4.05 plaque-forming units [PFU] of *C. jejuni*) treated with phage 12673 (106 PFU/cm^2) showed significantly reduced *Campylobacter* counts – down by around 95% (Goode et al., 2003).

A lytic phage preparation (SalmoFresh™) has also been found to be effective in reducing *Salmonella* on chicken breast fillets stored under aerobic, or oxygenated, and modified atmosphere conditions (Sukumaran et al., 2015). Results showed that phage treatment significantly reduced *Salmonella* by 0.8, 0.8 and 1.0 log_{10} CFU/g on days zero, one and seven of storage, respectively, under aerobic conditions.

Overall, studies have shown that the application of bacteriophages to bacterial contaminated chicken skin can significantly reduce the numbers of the bacteria. However, the approach does not appear to have progressed beyond the research and small trial stage, and there is no effective commercial product on the market.

Summary of in-feed intervention potential

From the literature, it is clear that there are inconsistencies and variability between trials. Finding a consistent and reliable feed additive that will obtain significant reductions in commercial settings is proving a challenge. However, there are positive results emerging in terms of selected plant extracts and organic acid products.

Results from a comparative study on the effects of probiotic (Primalac), organic acid (Selko®-pH) and plant extract (Sangrovit®) treatments found that, on day 49, all supplemented treatments showed a reduction in *Campylobacter* colonisation in cecal contents. In addition, faecal samples showed reductions on days 35 and 42 (Gharib Naseri et al., 2012). Both body weight and feed intake in the probiotic treated group were higher than the positive control, while the villi height of the duodenum and jejunum (which together make up the small intestine) in the probiotic and plant extract treated

groups were improved.[6] It was concluded that the supplementation of organic acid to the drinking water, and the addition of probiotic and plant extract to broiler feed, may reduce the incidence of *Campylobacter* infection (Gharib Naseri et al., 2012).

In-factory interventions

Surveys in the UK of chicken on retail sale undertaken by the Food Standards Agency and their practice of producing a "contamination league table" of retailers has focussed the minds of all the stakeholders along the supply chain on tackling *Campylobacter.* A more collaborative approach between the retailers and the processors and between competitors now exists, as all reputations and brands and the entire chicken sector are attracting adverse publicity.

The sector wishes to do everything practically possible to reduce the levels of *Campylobacter* contamination. It also has to be seen to be addressing the issue, which is a significant public health and consumer confidence problem. As a result there is now an urgency to develop effective factory intervention steps. Several are being tried, and old techniques are being revisited and modified.

Processing interventions

In the EU, chemical treatment of carcasses is currently not legal. A range of other approaches can be used including flock scheduling in the factory, chilling and the use of heat or steam.

Poultry in processing plants are subjected to multiple processing steps including stunning and bleeding, scalding, defeathering, evisceration (removal of the internal organs), washing, chilling, and post–chill treatments, all of which affect carcass contamination by *Campylobacter.*

Processing practices and control measures can significantly reduce cross-contamination and overall carcass contamination by *Campylobacter* in the final products.

Scheduling

Scheduling is a control measure that is implemented frequently in processing facilities in Norway. This involves testing each flock for *Campylobacter* presence one to two weeks prior to slaughter, using caecum or poultry house litter samples. Birds are then slaughtered in order of colonisation status, with clean flocks processed first and colonised flocks processed afterwards.

Scheduled slaughter means that colonised flocks can be subjected to additional decontamination treatments. Risk assessment, based on data from two countries, indicated that, when testing four days before slaughter, 75% of colonised flocks are detected (EFSA, 2011).

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[6] "Villi" are specialised structures on the intestinal walls that absorb fatty acids and glycerol into the bloodstream. An increase in height means an increased surface area on the villi and, thereby, improved absorption.

Scalding

This process is used to open the follicles of the skin sufficiently to facilitate the removal of feathers. Under poor conditions (stagnant water, excessive excreta or non-bacteriocidal temperatures), the scald tank may serve as a potential enrichment system, whereby pathogens are spread widely to all birds entering the tank. This may arise from soiling on the surface of the bird (Cason et al., 2007) or from the involuntary release of faecal matter.

Time, temperature, pH, use of antimicrobial chemicals (Russell, 2008) and even direction of flow (Cason & Hinton, 2006) in the scald tank are critical in terms of both maintaining product quality and minimising the prevalence of enteric pathogens.

Scalding tanks are currently used within the processing system, with gradual changes being made towards "aeroscalders" or steam scalders rather than immersion or water tank scalders. Results show that immersing carcasses in water at between 65 and 70 °C does not reduce *Campylobacter* on naturally contaminated carcasses but increasing the temperature to 75 °C for 30 seconds can yield reductions of about 1.0 $\log_{10}$ CFU/ml (Purnell et al., 2004). Unfortunately, at this temperature the chicken skin becomes fragile and tends to tear as the legs and wings are moved into position for a neat pack appearance. Increasing the temperature from 75 °C to 85 °C caused reductions in *Campylobacter*. However, temperatures > 75 °C caused skin damage and resulted in the discolouration and deterioration of the chicken's appearance (Whyte et al., 2003).

Inside–outside bird washers

Inside–outside washes facilitate further removal of faecal contamination of carcasses through a series of high-pressure sprayers. Their efficacy depends on a number of factors. These include the number and type of washers, water pressure, nozzle arrangement, flow rate, line speed, water temperature, and presence of sanitising agents such as chlorine and the use of surfactants (Northcutt et al., 2005). ("Surfactants" increase the solubility of oils, fats and proteins, allowing such substances to lift off surfaces more easily). Efficacy at this stage greatly impacts pathogen reduction during chilling (Smith et al., 2005). However, it must be noted that the use of chlorine in washers is not permitted currently in the EU.

It has been reported that the use of high-pressure spray with water at an appropriate pressure prior to the chilling step is equivalent to "trimming" of the contaminated area (essentially, removing unwanted body parts) without any loss of microbial quality or safety of the product (Giombelli et al., 2015). It is important that the efficacy of the washes are routinely tested as often the nozzles are not properly aligned and the entire bird inside and out is not washed adequately.

Chilling

The aim of this process, which may comprise several stages, is to reduce the carcass temperature, usually to below 4 °C, within four to eight hours (Cox & Pavic, 2009). There are numerous methods

used to chill poultry in processing factories, including immersion chilling, dry-air chilling and evaporative air chilling.

Research evaluations have found that water immersion chilling reduces the microbial contamination of carcasses, whereas air chillers have little overall effect on microbial contamination of the skin (Allen et al., 2000).

Immersion chilling is not now commonly used in the production of "fresh", chilled poultry in Europe, with dry air chilling being the preferred chilling method. There is a common belief in Europe that there is some clear microbiologically based reason behind the selection of air chilling. However, the published data do not appear to support this belief and, if anything, point to a possible hygienic advantage of immersion systems (James et al., 2006).

When a completely dry process is used, microbial numbers can be reduced by approximately ten-fold in the body cavity, while the use of water sprays tend to increase contamination of the cavity (Allen et al., 2000).

Cross-contamination has been considered to be one of the major problems with immersion chilling. However, a study by Mead and co-workers (2000) showed that microbial cross-contamination can also occur during air chilling of poultry, whether or not water sprays were incorporated in the chilling process.

The rate of chilling has some influence on the taste, texture and appearance of poultry meat: very rapid chilling can result in tougher chicken meat, while very slow chilling can produce pale, soft, exudative ("weeping") muscle. However, in both cases the effect is not as marked as with red meat (James et al., 2006).

Physical processing interventions

Physical decontamination treatments are mainly based on treatments that use a decrease or increase in temperature, applied to the carcass, to kill the *Campylobacter*, or else use ionising radiation (EFSA, 2011).

Freezing

In countries where meat is not sold as fresh, freezing to about -20 °C for a few weeks is used to treat carcasses from *Campylobacter*-colonised flocks. This reduces numbers by about 2 $\log_{10}$ cycles with minimal impact on the appearance and quality of the meat. Using this technique requires expanded cold storage facilities, and also increases the cost of frozen storage. More than 90% risk reduction can be obtained by freezing carcasses for two to three weeks, while a 50% to 90% risk reduction can be achieved by freezing for two to three days (EFSA, 2011).

Freezing can deliver the same level of reduction as that achieved by hot water carcass decontamination or chemical carcass decontamination with lactic acid, acidified sodium chlorite or trisodium phosphate (TSP). Unlike in other jurisdictions, in Ireland the consumers prefer fresh chicken and therefore the benefit of freezing interventions is not typically relevant.

Steaming or hot water spray

One of the most effective methods to completely eliminate *Campylobacter* from carcasses (assuming no post-process recontamination) is heat treatment, with cooking being the ultimate control step. Exposure of the chicken to high temperatures for a short period on the process line kills the bacteria present on the surface. Steaming or a hot water spray can be used to reduce or eliminate the bacterial load.

Treatment with steam at atmospheric pressure is an attractive option because it does not produce large volumes of dirty water. Both steam and hot water treatments reduce the numbers of *Campylobacter* by between 1.5 and 2.0 $\log_{10}$ cycles but any *Campylobacter* within the muscle are not inactivated (EFSA, 2011).

The problem with these treatments is that the appearance of carcasses treated by either method is changed. The most important of these changes is the tendency for the skin to shrink and become more fragile, and for any exposed muscle to change colour slightly. In addition, the carcasses stiffen up, making "trussing" – tying up the wings and legs – for packaging whole birds more difficult. However, the appearance of portions prepared after treatment of carcasses is almost unaffected (EFSA, 2011; Zhang et al., 2013; James et al., 2007). Research has found the combination of water spraying and immersion chilling yields higher reductions in *Campylobacter jejuni* than spraying alone (Li et al., 2002).

Steam treatments at atmospheric pressure on *Campylobacter jejuni*- and *Escherichia coli*- inoculated carcasses can reduce the numbers of *Campylobacter* by approximately 1.8, 2.6 and 3.3 $\log_{10}$ CFU/cm^2 in 10, 12 and 20 seconds, respectively (James et al., 2007). However, such treatments cause the skin to shrink and change colour. The optimum treatment for maximum reductions of *C. jejuni* and *E. coli,* with the least skin shrinkage and change of colour, was concluded to be less than 12 seconds.

Hot water spraying at 71 °C for one minute has been shown to cause > 1 $\log_{10}$ unit of reduction in mesophilic aerobic bacteria (those that thrive in moderate temperatures, and also require oxygen) immediately after evisceration and immediately after chilling, and to reduce the prevalence of *Salmonella* after chilling. However, after chilling only loosely attached *Campylobacter* cells were reduced (Zhang et al., 2013). In addition, a partially cooked appearance ensued on both broiler skin and skinless breast surface.

Figure 5: Populations of *Campylobacter* tightly attached to skin

Populations of Campylobacter, Tightly attached to skin (log cfu/g)
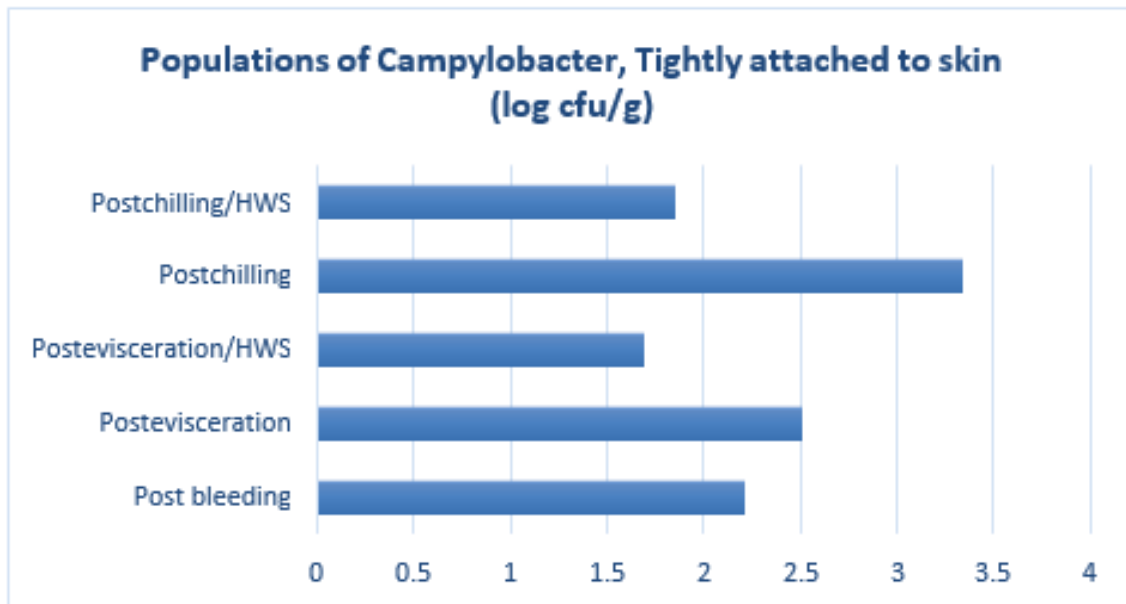
SonoSteam® (steam ultrasound)

SonoSteam® treatment combines the use of steam and ultrasound, which are both generated in nozzles by the supply of steam at high pressure (Figure 6). The treatment time is usually below one second. The ultrasound disturbs the naturally occurring zone of air closest to the surface (the laminar boundary layer), which restricts vapour and heat exchange across the surface, by setting the air in a state with intensified molecular oscillations. When the laminar layer is destructed, hot steam can enter microstructures and pits in the surface and secure a fast heat transfer. The microorganisms are quickly heated up and killed, which means that the treatment can end before the heat affects the surface of the product (Turantaş et al., 2015).

Figure 6: Effect of ultrasound on surfaces

Source: http://sonosteam.com/working-principles/
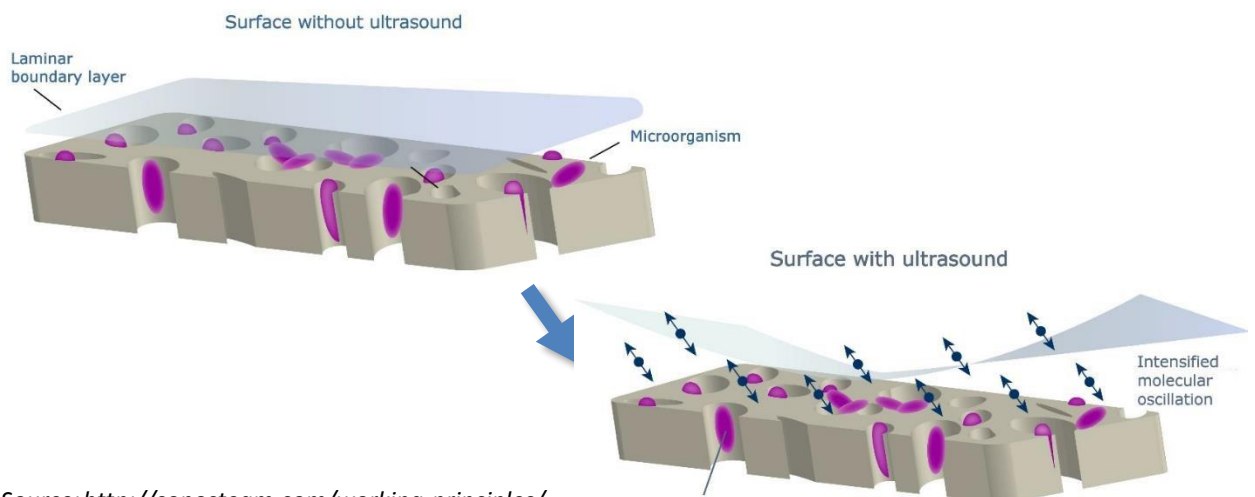
Until recently, only limited data existed on the application of ultrasound to solid foods. In 1991, Sams and Feria found that ultrasound (25 or 40 °C for 15 or 30 minutes) yielded reductions of aerobic bacteria ranging from no effect to 0.8 $\log_{10}$ CFU/cm^2 on chicken legs. The authors hypothesised that the low efficacy could be related to the irregular skin surface providing protection for the bacteria.

Reductions of approximately 2.51 $\log_{10}$ units (CFU/ml) and 2.5 log CFU per carcass, with no visual changes of the chicken carcasses, have been found more recently (Hansen & Larson, 2007; Boysen & Rosenquist, 2009). In the study by Boysen and Rosenquist (2009), the levels of *Campylobacter* were already low, so any further reductions in contamination were all the more significant.

In a Danish study, SonoSteam® significantly reduced the level of *Campylobacter* contamination from 2.35 $\log_{10}$ CFU to 1.40 $\log_{10}$ CFU after treatment (Musavian et al., 2014). In addition, an authorised sensory panel at the Danish Veterinary and Food Administration concluded that broiler carcasses treated with SonoSteam® were acceptable for purchase (Musavian et al., 2014). These conclusions were based on organoleptic, or sensory, differences (that is, the smell, and the skin and meat consistency, texture and colour) of treated carcasses compared with untreated carcasses.

Results from a Danish slaughterhouse have shown that *Campylobacter* is reduced by up to 1.5 or 2.0 $\log_{10}$, depending on the initial concentrations of *Campylobacter*. The higher the concentrations are, the higher are the reductions achieved. This means that broilers with levels above 1,000 CFU are reduced by around 1.5 $\log_{10}$ (SonoSteam®).

SonoSteam® technology can also reduce the level of other pathogenic species, with steam–ultrasound treatments for 0.5, 1.0, 1.5 and 2.0 seconds on both skin and meat surfaces of pork (inoculated at two levels) significantly reducing *Salmonella typhimurium*, *Y. enterocolitica*, and *E. coli* (Morild et al., 2011).

Currently, SonoSteam® technology is being investigated and assessed commercially by a number of processors in the UK as a means of *Campylobacter* reduction.

Chemical and ultrasonication

Ultrasound refers to pressure waves with a frequency of 20 kHz or more and, generally, ultrasound equipment uses frequencies from 20 kHz to 10 MHz. High-power ultrasound at lower frequencies (20 kHz to 100 kHz) is referred to as "power ultrasound", and has the ability to create physical (micromechanical) and chemical antimicrobial effects.

The mechanism of microbial inhibition is mainly attributed to the generation of intracellular cavitation. This effect can cause thinning of cell membranes, heating and the production of "free radicals" (Chemat et al., 2011), which often are highly reactive elements that damage the body.

Studies have shown that an increased effectiveness of ultrasound can be accomplished in decontaminating meat and poultry skin inoculated with different microorganisms when combined with chlorine, other chemicals, heat process and other physical treatments (Koolman et al., 2014b; Kordowska–Wiater & Stasiak, 2011; Smith, 2011). This is because the microorganisms can be easily released from the skin or carcass surface by means of ultrasound cavitation and so the penetration and inactivation effect of chemicals and other methods are enhanced.

A recent review reported that, although dependent on many factors, ultrasound applied by itself in different surrounding solutions showed significant reduction (1–2 $\log_{10}$ units) of some bacteria in meat samples (Turantaş et al., 2015).

The sequential treatment of immersion in 12% TSP and 5% capric acid sodium salt (CP) for one minute, with ultrasonication at 80 kHz, achieved large reductions of *C. jejuni* (4.5–4.6 $\log_{10}$ CFU/cm^2) and total viable counts (TVC) (1.9 $\log_{10}$ CFU/cm^2) (Koolman et al., 2014 a).

The total viable count and *Salmonella* contamination level on the skin of broilers can be decreased significantly when immersed in a 1.0% lactic acid solution with six minutes of sonication, with up to 4-$\log_{10}$ CFU/cm^2 reductions reported for *Salmonella* (Stasiak et al., 2007; Kordowska–Wiater & Stasiak, 2011). Ultrasound with distilled water for three minutes yielded between 0.63 and 1.07 $\log_{10}$ CFU/cm^2 reductions in selected Gram-negative bacteria (Kordowska–Wiater & Stasiak, 2011), while the six-minute treatment yielded between 0.97 and 2.27 $\log_{10}$.

Interestingly, ultrasound treatment in combination with marination in red wine led to significantly higher reductions of *B. thermosphacta*, *L. monocytogenes*, and *C. jejuni* viable cells compared with ultrasound treatment alone (Birk & Knøchel, 2009).

The application of ultrasound on transport equipment is also very valuable in reducing microbial contamination of carcasses through such sources. Ultrasound application of 4 kW (60 °C, for one to three minutes) on poultry crates reduced the counts of Enterobacteriaceae to below the detection limit within one to three minutes, while the standard plate count was reduced by 2 $\log_{10}$ units after three minutes (Allen et al., 2008a).

Forced air chilling

The process of forced air chilling involves high speed cold air passing over the surface of the chicken. The rapid reduction in temperature, combined with the high speed of the air over the chicken, kills the bacteria.

Forced air chilling (around 150 minutes at -1.1 °C and air speed of 3.5 m/s) has had variable effects on the level of *C. jejuni* reduction in poultry processing. Reductions of 1.4 to 1.8 $\log_{10}$ CFU/ml have been reported (Huezo et al., 2007 a &b ; James et al., 2007), with researchers suggesting that

greater reductions (1.6–3.2 $\log_{10}$ CFU/cm^2 for *C. jejuni* and *E. coli*) can be obtained when using rapid air chilling combined with previous steam or hot water treatment (James et al., 2007).

However, in other studies, reductions of just 0.09 to 0.40 $\log_{10}$ CFU have been found using forced air chilling (Boysen & Rosenquist, 2009; Musavian et al., 2014). Small reductions of aerobic bacteria, Enterobacteriaceae and *Pseudomonas* (0.1–0.2 $\log_{10}$ CFU/g) have also been reported (Gonzàlez–Miret et al., 200).

Crust freezing

Crust freezing (CF) is a process whereby the surface of the carcass is temporarily and rapidly frozen to -2 °C during processing with a stream of cold air such as carbon dioxide (CO_2) or nitrogen (N_2). The technique is based on rapid ice crystallisation on the meat surface, resulting in a thin frozen crust followed by temperature equalisation. Crust freezing is done to achieve a 3 mm to 7 mm frozen layer depending on the thickness of the meat itself. Like freezing, crust freezing reduces the numbers of *Campylobacter* but to a lesser degree than freezing the whole carcass. Crust freezing also does not affect *Campylobacter* within the muscle.

For CF within the EU, chicken meat that has undergone the process of CF can be sold as "fresh" meat, provided the temperature of the meat remains greater than or equal to -2 °C (Commission Regulation [EC] No. 543/2008). According to the FSAI (2011), CF is recommended as an intervention that should be considered by processors.

The time required for CF depends on the temperature of the freezer, the thickness of the poultry part, and the thickness of the ice crust desired. Freezing can kill bacteria or weaken them such that other pathogen interventions have greater effectiveness.

Published evidence shows that CF has little adverse effect on meat quality (James et al., 2007). An optimum treatment combination of hot water at 80 °C for 20 seconds followed by CF reduced the numbers of *Campylobacter* and *E. coli* by around 2.9 and 3.2 $\log_{10}$ CFU/cm^2, respectively, without extensive degradation of carcass appearance (James et al., 2007).

The colour of chicken parts, such as drumsticks, is found not to be affected by CF treatments. However, CF can result in increased "drip loss" – fluid leakage from the meat – which increases over storage time and is greater at more severe CF temperatures (Haughton et al., 2012b).

Reductions from 0.42 to 1.50 $\log_{10}$ CFU/g have been obtained from the use of crust freezing (Boysen & Rosenquist, 2009; Haughton et al., 2012b). However, the technique was reported not to be as effective as freezing (Boysen & Rosenquist, 2009). In addition, combining CF with ultraviolet (UV) light resulted in significant reductions for *C. jejuni.* Even so, the combined treatments are generally no more effective than treatment by CF alone (Haughton et al., 2012b).

In contrast, some studies report minimal reductions in bacterial contamination, with average reductions for *E. coli* and *Salmonella typhimurium* only 0.15 $\log_{10}$ CFU/mL and 0.10 $\log_{10}$ CFU/mL of rinse, respectively (Chaves et al., 2011).

Crust freezing is currently being assessed by numerous commercial processors, in both the ROI and the UK, as a *Campylobacter* processing intervention strategy.

Irradiation

Research suggests that, post–slaughter, a 100% risk reduction can be reached by irradiation or cooking on an industrial scale, if recontamination is prevented (EFSA, 2011). The antimicrobial activity of ionising radiation is due to the direct damage to DNA (deoxyribonucleic acid) and the effect of generated free radicals (Demirci & Ngadi, 2012).

Irradiation leaves the meat essentially unchanged in appearance. The process uses gamma rays from isotopes such as cobalt-60, or x-rays or electrons with appropriate energy spectra (FSAI, 2013). Gamma rays and x-rays are more penetrating, and could be used to treat whole carcasses, while electrons are less penetrating, and so would most easily be used on portions.

An advantage of x-rays or electrons is that they can be generated using relatively inexpensive machines that can be switched on and off as required and easily installed in most slaughterhouses (Clements, 2011). Another advantage of irradiation is that it would inactivate *Campylobacter* within the meat as well as on the outside, and it could be used on prepacked, frozen or chilled product. Irradiation of prepacked product would prevent post-process recontamination.

However, public resistance is a significant barrier; even after education campaigns regarding the safety of irradiation, 33% of consumers still will not purchase irradiated foods (Brewer & Rojas, 2008). Irradiation is reported (Ahn et al., 2013) to produce a characteristic aroma and alters flavour and colour, which consequently significantly affects consumers' acceptance of irradiated meat.

Campylobacter species are more radiation-sensitive than *Salmonella* and *Listeria monocytogenes* irradiated under similar conditions, as suggested by the D10 values of *C. jejuni, C. fetus* and *C. lari*, which ranged from 0.12 to 0.25 kGy (Patterson, 1995). (A "D10" value is the irradiating dose required to reduce the population of pathogens by 90 %.)

Complete elimination of *Campylobacter* in inoculated poultry meat with irradiation of 1 kGy can be achieved (Raut et al., 2011). Irradiation is also effective in eliminating *Campylobacter* from meat or poultry packaged in vacuum or "modified atmosphere packaging" (MAP) (Kudra et al., 2012). However, an "off–odour" and sour smell can be observed.

Ultraviolet radiation or light

Another possibility to reduce contamination is UV radiation, which is commonly used for the decontamination of packing surfaces or in food processing environments. The range of UV radiation that is considered to be germicidal against bacteria is between 220 nm and 300 nm (ultraviolet C, or "UVC"), and generally a wavelength of 254 nm is used for decontamination (Guerrero–Beltrán & Barbosa–Cánovas, 2004).

This range of UV contains high-energy photons that generate pyrimidine dimers and denature bacterial DNA, leading to the destruction of bacteria by degradation of the cell walls (Guerrero–Beltrán & Barbosa–Cánovas, 2004).

Ultraviolet radiation or light is different to irradiation. It is an electromagnetic radiation and is present in sunlight. In contrast, irradiation uses gamma rays from isotopes such as cobalt-60, or x-rays or electrons with appropriate energy spectra.

Some studies report disappointing results for UV radiation. At a wavelength of 254 nm, using doses ranging between 9.4 and 32.9 mW/s per cm^2, the maximum reductions achieved on broiler meat and skin were only 0.7 log_{10} and 0.8 log_{10}, respectively. On broiler carcasses, the maximum reduction using UV radiation and UV with activated oxygen was only 0.4 log_{10} (Isohanni & Lyh, 2009). Additionally, treatment with UV yielded *Campylobacter* reductions of 0.8 log_{10} CFU/g and 0.5 log_{10} CFU/g on skinless chicken breast and chicken skins (Haughton et al., 2011).

However, reductions of more than 7 log_{10} CFU/ml were achieved when *Campylobacter jejuni* and *Campylobacter coli* in liquid were exposed to high intensity near ultraviolet–visible (NUV–Vis) 395 ± 5nm light for two minutes at 3 cm distance. Exposure of a skinless chicken fillet to NUV–Vis light for one or five minutes at 3 cm distance reduced *Campylobacter* by 2.21 and 2.62 log_{10} CFU/g, respectively (Haughton et al., 2012 a). A maximum reduction of 0.95 log_{10} CFU/g was achieved for *Campylobacter* following 10 minutes of exposure to NUV–Vis light at 12 cm distance. In addition, *Campylobacter* was reduced by between 1.2 and 1.3 log_{10} CFU/g after treatments of UVC at 5 Kj/m^2 (Chun et al., 2010).

In terms of meat quality, the use of UV treatment has been shown not to affect the colour or sensory quality of raw chicken (Isohanni & Lyh, 2009; Haughton et al., 2012; Chun et al., 2010). However, in order to avoid meat quality degradation, it is suggested that 600 to 1,200 mWs/cm^2 of UVC radiation is used, in combination with other decontamination techniques, to inactivate foodborne viruses and for meat decontamination (Park & Ha, 2015).

Cold plasma treatment

Cold plasma is a novel non-thermal food processing technology that uses energetic, reactive gases to inactivate contaminating microbes on meats, poultry, fruits and vegetables. This sanitising method uses electricity and a carrier gas, such as air, oxygen, nitrogen or helium (He). An advantage is that antimicrobial chemical agents are not required in the process (Niemira, 2012).

Gas plasmas are usually generated by means of an external electric field; when the voltage applied to a gas exceeds a certain threshold value the gas will become ionised (Noreiga et al., 2011). Gas plasmas comprise mixtures of electrons, ions, atomic species, free radicals and UV photons, all of which have the capability of inactivating microorganisms (Shankar et al., 2014; Fernández & Thompson, 2012).

In order to decontaminate foods without bringing about undesired changes, gas plasmas are operated at or near room temperature. Cold atmospheric plasmas have been reported to be very effective against a wide range of microorganisms, including biofilm-formers and bacterial spores (Montie et al., 2000; Deng et al., 2005; Vleugels et al., 2005).

No real effect has been found on the chemical composition or on the sensory characteristics for appearance, odour and texture of sliced chicken (Aly & El-Aragi, 2013).

Chicken breast and skin samples inoculated with antibiotic-resistant strains of *C. jejuni* at levels of 10^2, 10^3 and 10^4 CFU and exposed to three minutess of plasma resulted in reduction levels of 1.65, 2.45 and 2.45 $\log_{10}$, respectively, on chicken breast; and 1.42, 1.87 and 3.11 $\log_{10}$, respectively, on chicken skin (Dirks et al., 2012). Reductions of 1.37 to 4.73 $\log_{10}$ of *L. monocytogenes* on cooked chicken breast have also been found after two minutes of treatment with He, N_2 and their mixtures with O_2 gas (Lee et al., 2011). A cold atmospheric plasma pen (CAP-Pen) obtained > 3 $\log_{10}$ reductions of *L. innocua* on membrane filters after 10 seconds, 1 $\log_{10}$ reduction on chicken skin after eight minutes and > 3 $\log_{10}$ reductions on chicken muscle after four minutes of treatment (Noreiga et al., 2011).

Mean reductions in *Campylobacter* of 1.30 $\log_{10}$ CFU/ml and 1.57 $\log_{10}$ CFU/ml for inoculated (10^6 CFU/ml) fillets packaged in air and MAP were found after three minutes of treatment using a non-thermal dielectric barrier discharge (DBD) plasma system at a voltage of 75 kV (Kronn, 2013). It was also found that treatment with the DBD plasma system was able to maintain the microbial quality of the fresh broiler breast fillets for 14 days (4 °C), which is around seven days longer than the typical shelf life.

The technology can also be used to disinfect surfaces of processing equipment and packaging materials. Because the plasma can penetrate cracks and crevices, unlike other potential surface treatments such as ultraviolet light, it functions more effectively over uneven or cracked surfaces (Shankar et al., 2014).

This intervention is in the early stages of use, and research is limited but ongoing as to its future potential benefits. However, the initial findings are proving promising.

Chemical processing interventions

Antimicrobial chemicals are commonly used during processing to reduce microbial contamination on carcasses outside of the EU. The most common antimicrobial treatment used for decontamination of poultry meat is chlorine (sodium hypochlorite) mostly because it is inexpensive. However, failure to optimise the disinfectant properties of chlorine (improper pH, concentration or composition of incoming water) can reduce its efficacy. Chlorine treatment may also cause offensive and harmful odours due to the production of chlorine gas and trichloramines.

The use of organic acids may be a viable alternative as a safer and effective method of pathogen control (Menconi et al., 2014). Previously, organic acids have been demonstrated to have beneficial effects on reducing spoilage microorganisms on poultry carcasses. Other chemical interventions include the use of ozone and electrolysed oxidising water.

Electrolysed oxidising water

Electrolysed oxidising (EO) water is gaining popularity as a sanitiser in the food industry. By electrolysis, a dilute sodium chloride solution dissociates (or separates) into electrolysed oxidising water and electrolysed reducing water (Rahman, 2016). Electrolysed oxidising water exerts strong antimicrobial properties against a variety of microorganisms.

Studies have shown that treatment of artificially contaminated poultry carcasses and parts with acidic EO water resulted in bacterial load reductions of between 0.6 and 3.0 $\log_{10}$ orders of magnitude, especially for *Campylobacter* (Loretz et al., 2010). Combining acidic EO treatment with immersion chilling tended to yield the highest reductions.

Submersion in acidic EO water (pH 2.6, chlorine 20 to 50 ppm) has been found to reduce *Salmonella* by 0.86 $\log_{10}$. After seven days of storage, acidic EO water reduced *Salmonella,* with detection only possible after selective enrichment (that is, feeding the Salmonella to produce a detectable population) (Fabrizio et al., 2002).

Spray-washing treatments with acidic EO water has been shown not to reduce *Salmonella* at day zero but did reduce *Salmonella* by 1.06 $\log_{10}$ at day seven (Fabrizio et al., 2002). In contrast, spraying (0.03–0.30 minutes) of poultry carcasses with EO yielded considerably high reductions for aerobic bacteria (1.0 log CFU/ml), *Campylobacter* (2.2 $\log_{10}$ CFU/ml), *E. coli* (1.7 $\log_{10}$ CFU/ml), and *Salmonella* (2.7 $\log_{10}$ CFU/ml) (Northcutt et al., 2007).

During washing, EO water treatment has been found to be as effective as chlorinated water (both containing 50 mg/l residual chlorine), with both achieving *Campylobacter* reductions of about 3 $\log_{10}$ CFU/g on chicken. This is compared with deionised water (control), which resulted in only 1 $\log_{10}$ CFU/g reduction (Park et al., 2002). In addition, a strong bactericidal activity was also observed in the diluted EO water (containing 25 mg/l of residual chlorine). No viable cells of *Campylobacter* were recovered in EO and chlorinated water after washing treatment, whereas high populations (4 $\log_{10}$ CFU/ml) were recovered in the wash solution after the control treatment (Park et al., 2002).

Submerging carcasses after scalding in EO water can yield *Campylobacter* reductions. A significant 1.31 $\log_{10}$ CFU per carcass reduction was obtained through plate enumeration and a non-significant reduction of 0.53 $\log_{10}$ CFU per carcass by qPCR (Rasschaert et al., 2013).

Ozone

Ozone (O_3) is a tri-atomic gaseous molecule consisting of three oxygen atoms. It is an allotrope – a different form – of oxygen. It is much less stable than the diatomic allotrope (O_2), and is characterised by its strong oxidising nature, which makes it a useful tool for the inactivation of bacteria, fungi and viruses (Mercogliano et al., 2014). Ozone first attacks the bacterial membrane at the glycoproteins, glycol lipids, or certain amino acids such as tryptophan. It then also acts on the sulphydryl groups, resulting in disruption of the normal cell.

Bacterial death is rapid and often attributed to changes in cell permeability followed by lysis. The bactericidal effect depends on several factors, such as temperature, relative humidity, pH values and the presence of organic matter (Moore et al., 2000).

Because of the short-lived nature of ozone, it must be generated on-site, leading to higher operating costs than other modes of disinfection (Jensen, 2014).

Ozonisation has been used as a disinfectant treatment in the poultry industry in several situations with varying success. Uses have included air treatment of hatcheries, surface decontamination of table eggs (that is, eggs in their shells) and reconditioning of chill water in food processing units. In the literature, results of the effectiveness of ozone as a decontamination method are varied. Some studies report only small reductions in bacterial contamination after ozone treatment.

Reductions in the levels of *Pseudomonas aeruginosa,* Gram-negative and Gram-positive bacteria of 0.38, 1.11 and 1.14 $\log_{10}$ on pre-chill drumsticks using ozone have been reported. However, treatment did extend their shelf life by up to two days (Jindal et al., 1995).

Aerobic bacteria, coliforms, *E. coli* or *S. typhimurium* were reduced on inoculated carcasses after spraying (0.3 minutes) and immersion chilling (45 minutes) in ozonated water by only 0.4 to 0.6 log CFU_{10}/ml and 0.7 to 0.9 log CFU_{10}/ml, respectively (Fabrizio et al., 2002).

The application of atmospheric ozone at a target level of 0.05 ppm to rooms housing broilers caused a reduced growth rate. It also increased mortality and the incidence of heart-related condemnations and birds found dead on arrival (Schwean–Lardner et al., 2009). As well as this, ozone treatment of broiler barn air did not result in significant reductions in aerosol bacteria (that is, bacteria in moisture droplets suspended in the air) or the atmospheric ammonia level.

In contrast, positive results for ozone treatment have been found where the use of gaseous ozone, using an ozone generator to reach a concentration of 0.4 ppm, led to significant differences between the control and the treated batches for total aerobic counts and Enterobacteriaceae. In addition, acceptable sensory qualities were observed until day 14 and day 20 after slaughter for both the control and the treated batches, respectively (Cortesi et al., 2011).

Other trials using the UltraPure™ ozonation system found that, after installation, the percentage of live birds alive rose from an average of 96.1% to 97.2%. The average chicken weight rose from 4.05 lbs to 4.15 lbs, while the total bacteria decreased from over 100 ppm to less than 2 ppm (Earth Safe Ozone, 2014).

Chemical wash

Chemical washes are routinely used in the US to decontaminate poultry. Their use in Europe is currently prohibited. Consumers have also previously condemned the use of chemicals due to the fear of residues, "off" odours or flavours and colour or texture changes. As well as this, many highlight the fear that chemical washes will reduce or mask the hygiene standards on poultry farms and in factories.

The use of chemical washes has been shown to be effective against a range of pathogens, including *Campylobacter, Salmonella* and *E. coli* (Fabrizio et al., 2002).

Chlorine, hypochlorite, sodium hypochlorite and sodium chlorite

Chlorine-containing compounds are widely used for pre- and post-chill spraying or washing of poultry carcasses or in carcass chillers, especially in the US and Canada. Chlorine (gas or solid), dissolves in water to form hypochlorous acid and hypochlorite ions. Chlorine treatment of naturally contaminated and inoculated poultry carcasses and parts can reduce *Campylobacter* by betweem 0.2 and 3.0 $\log_{10}$ CFU/ml (Demirci & Ngadi, 2012; Bashor et al., 2004; Berrang et al., 2007) whether incorporated into carcass washers, spray-washing systems or chill tanks.

Chlorine dioxide

Chlorine dioxide inactivates microorganisms by altering nutrient transport and disrupting protein synthesis after penetrating into cells. Antibacterial activity seems to be less affected by organic matter than by chlorine (Vandekinderen et al., 2009). Aqueous chlorine dioxide has been found to

reduce *Campylobacter* inoculated on chicken breast and legs by between 1.0 and 1.2 $\log_{10}$ CFU/g (Hong et al., 2007).

Acidified sodium chlorite

Acidified sodium chlorite (ASC) is a type of chlorine compound that is a strong oxidiser. The antimicrobial activity of ASC is derived from chlorous acid and chlorine dioxide, which inactivate microorganisms through the damage of cellular membranes and oxidation of cellular constituents (Rao, 2007). ASC is safe and suitable for use on poultry carcasses and parts at concentrations of 500 to 1,200 ppm (United States Department of Agriculture Food Safety and Inspection Service [USA FSIS], 2015). It is used at pH 2.3 to 2.7 and acidified with an organic acid, such as lactic acid, citric acid or acetic acid. A benefit of ASC is that it is not as highly affected by the presence of organic material as chlorine.

The addition of ASC to carcass washers can increase *Campylobacter* reductions by 1.3 $\log_{10}$ above what is achieved with chlorine spraying (Bashor et al., 2004). The immersion of inoculated breast samples in ASC has led to *Campylobacter* reductions of between 1.6 and 1.9 CFU/g (Özdemir et al., 2006). In addition, reprocessing with a commercial ASC-containing product (Sanova®) has yielded reductions that were 0.6 $\log_{10}$ CFU/ml higher than after reprocessing without chemicals (Berrang et al., 2007). Sanova® has also led to *Campylobacter* reductions of 1.6 $\log_{10}$ CFU/g on inoculated chicken legs (Mehyar et al., 2005).

Cetylpyridinium chloride

Cetylpyridinium chloride (CPC) belongs to the group of quaternary ammonium compounds. CPC is a cationic surfactant that has a neutral pH. Its antibacterial activity results from interaction with acidic groups at the surface or within bacteria to form weakly ionised compounds that inhibit bacterial metabolism (Demirci & Ngadi, 2012). CPC is an odourless, colourless, stable compound that does not self-decompose and is not affected by organic material. CPC must be rinsed off poultry after use with water containing no more than 50 ppm chlorine (USDA FSIS, 2015). The major disadvantage of CPC is that some may be less effective in hard water that contains > 500 mg/L hardness. Levels of 0.5% and 0.1% CPC have been shown to reduce *C. jejuni* and *S. typhimurium* populations on poultry products. However, limitations such as short contact time, use of specialised equipment for its application and recycling of CPC (which is a regulated requirement) have been a deterrent for its use in processing plants (Wideman et al., 2015). From the literature, the use of a post-chill antimicrobial immersion tank or the use of a CPC spray cabinet was reported to further reduce the microbial levels on poultry (Wideman et al., 2015). In addition, reductions of 1.4 $\log_{10}$ CFU/g of *Campylobacter* on poultry legs were obtained using the CPC product, Cecure® (Mehyar et al., 2005).

Trisodium phosphate

The use of trisodium phosphate (TSP) for the decontamination of poultry is well documented. Two important elements of its antimicrobial effect are its high pH and its ionic strength, which cause

bacterial cell autolysis (Capita et al., 2002). Reprocessing with TSP has yielded greater *Campylobacter* reductions on naturally contaminated carcasses, which were 1.2 $\log_{10}$ CFU/ml higher than after reprocessing without chemicals (Berrang et al., 2007). *Campylobacter* reductions of 1.7 to 2.4 $\log_{10}$ CFU/g have been obtained on inoculated chicken breast skin samples following immersion in TSP (Özdemir et al., 2006).

In a recent study, 12% TSP (1.9–2.3 $\log_{10}$ CFU/cm²) and 5% CP (2.2–2.4 $\log_{10}$ CFU/cm²) were found to give the largest *Campylobacter* reductions. In addition, the combination of TSP with CP was the most effective (2.9 $\log_{10}$ CFU/cm²) for reducing *Campylobacter* counts and was significantly greater than any of the single chemical treatments.

Similarly, significant *Campylobacter* reductions of 1.2 to 6.4 $\log_{10}$ CFU/cm² were found on both duck and chicken meat when TSP was used at 8%, 10% and 12% (Sarjit & Dykes, 2015). On duck meat, the numbers of *Campylobacter* were less than the limit of detection at higher concentrations of TSP. (The "limit of detection" is the level at which the presence of the microorganism can distinguished – usually around 1% of the sample.) On chicken meat, the numbers of *Campylobacter* and *Salmonella* were only less than the limit of detection at the lower inoculum level and higher TSP concentrations.

Finally, dip-treating broiler carcasses with 14% TSP can reduce *Campylobacter* levels by approximately 3 $\log_{10}$ CFU/cm² (Bolton et al., 2012). However, cloacal washing with TSP is not effective.

Sodium hydroxide
Sodium hydroxide can reduce *Campylobacter* by 3.5 to 3.7 $\log_{10}$ CFU/g on chicken wings (Zhao & Doyle, 2006). However, in other studies, in contrast to TSP, only some concentrations of sodium hydroxide used significantly reduces numbers of *Campylobacter* and *Salmonella* (0.2–1.5 $\log_{10}$ CFU/cm²) on poultry meats (Sarjit & Dykes, 2015).

Scalding is a method of heating poulty carcasses making the skin looser and as a result makes it iseasier to remove feathers. "RP Scald" is a commercial scald additive, whose active ingredient is sodium hydroxide, which has been used to help reduce the appearance of bruising on broilers. It creates a highly alkaline environment when mixed with water. Hard scaldingis is scalding thas is carried out at higher temperatures than other scalding methods. The addition of RP Scald can increase *Salmonella typhimurium* reduction, particularly when hard scald temperatures are used. (McKee et al., 2008).

Peracetic acid or peroxyacetic acid
Peroxyacetic acid (PAA) is an organic oxidiser. It is a mixture of the peroxy compound hydrogen peroxide and acetic acid (Azanza, 2004). The combination of antimicrobial washes allows the use of lower levels of organic acids while maintaining the antimicrobial efficacy of the compound. It is a versatile compound, as different formulations are available that may be used over a wide

temperature range (0 to 40 °C) and wide pH range (pH 3 to 7.5). Additionally, PAA is not as affected by protein or other organic materials as chlorine.

Studies have shown that a PAA level of 0.020% decreased *Campylobacter* compared with chlorine treatment, while 0.015% and 0.020% PAA extended the shelf life (Bauermeister et al., 2008). $\log_{10}$ unit reductions of 0.04 (*Salmonella*), 0.32 (*Campylobacter*) and 0.63 (*E. coli* O157) above the control using 200 ppm PAA on inoculated chicken wing parts were also found (Mehyar et al., 2005).

A study by the FMC Corporation (2009) showed a relative prevalence reduction of *Salmonella* by 97.5% (from 62.1% to 1.6%) and *Campylobacter* by 96.6% (from 79.3% to 3.1%) using PAA treatment (EFSA, 2014).

Treatments with 0.04% and 0.10% PAA have been shown to be the most effective in reducing populations of *Salmonella* and *Campylobacter* (Nagel et al., 2013; Wideman et al., 2015) when comparing chemical treatments. In addition, the antimicrobial was not found to have negative impacts on sensory attributes. Highly significant reductions of 1.57 $\log_{10}$ units for *S. typhimurium* and 3.00 $\log_{10}$ units for *C. jejuni*, above the effect of water, were found using a PAA concentration of 500 ppm (Rodrigues et al., 2011).

Organic acid wash

Organic acids have considerable potential for acceptance by the industry because they are quite inexpensive and generally regarded as safe (Demirci & Ngadi, 2012). According to research, 0.2% to 0.8% concentrations of an equal percentage organic acid mixture of citric, acetic and propionic acid is capable of reducing pathogens and spoilage organisms and thereby improve the food safety properties of raw poultry (Menconi et al., 2013).

Spraying with 2% acetic, lactic or levulinic acid can yield *Salmonella* reductions ranging from 1.1 to 1.3 $\log_{10}$ CFU/cm^2 (Carpenter et al., 2011). A marinade containing different organic acids (tartaric, acetic, lactic, malic and citric acids, 0.5%) was found to reduce populations of *Campylobacter* in broth by between 4 and 6 $\log_{10}$ (after 24 hours), with tartaric acid being the most efficient treatment (Birk et al., 2010). On chicken meat medallions, reductions of *Campylobacter* of 0.5 to 2 $\log_{10}$ were found when tartaric acid solutions (2%, 4%, 6% and 10%) were spread onto the meat. Further analysis of acidic food ingredients (for example, vinegar, lemon juice, pomegranate syrup and soya sauce) also revealed that such ingredients can reduce the counts of *Campylobacter* by at least 0.8 $\log_{10}$ units on meat medallions.

Surface treatment with caprylic acid at 1.25 and 2.5 mg/mL for one minute can significantly reduce *C. jejuni* contamination of chicken skin by 0.29 to 0.53 $\log_{10}$ CFU/g and 1.14 to 1.58 $\log_{10}$ CFU/g of skin, respectively (Hovorková & Skřivanová, 2015). In addition, the study found that counts of *C. jejuni* were reduced by 0.68 to 1.65 $\log_{10}$ CFU/g of skin.

Washing inoculated chicken legs in 2% propionic acid has been found to significantly reduce *C. jejuni* counts, with a decrease of about 1.62 $\log_{10}$ after treatment (González-Fandos et al., 2015). In addition, the treatment of chicken legs with 1% or 2% propionic acid significantly reduced the numbers of psychrotrophs – bacteria that can thrive at low temperatures – (1.01 and 1.08 $\log_{10}$) and *Pseudomonas* (0.75 and 0.96 $\log_{10}$, respectively). The reduction in psychrotrophs and *Pseudomonas* increased throughout storage.

Lactic acid

The literature surrounding the use of lactic acid is quite varied and inconsistent, with some studies reporting greater reductions than others, and some highlighting meat quality detriment or reduction. Studies have shown that spray-treating carcasses with 4% lactic acid reduced the numbers of *Campylobacter* on the breast skin and on the back and neck skin by 0.4 $\log_{10}$ CFU/g and 0.8 $\log_{10}$ CFU/g, respectively (Burfoot et al., 2015). Spraying with an 8% acid solution produced a 1.9 $\log_{10}$ CFU/g reduction on breast skin but the appearance of the carcass was adversely affected.

Similarly, in another study spraying the carcasses with lactic acid (1.5%) led to non-significant reductions of 0.68 and 0.26 $\log_{10}$ CFU/carcass by qPCR and by enumeration, or counting, respectively (Rasschaert et al., 2013). However, significant reductions of 1.62 and 1.24 $\log_{10}$ CFU/carcass by qPCR and enumeration, respectively, were obtained when carcasses were submerged in a 1.5% lactic acid solution.

Larger reductions using lactic acid have been found by combining the use of steam treatment at 100 °C for eight seconds and a 5% lactic acid treatment for one minute. This led to reductions of approximately 6 and 5 $\log_{10}$ CFU/cm^2, respectively, for *S. Enteritidis* and *C. jejuni* (Chaine et al., 2013).

The addition of 0.90% sodium lactate and 0.09% lactic acid to marinated chicken was shown to help delay the proliferation of spoilage microorganisms (for example, *Salmonella*). It was also shown to prevent the generation of undesirable chemicals, improve the levels of sensory attributes and extend the shelf life of products during refrigerated storage (Samoui et al., 2012).

In a comparative study of different chemical treatments on inoculated poultry samples, it was found that 2% lactic acid produced a significant *Salmonella* reduction compared with the other treatments (Killinger et al., 2010).

Additionally, cloacal washing with citric acid (1%, 5% and 10%) and lactic acid (1%, 5% and 10%) does not significantly affect carcass *Campylobacter* counts (Bolton et al., 2012).

Monocaprin emulsion

The immersion of naturally contaminated chicken legs in 20 mM (0.5%) monocaprin emulsion at pH 4.1 for one minute at 20 °C can reduce the number of *Campylobacter* by 2.0 to 2.7 $\log_{10}$ CFU (Thormar et al., 2011).

In addition, pre-chill dipping of whole carcases into 20 mM monocaprin emulsion in the slaughterhouse had led to a significant reduction in *Campylobacter* contamination. After storage of up to 14 days at 3 °C, lower psychrotrophic spoilage bacteria counts were found on monocaprin-treated chicken parts than on untreated controls (Thormar et al., 2011).

Effect of chemical washes on sensory attributes of poultry

A common barrier to the use of chemical washes for pathogen reduction is the perceived negative affect they may have on the sensory attributes – the smell, taste, texture and appearance – of chicken. It was reported that broiler carcases treated with PAA were to "have a rather unpleasant vinegar-like odour" (Bureau Européen des Unions de Consommateurs [BEUC], 2014). Many studies compare the effect of various post-chill antimicrobials on both microbial reduction and meat quality attributes. In one such study, treating ground chicken with 0.07% and 0.10% PAA was shown to achieve the greatest reductions in *Salmonella* and *Campylobacter*, providing approximately a 1.5-$\log_{10}$ reduction, followed by a 0.8-$\log_{10}$ reduction after treatment with 0.35% and 0.60% CPC (Chen et al., 2014). In addition, chlorine (0.003%) was the least effective treatment. Importantly, the 0.07 and 0.10% PAA extended the shelf life of ground chicken for three days, while none of the treatments had a negative impact on colour or sensory attributes of the meat during storage.

Similarly, evaluations showed similar colour, smell and overall acceptability scores for treatment-dipped (12% TSP, 1,200 ppm ASC, 2% citric acid, 220 ppm PAA, water) and untreated samples on day zero and day one. From day three, sensorial attributes scored lower for untreated, PAA and water-dipped legs compared with legs treated with TSP, ASC and CA (Del Rio et al., 2007). Furthermore, the immersion treatment of poultry samples in TSP or CA has achieved *Campylobacter* reductions of 2.49 and 1.44 $\log_{10}$ CFU/cm^2, respectively, while not adversely affecting the sensory quality of the meat (Meredith et al., 2013).

Customer acceptability of in-factory processing interventions

The acceptability of interventions by consumers is an important determinant of government decision making as effective policy initiatives are reinforced by public preferences and concerns (Cope et al., 2010). Consumers may be more willing to accept new interventions where they have a role in choosing these themselves.

Factors that may influence the acceptability of decontamination interventions include the level of concern that people associate with interventions; the awareness the public has about the

intervention; the willingness to voluntarily accept the intervention; and the severity or extent of the consequences the consumer would have to endure if it was not in place (MacRitchie et al., 2014).

In one survey, it was found that on-farm hygiene practices had the greatest acceptability compared with other interventions. This was followed by freezing, steaming, vaccination and feeding additives (MacRitchie et al., 2014) (Figure 7). Chemical washes and irradiation always had the fewest number of respondents indicating acceptability and, no matter what the level of effectiveness, they were never acceptable to 53% and 54% of participants, respectively.

Figure 7: Percentage of participants who stated interventions as acceptable before additional information was provided
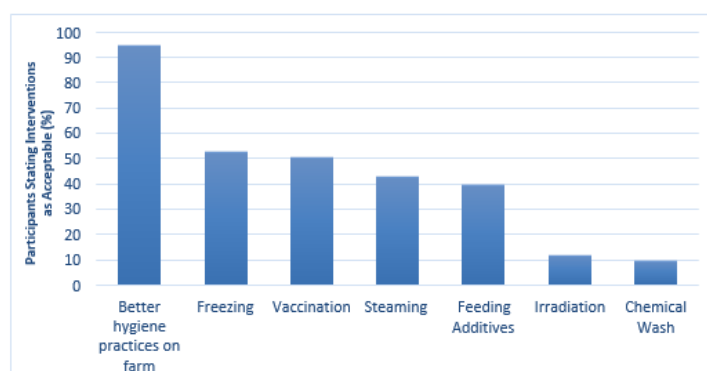
Even with the provision of additional information to the participants to increase their awareness of *Campylobacter,* the overall trend of acceptability was not altered. However, increased awareness of the effectiveness of various interventions did make each of them more acceptable. For example, there was an average increase of 26% in acceptability of the interventions after increased awareness of the presence of *Campylobacter* and its dangers to public health was presented (based on 90% efficiency of interventions) (MacRitchie et al., 2014).

Summary of processing interventions potential

From the literature, there are many different processing interventions available that could be implemented in the IOI to reduce the level of *Campylobacter* contamination. However, from previous surveys, some interventions are not as accepted as others by the consumer or the retailer, even though they provide higher and more consistent decontamination rates (chemical washes and irradiation).

When analysing the literature, it is difficult to obtain an accurate comparison as some studies use naturally contaminated chicken and others inoculated chicken (with varying levels of inoculation).

In addition, the parts of the chicken – fillets, wings, whole carcasses and so on – used in the experiments varies.

In terms of their efficacy in decontaminating poultry parts and carcasses, Table 4 provides an overview of some of the main processing interventions reviewed (FSA, 2010).

Table 4: Efficacy of processing interventions in the decontamination of poultry parts and carcasses

Process	Intervention for *Campylobacter* control	Log_{10} reduction
Inside–outside wash	Carcass washing with chlorine (25–35 ppm)	0.5
Inside–outside wash	Carcass washing with ASC	1.3
On-line processing	Carcass spraying with ASC and citric acid	2.1
Chill carcass	Forced air chilling	0.4
Chill carcass	Immersion chilling	1.1–1.3
Post-chill applications	Carcass immersion with ASC (600–800 ppm, pH 2.5–2.7, 15 secondss)	0.9–1.2
Packing	Modified atmosphere packing (70% O_2)	2.0–2.6 (over eight days chilled storage)
Packing	Irradiation	Elimination
Chill or freeze carcass	Freezing	0.7–2.9
Chill or freeze carcass	Crust Freezing	0.4
Retail of food service	Cooking	> 7
Consumer	Cooking	> 7

Conclusions from desk research

It is apparent that no single intervention exists that will resolve the *Campylobacter* problem and that a series of *Campylobacter* prevention interventions must take place across the entire industry. These must begin with preventative protocols on-farm and follow through to implementing processing interventions at factory level, in order to protect the consumer from camplyobacteriosis infection.

Biosecurity, although crucially important, even at the most stringent level is not the sole answer to reducing *Campylobacter* colonisation. Introducing measures such as no-thinning policies and reducing the stocking density could be beneficial in terms of reducing colonisation in birds. However, in terms of industry practices and economics, these measures have commercial consequences.

Feed interventions, in combination with biosecurity and other measures, could be a successful mechanism for *Campylobacter* reduction. However, finding a feed additive or supplement that has reliable and repeatable results both in vitro and in vivo is proving quite a difficult task to researchers.

In terms of processing, there are a vast number of interventions that can significantly reduce the *Campylobacter* load of poultry. Crust freezing, steam plus ultrasound (SonoSteam®), cold plasma treatments, organic washes and UV light all provide excellent results for *Campylobacter* reduction. In addition, these interventions do not cause any detriment to the sensory quality of the poultry meat.

Treatments such as forced air chilling and hot water or steam treatment are less likely to be implemented by processors, due to both the space required in the factory for forced air chilling, and the damage that steam or hot water spraying does to the meat quality.

Although successful in reducing *Campylobacter*, irradiation and chemical washes, according to recent literature and surveys, remain unacceptable to consumers, with perceived damaging effects to both the consumer's health and the quality of the poultry product.

Therefore, a combination of acceptable, economically viable interventions should be implemented by industry. Many of the researched approaches mentioned in this review are already under implementation or experimentation to determine their ongoing success in *Campylobacter* $\log_{10}$ reduction.

This review provides a base to inform survey questionnaires and consumer focus group strategies, in order to successfully communicate the current potential interventions and to extract the acceptability of such interventions, and the awareness of *Campylobacter,* effectively from the consumers. Ipsos, a designated marketing group, coordinated the telephone questionnaires and the consumer focus group sessions.

4 Results, discussion and key findings

Chapter 4 in this publication presents the findings from the qualitative and quantitative research conducted in May and June 2016.

Qualitative research

During the qualitative research, a total of five consumer focus groups, each with nine respondents per group, were conducted across the ROI and NI. The participants incorporated a mix of ages and life stages, with two groups female–only and three groups mixed gender.

The overall aim of the qualitative investigation was to gain an initial understanding about how consumers react to the various meat decontamination treatments presented, with a view to identify the six most suitable ones to include in the subsequent quantitative research. Other objectives of the qualitative research included

- Understanding meat preparation and consumption practices
- Identifying what type of precautions, if any, are taken during storage, defrosting and cooking
- Assessing awareness of *Campylobacter* and other bacteria causing food poisoning
- Identifying respondents' attitudes towards and awareness about the origin and processing of meat.

Quantitative research

The two quantitative surveys conducted as part of this study interviewed nationally representative samples of the ROI and NI. Each of the two surveys were part of an omnibus style research project. Respondents in the ROI were interviewed over the phone, while NI respondents were interviewed face–to–face. Fieldwork was conducted in June, 2016.

Each of the two samples interviewed were monitored during fieldwork in terms of age, gender, social class and region. In addition, at analysis stage, each of the two data sets were weighted (adjusted to best fit) to the known profile of the ROI and NI populations using the latest Central Statistics Office (CSO) estimates. Table 5 shows the composition of the focus groups.

The main objective of the surveys was to present the six different meat decontamination treatments to respondents and assess how acceptable or not acceptable these interventions are in the public's perception. Nationally representative "metrics" (data to be used as a standard for comparison against later) were collected on topics such as: consumers' shopping for and cooking of meat; awareness of *Campylobacter* and

other food poisoning bacteria; and the incidence of people under four or over 65 years old, or with diabetes or other long-term illness, in the household.

This statistically robust data helped to understand if and to what degree people's perceptions of the meat decontamination treatments vary, as well as providing profile information for the subsequent cluster analysis (Chapter 5 in this publication).

Table 5: Composition of the focus groups

Group Number	Gender	Age (years)	Life stage	Date	Location
1	Female	30–50	Younger or older children	23rd May, 2016	Navan
2	Mixed	25–35	Single or cohabiting	23rd May, 2016	Dublin
3	Female	30–50	Younger or older children	24th May, 2016	Belfast
4	Mixed	25–35	Single or cohabiting	24th May, 2016	Newry
5	Mixed	Over 55	"Empty nesters"	26th May, 2016	Thurles

Qualitative findings

The overall aim of this qualitative study was to gain initial understanding about how consumers react to the various meat decontamination treatments presented, with a view to identify the six most suitable interventions to include in the subsequent quantitative research. The final choice of treatments was agreed with industry experts.

Given the very low awareness of *Campylobacter* or other food poisoning bacteria, the moderator shared with respondents information on this topic as well as measures that could be taken to reduce the risk of food poisoning bacteria.

Chicken consumption and preparation

Across all groups, chicken was referenced as the most convenient, versatile and potentially the best meat choice in terms of value for money. Minced beef was the closest in terms of value for money and

convenience. The relatively neutral taste of chicken means that it is rarely rejected by anyone and can be utilised with a vast array of sauces, meal types and styles of cooking.

However, in addition to being the most versatile, chicken was also the most likely meat category to be associated with potential food poisoning issues, to be treated with the most care during its preparation. Fish was considered to be the next most likely to need care and attention.

Concerns about chicken lead to a large number of precautions in the home, outlined here. These behaviours are consistent with the management of most raw meat but some extend particularly to chicken more than to others.

Correct storage and dangers of refreezing

This refers to placing raw meat produce on the correct shelf. It became evident during groups that correct storage is not a cautionary step that all respondents undertake.

However, there was good awareness across all groups of the dangers of refreezing raw meat.

Cross-contamination outside the refrigerator

Allocating different chopping boards to meat and vegetables is common, although again not applicable among all respondents – some often choose to turn the chopping board over.

Most respondents wash their hands every time chicken is touched.

Defrosting

There was some variance in chicken defrosting practices. Some respondents are happy to defrost using the microwave, while others prefer to leave the chicken out on the kitchen counter (in a bowl) until it defrosts. There are also some who typically choose to leave the chicken in the fridge to defrost.

Cooking correctly or overcooking

Many respondents admitted to often relying on the instructions on the package regarding how to ensure the chicken is fully cooked. In most cases they exceed these recommendations in order to ensure the meat is "fully done", even if that might result in overcooking.

Avoiding direct contact

Some respondents admitted to using gloves when handling the chicken, something they would never do with other protein sources. In addition to gloves, a few dislike the feel of the chicken meat and therefore prefer using utensils as well during its preparation.

Awareness of food poisoning bacteria and food origins

Salmonella and *E. coli* were the only bacteria commonly mentioned across all groups and the ones most likely to be associated with chicken and fish. *Listeria* was the only other bacteria mentioned but mostly only when prompted and not across all groups – respondents associated *Listeria* more with water and some cheeses.

There was virtually no awareness or recall of *Campylobacter,* even when specifically prompted. Only one respondent across the five groups referenced *Campylobacter* in the discussion – the other respondents had no understanding or knowledge of it.

When asked about the origin of the bacteria that can be found on chicken, there was no definitive view. Some respondents made reference to the development of bacteria during the rearing stage, with a focus on the farm. Many others presumed bacteria developed over time and could be triggered by inadequate storage or through incorrect handling, for example, incorrect defrosting, wrong room temperature, and so on.

It quickly became evident during the qualitative research that origin of meat bacteria was not something that had been considered by respondents. The general opinion was that they are often advised to take precautions to avoid the consequences of food bacteria, rather than consider the origins of the issue. Moreover, there was little to no evidence that the processor is specifically highlighted as a potential cause of spreading the bacteria.

Respondents' attitudes towards food origins

The qualitative research conducted as part of this project suggests that modern consumers are relatively detached from the processes associated with the production of meat. Furthermore, there was little evidence that the specifics of meat production are considered at any stage of the food purchase, preparation and consumption process.

Consumers tend to abdicate, or give over, the responsibility of delivering a high quality product to retailers. This trust is usually combined with assumptions that the product is fully traceable and adheres to appropriate quality marks.

The cognitive, or mental, effort required to assess every decision in a supermarket is too high. In order to avoid cognitive duress, or pressure, consumers will take heuristics (shortcuts) when making purchasing decisions. Given this abdication of responsibility from the poultry process, introducing very specific elements of the process can present challenges:

- When a specific decontamination process is separated out from other elements of processing, consumers are asked to consider that process without any further context. This can bring undue focus on the process.

- Consumers may have ideas about the overall poultry process that do not match reality, or beliefs about the environment and processes that do not match current production practices.

- Demonstrated processes are negatively perceived, as consumers have no knowledge of current processes.

- Consumers will look for the most "natural" process; that is, with the least number of interventions as possible.

- Consumers are looking for the process that feels the least unnatural given their incomplete knowledge of the overall process.

- Consumers are susceptible to the language used when discussing different processes. An illustration of this is provided in Figure 8.

Organic Acid Wash

- All chicken is washed with water as standard in current processing practice
- This option involves chicken being either sprayed or dipped with organic acids (which occur in nature)
  - Lactic acid (occurs in muscles during exercise)
  - Citric acid (lemon juice)
  - Acetic acid (vinegar)
- The lower levels of pH kill the bacteria
- Zero detriment to chicken quality
- Permitted in the EU; fruit and vegetables already commonly treated in this way

Subtle changes can impact on the way the treatments are perceived. The references highlighted in the illustration (Figure 8) were not included in the initial groups and this process was considered to be distinctly unpopular. The introduction of these new terms had the noticeable effect of reducing consumers' negativity towards the process. This suggests that the public reaction to any decontamination processes is likely to be strongly influenced by the language used when the process is described in communications.

Decontamination treatments: clear preference for more natural, less invasive interventions

During the qualitative research it became evident that, when thinking of potential ways of decontaminating meat, respondents had the tendency to judge these interventions by using a two-scale system of

1. The extent to which the intervention is "natural" or not (whether it is perceived to involve natural substances or processes)

2. The degree to which the intervention is invasive (the perceived level of contact or potential for product alteration).

The optimal solution for them would be a treatment that is either natural, (or more natural than others) and non-invasive (or less invasive than others).

Inversely, then, the least accepted treatment would be one that is considered both less natural and more invasive than others, and makes consumers worry that it involves elements not typically associated with food (not "natural" elements) that interact with the product in some potentially altering form (they are invasive).

Decontamination treatments investigated during focus groups

The potential meat decontamination treatments discussed in this document were presented to respondents during the focus groups. The definitions used are given here.

Crust freezing

In this process, the skin and approximately 3 mm of the surface of the chicken are reduced to -2 degrees temporarily and the chicken is then returned to a normal chilled temperature. During this short time, the rapid ice crystallisation freezing kills the *Campylobacter* bacteria. This process is currently being used in chicken processing in Ireland, the UK and Europe. Zero detriment to chicken quality.

Steam ultrasound

This process combines the use of ultrasound and steam at high pressure. Ultrasound disturbs the very thin outer layer of the chicken, which allows the steam to easily reach any bacteria present. The bacteria is quickly heated up and killed before the heat affects the chicken itself. This process is currently being used in chicken processing in the UK and Europe. Zero detriment to chicken quality.

Organic acid wash

Chicken is washed with water as standard in current processing practice. This option involves chicken being either sprayed or dipped with organic acids (which occur in nature) such as lactic acid (occurs in muscles during exercise), citric acid (lemon juice) or acetic acid (vinegar). The lower levels of pH kill the bacteria. Zero detriment to chicken quality. Permitted in the EU; fruit and vegetables already commonly treated in this way.

Chemical wash

These washes are slightly stronger than organic washes, which may lead to greater reductions in *Campylobacter* risk. Chlorinated and other acidic washes are commonly used in the USA. The chlorinated/chemical compounds are particularly effective at eliminating the harmful bacteria. Currently not allowed in EU, although under investigation.

Forced air chilling

Method is based on the surface drying achieved by high air velocity. The rapid reduction in temperature, combined with the high speed of the air over the chicken causes the bacterial cell walls to burst, thereby killing them. No reported detriments to chicken quality. Permitted in the EU.

Light technology

Light technology (example UV light) destroys the bacterial DNA. The light contains high-energy photons that break the bacterial DNA, leading to the degradation of the bacterial cell walls. Commonly used for the decontamination of packing surfaces or in food-processing environments.

Irradiation

The irradiation process uses gamma rays from isotopes (such as cobalt-60). No reported detriments to chicken quality. Spices and pepper and some fruit are already commonly irradiated in this manner. Permitted in the EU.

Ozone treatment

Ozone is a gas that occurs naturally (O_3). Ozone treatment can be implemented either through water or gas. This involves a simple radiation of oxygen by UV light. The ozone kills the bacteria and then it evaporates so it leaves no residue. No reported detriments to chicken quality. Permitted in the EU.

Electrolysed oxidising water

This process involves electrifying salt water, which causes naturally occurring chlorine molecules to form. This chlorine acts as a natural disinfectant, killing the bacteria with no chlorine residues left on the chicken meat. Permitted in the EU.

Cold plasma treatment

Packaged chicken goes through a magnetic field. This temporarily changes the atmosphere in the package resulting in bacteria destruction. When the package comes out of the magnetic field, the atmosphere inside the package goes back to normal. Novel technique. Currently being trialled on fruit and vegetables in the EU.

Decontamination treatments by type of intervention

Figure 9 serves to illustrate how respondents reacted to the 10 meat decontamination treatments according to how natural (or not) and invasive (or not) they were perceived to be. The impression was that forced air chilling sits in the "optimal" space of being both more natural and less invasive than other options. Crust freezing and steam ultrasound were placed in the upper left hand side, being perceived as more invasive but still considered natural.

Cold plasma, electrolysed oxidising water, ozone treatment and light technology sit in a more debatable space on the spectrum – that of being potentially acceptable but to varying degrees. While considered less natural than others (even quite technical for most people), they presented the benefit of not being too invasive.

Irradiation and organic and chemical acid washes were considered invasive. However, organic wash was less straightforward to place in terms of "natural" or "unnatural" and was categorically preferred to both irradiation and chemical wash; these had the perceived drawbacks of being both more invasive and less natural than the other treatments.

Figure 9: Schematic of decontamination treatment perception analysis
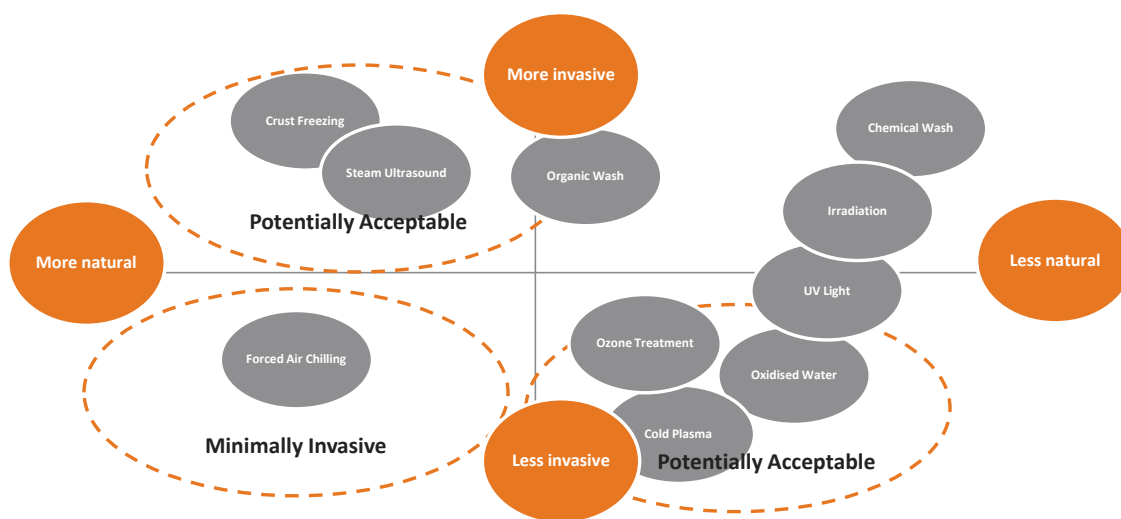
Based on the reactions noticed during the groups as well as how the proposed treatments were considered by industry experts, the six treatments chosen to be analysed during the subsequent quantitative stage were crust freezing, steam ultrasound, forced air chilling, organic acid wash, chemical wash and cold plasma treatment.

Quantitative findings

Section 4.4 in this publication looks at the six different meat decontamination treatments that were examined in the study in terms of their level of acceptability. The perceived acceptability of treatments is discussed first. This is followed by an analysis into how the different variables presented so far (that is, awareness of *Campylobacter* and other food poisoning mechanisms; cooking and shopping behaviour; presence of young, old, diabetic or chronically ill people in the household) have an impact, if any, on the extent to which the treatments are accepted.

Respondent profile

The two quantitative surveys conducted as part of this study interviewed nationally representative samples of the ROI and NI. Each of the two samples interviewed were monitored during fieldwork in terms of age, gender, social class and region. In addition, at analysis stage, each of the two data sets was weighted to the known profile of the ROI and NI populations using the latest CSO estimates. The findings were then combined and the overall respondent profile is presented in Figure 10.

Figure 10: Quantitative survey respondent profile

Gender
49% 51%

Age
- 15-17: 5%
- 18-24: 10%
- 25-34: 18%
- 35-44: 18%
- 45-54: 17%
- 55-64: 14%
- 65+: 18%

Region
Greater Belfast 21%
Rest of N.I. 29%

N.I. 50%
ROI 50%

Dublin 14%
ROL 13%
Munster 14%
Conn/Ulster 9%

Social Class
- ABC1: 43
- C2DE: 54
- F*: 3

* Due to small sample size, findings from th social group aren't included in this documer
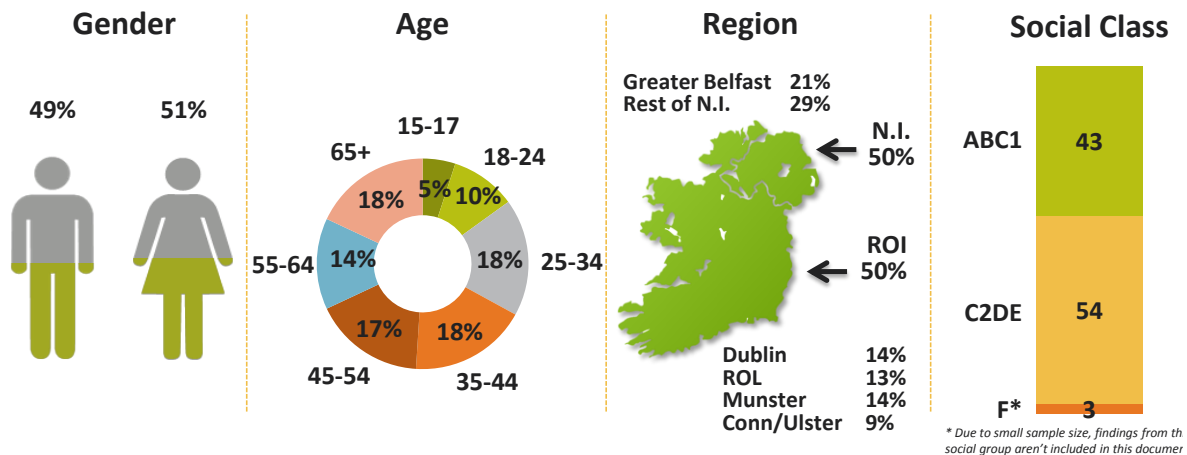
A similar number of interviews was carried out in the ROI and NI resulting in a 50:50 ratio. Within this, Greater Belfast respondents form 21% and Dublin residents 14% of the sample interviewed. Just over half of respondents were female (51%), with males at 49%. In terms of social class, 43% of respondents are ABCIs and 54% are C2DEs, with a small proportion (3%) being farmers.

Cooking raw chicken and frequency of consumption

Figure 11 illustrates the profile of respondents in terms of their cooking habits, and the frequency of cooking raw chicken in particular. Half of respondents (51%) usually do most or all of the cooking in their household (with an unsurprisingly much higher incidence of this among women at 72%). A third of the sample (34%) share the cooking responsibilities of the household.

Figure 11: Respondents' cooking habits, and frequency of cooking or consuming raw chicken
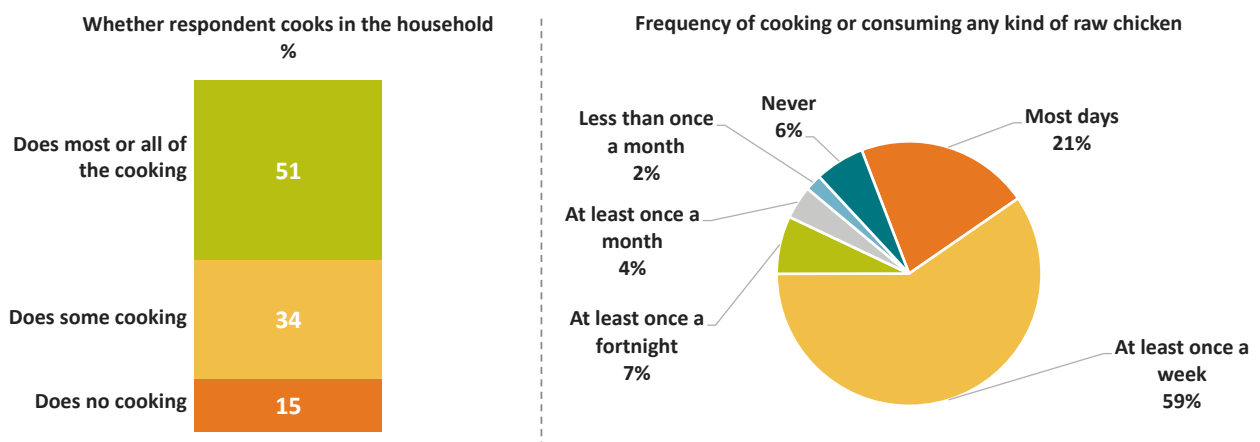
Whether respondent cooks in the household %
- Does most or all of the cooking: 51
- Does some cooking: 34
- Does no cooking: 15

Frequency of cooking or consuming any kind of raw chicken
- Never: 6%
- Less than once a month: 2%
- At least once a month: 4%
- At least once a fortnight: 7%
- At least once a week: 59%
- Most days: 21%

Q.1   Are you the person who usually does most of the cooking in this household, or do you just do some of the cooking, or do you not usually do any cooking at all?
Q.2   How often do you cook/consume any kind of raw chicken, including chicken fillets or things like chicken Kiev?
Base: All Respondents: 2,011

When asked how often they cook raw chicken (or cook *and* consume it) it appears that the majority of those interviewed (8 in 10), do so weekly or more. There is a higher incidence among ROI residents at 83%, compared with NI at 78%. In terms of age groups, cooking chicken on at least a weekly basis is most prevalent among those aged 25 to 44 years (86%) and least prevalent among those aged 65 years or older (69%). 84% of ABC1 respondents cook raw chicken weekly or more, compared with 78% of C2DEs.

Incidence of vulnerable individuals in household

As these groups present higher risks when exposed to *Campylobacter*, it was important to establish the proportion of households that include people under the age of four or over the age of 65, or with diabetes or other long-term illness.

The research found that 12% of households include residents under or up to the age of four years and 17% have residents of 65 years old or over. One in 10 households include someone with diabetes or other long-term illness. This results in just over a third of all households (35%) across the IOI with at least one resident from a high-risk group (Figure 12).

Respondents who reported to have someone in the household from the above-mentioned groups were subsequently asked if they typically take any special measures when preparing food for them. Responses to this question were divided, with 51% confirming they take special measures and 46% not taking any special measures when cooking for vulnerable individuals.

Figure 12: Incidence of people under four years and over 65 or with long-term illness in households, and frequency of special cooking measures taken

Q.14   Are there any people from the below groups residing in your household?
Q.15   And would you typically take any special measures when preparing food for them?
Base: All Respondents: 2,011

Base: All respondents with these groups in Household: 751
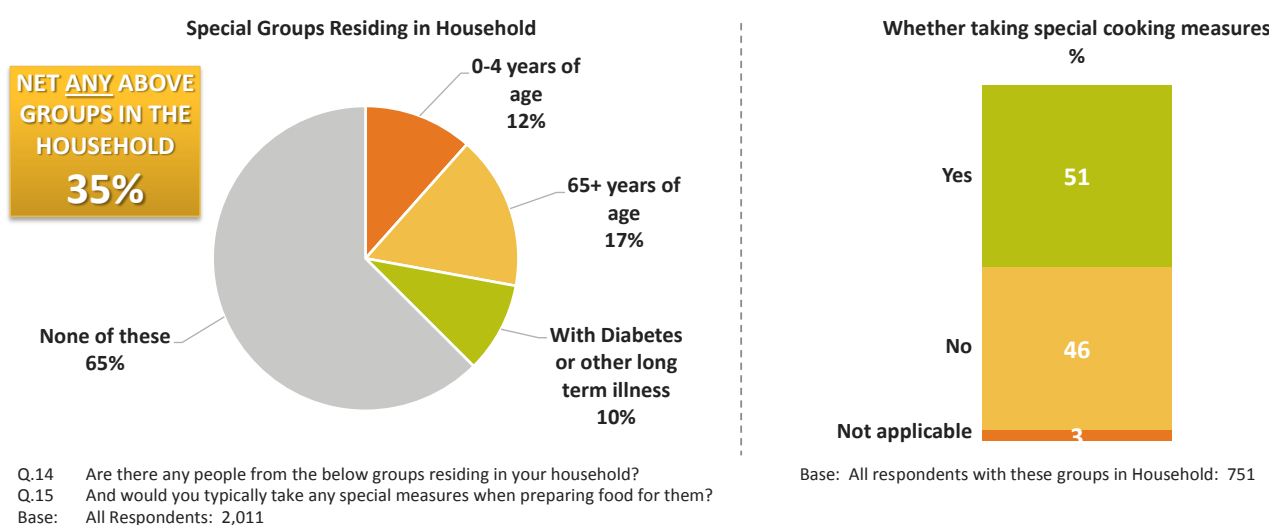
The incidence of taking special measures when cooking for someone under four or over 65 years of age or with a long-term illness is higher among NI residents (58%), compared with ROI (44%). While no significant differences are noted within the ROI sample, it appears that for NI the incidence of taking special measures when cooking for these groups is highest among those aged 25 to 44 years old (70%) (Figure 13).

Figure 13: Incidence of taking special measures when cooking for people under four years and over 65 or with long-term illness in NI and the ROI

	Total %	REGION		GENDER		AGE				SOCIAL CLASS	
		ROI	NI	Male	Female	15-24	25-44	45-64	65+	ABC1	C2DE
		(379)	(372)	(321)	(430)	(64)	(255)	(139)	(293)	(291)	(443)
		%	%	%	%	%	%	%	%	%	%
Yes	51	44	58	47	53	47	55	42	52	46	55
No	46	54	38	48	45	50	44	56	43	52	42
Not applicable	3	2	4	4	2	3	2	2	5	2	3

Q.15   And would you typically take any special measures when preparing food for them?
Base: All Respondents with these groups in Household: 751

Awareness of food poisoning bacteria

Perceived causes of food poisoning

Before identifying people's attitudes towards the various meat decontamination treatments proposed, the research wanted to establish consumers' perceptions in terms of what the most frequent food poisoning culprit is among meat, poultry or fish. Overall, more than seven in 10 respondents (73%) think of chicken as the most common cause of food poisoning, significantly ahead of all other categories (Figure 14).
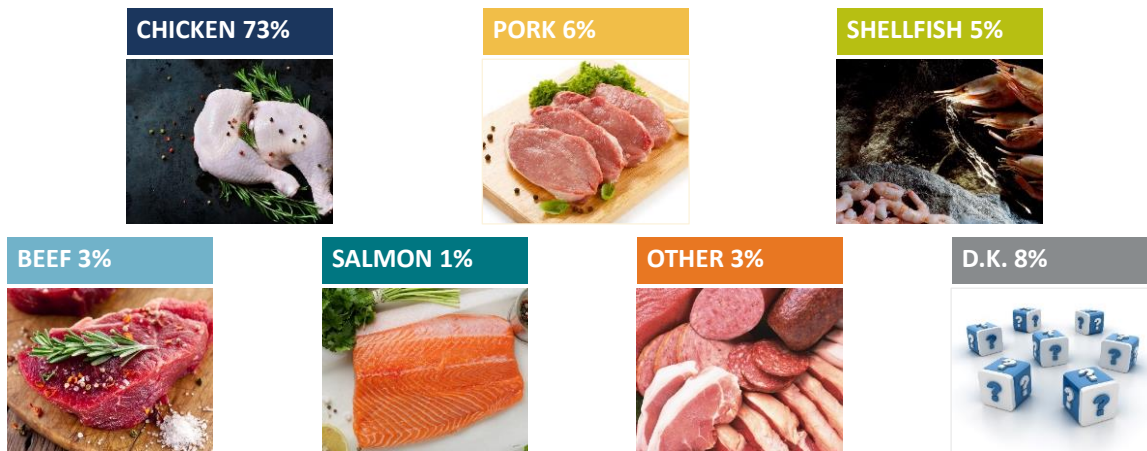
CHICKEN 73%	PORK 6%	SHELLFISH 5%

BEEF 3%	SALMON 1%	OTHER 3%	D.K. 8%

*Responses ≤1% not shown

Q.3   In your opinion, what is the one category of meat, poultry or fish that causes food poisoning most often?
Base: All Respondents: 2,011

*D.K. – Do not know

Particular groups appear more likely to perceive chicken as the meat or poultry category most likely to cause food poisoning. They are those with most cooking responsibility in the household (79%), as well as those cooking or consuming chicken frequently (76%) and those who take special measures when cooking for the more vulnerable or higher-risk individuals in the household (78%). Looking at results by demographic breakdown (age, gender and so on), a noteworthy difference between ROI and NI residents is observed: a higher incidence among ROI respondents (77%) of thinking that chicken is the most frequent cause of food poisoning, compared with NI respondents (69%). Overall, as well as within the ROI and NI separately, figures reveal that females show a higher incidence of associating chicken with food poisoning (Figure 15).

Figure 15: Perceived causes of food poisoning by region, gender, age and social class
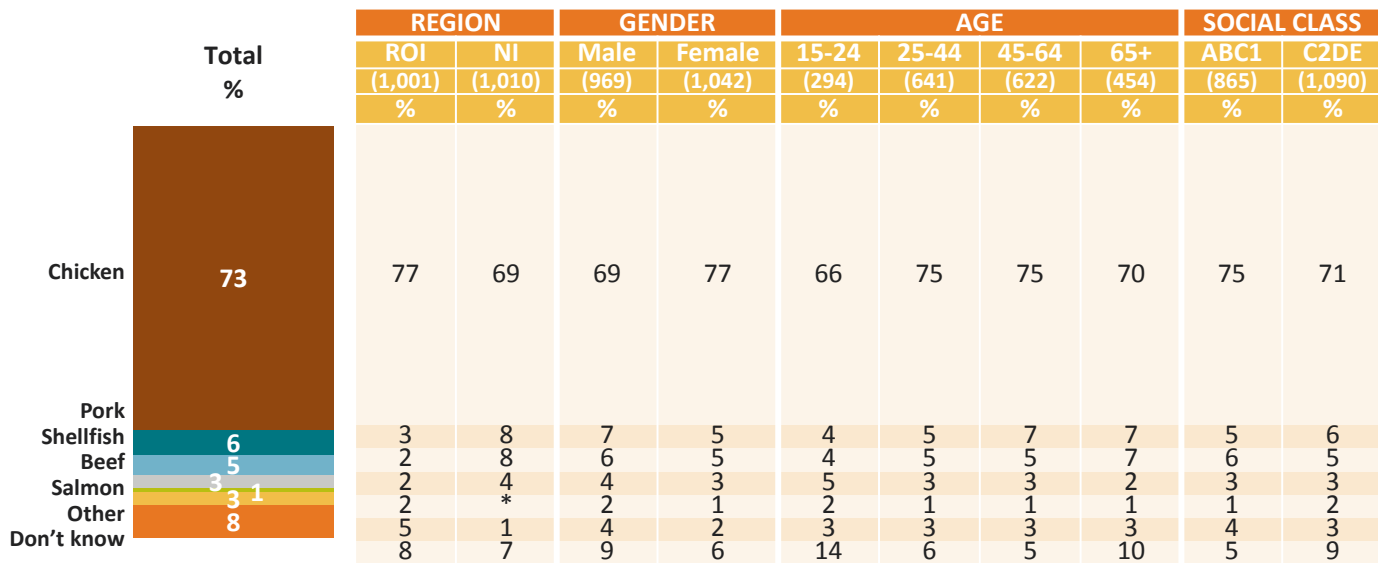
	Total %	REGION		GENDER		AGE				SOCIAL CLASS	
		ROI (1,001)	NI (1,010)	Male (969)	Female (1,042)	15-24 (294)	25-44 (641)	45-64 (622)	65+ (454)	ABC1 (865)	C2DE (1,090)
		%	%	%	%	%	%	%	%	%	%
Chicken	73	77	69	69	77	66	75	75	70	75	71
Pork		3	8	7	5	4	5	7	7	5	6
Shellfish	6	2	8	6	5	4	5	5	7	6	5
Beef	5	2	4	4	3	5	3	3	2	3	3
Salmon	3 3 1	2	*	2	1	2	1	1	1	1	2
Other	8	5	1	4	2	3	3	3	3	4	3
Don't know		8	7	9	6	14	6	5	10	5	9

Q.3   In your opinion, what is the one category of meat, poultry or fish that causes food poisoning most often?
Base: All Respondents: 2,011

Awareness of *Campylobacter* and other food poisoning bacteria

When spontaneously asked what bacteria they are aware of that causes food poisoning, *Salmonella* registers the highest level of recall among respondents, at 54%, followed by *E. coli* at 37% (Figure 16).

Figure 16: Awareness of *Campylobacter* and other food poisoning bacteria
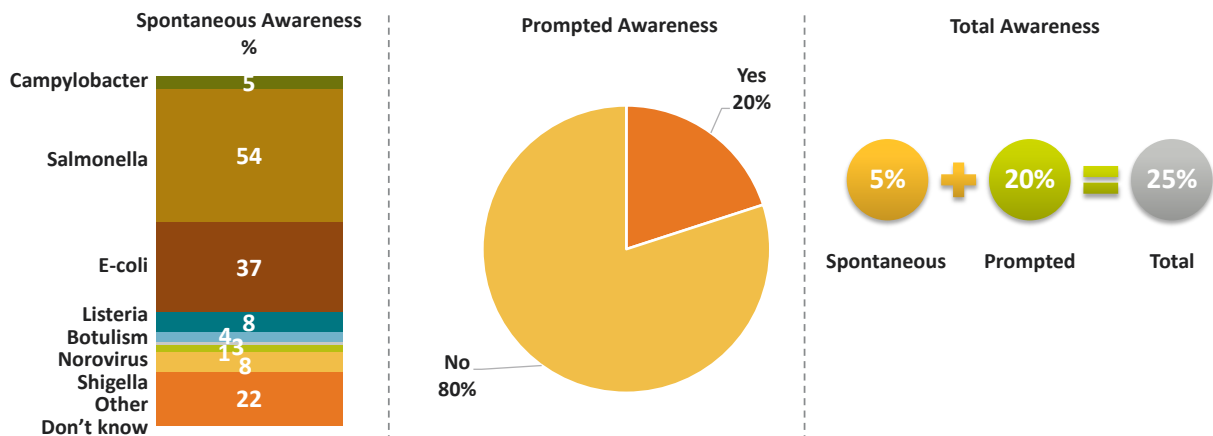
Spontaneous Awareness %
- Campylobacter: 5
- Salmonella: 54
- E-coli: 37
- Listeria: 8
- Botulism: 4
- Norovirus: 3
- Shigella: 1
- Other: 8
- Don't know: 22

Prompted Awareness
- Yes 20%
- No 80%

Total Awareness
- Spontaneous 5% + Prompted 20% = Total 25%

Q.4   What bacteria would you be aware of that causes food poisoning?
Q.5   Have you ever heard of Campylobacter?
Base: All Respondents: 2,011

Other food poisoning bacteria is mentioned far less spontaneously: *Listeria* at 8%, *Campylobacter* at 5%, botulism at 4%, norovirus at 3% and *Shigella* at 1%. Over two in 10 people admit to not having awareness or knowledge on the subject.

However, when prompted specifically on *Campylobacter*, an additional two in 10 respondents claim to be aware of the bacteria, which results in a total awareness level ("spontaneous" plus "prompted") of 25%, or a quarter of the population interviewed.

The incidence of total awareness increases among those who do most cooking in the household (29%); and those who have anyone under the age of four or over the age of 65 years, or with diabetes or other long-term illness, in the household (29%) and who typically take special measures when cooking for them (31%).

Figure 17: Awareness of *Campylobacter* and other food poisoning bacteria by region, gender, age and social class
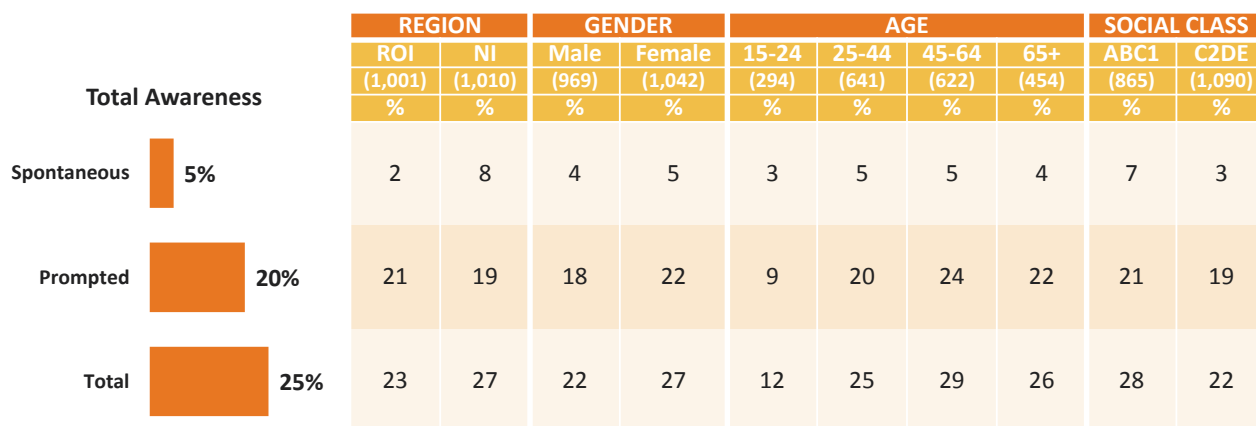
Total Awareness		REGION		GENDER		AGE				SOCIAL CLASS	
		ROI	NI	Male	Female	15-24	25-44	45-64	65+	ABC1	C2DE
		(1,001)	(1,010)	(969)	(1,042)	(294)	(641)	(622)	(454)	(865)	(1,090)
		%	%	%	%	%	%	%	%	%	%
Spontaneous	5%	2	8	4	5	3	5	5	4	7	3
Prompted	20%	21	19	18	22	9	20	24	22	21	19
Total	25%	23	27	22	27	12	25	29	26	28	22

Q.4   What bacteria would you be aware of that causes food poisoning?
Q.5   Have you ever heard of Campylobacter?
Base: All Respondents: 2,011

A few slight differences in total awareness are noticed in terms of males as against female respondents, as well as ROI compared with NI residents (Figure 17). Among age groups, the highest total awareness of *Campylobacter* is recorded among those aged 45 to 64 years old. The lowest awareness is noticed among the younger age group, at 12%.

Purchasing raw meat, and information on labels

Respondents were asked where they typically buy raw meat and if they have any preference for seeing information on the label about the treatment used in the slaughterhouse to kill bacteria. The resulting data shows just under half of the population (49%) tends to buy raw meat from the supermarket, with butchers being the second most used source, at 45% (Figure 18).

At 59%, those aged 18 to 24 years show a higher incidence of buying raw meat from the supermarket. Moreover, at 53%, ROI residents use the supermarket more often than their NI counterparts (at 46%) for buying raw meat.

Figure 18: Purchasing habits associated with raw meat, and preference for seeing treatment information on food labels
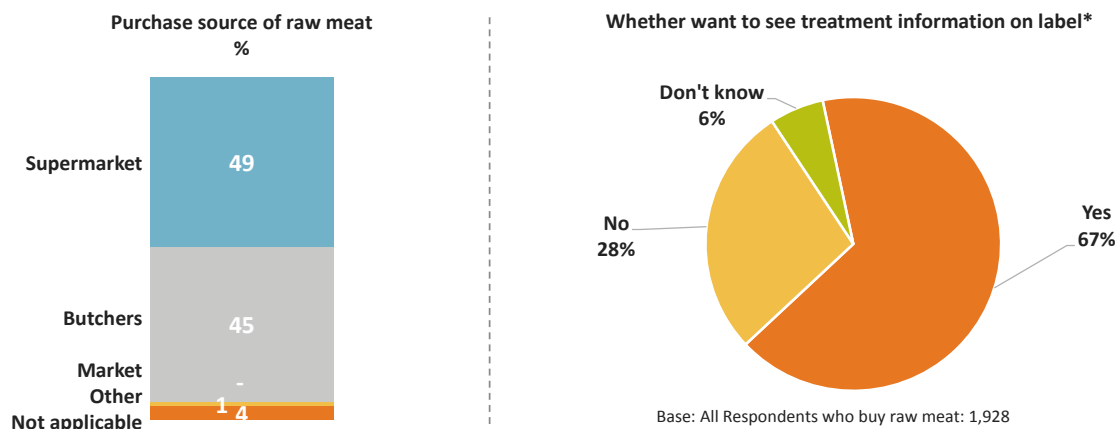
Purchase source of raw meat %

Supermarket	49
Butchers	45
Market	-
Other	1
Not applicable	4

Whether want to see treatment information on label*

Don't know 6%
No 28%
Yes 67%

Base: All Respondents who buy raw meat: 1,928

Q.12   Do you buy most of your raw meat from a supermarket, a butcher's, a market, or some other kind of shop?
Q.13   When buying raw meat in the supermarket, would you want to see information on the label about the treatment used in the slaughterhouse to kill bacteria?
Base: All Respondents: 2,011

Among those who buy raw meat, two in three (67%) would want to see information on the product label about the treatment used in the slaughterhouse to kill bacteria. Preference for seeing treatment information is higher among the ROI sample, at 72%, compared with NI, at 61%. Similarly, overall, female respondents appear more interested in seeing this information than males (71% as against 62%, respectively). The older age group – 65 years and above – shows the least interest (55%) in this information being displayed on the meat package.

Treatments and overall ranking

During the interview, the order in which the treatments were presented was rotated in order to minimise the risk of respondent bias.

The information given here was presented to the respondent before he or she was asked about the extent to which the treatments are acceptable.

Crust freezing

In this process, the skin and approximately 3 mm of the surface of the chicken are reduced to -2 degrees temporarily and the chicken is then very quickly returned to a normal chilled temperature. During this short time, the rapid freezing kills the bacteria. This process has no detrimental impact on chicken quality.

Steam ultrasound

This process combines the use of ultrasound and steam at high pressure. Ultrasound disturbs the very thin outer layer of the chicken, which allows the steam to penetrate and kill the bacteria before the heat affects the chicken itself. This process has no detrimental impact on chicken quality.

Forced air chilling

This process involves high speed cold air passing over the surface of the chicken. The rapid reduction in temperature, combined with the high speed of the air over the chicken, kills the bacteria. This process has no detrimental impact on chicken quality.

Organic acid wash

This process involves the meat being either sprayed with or dipped in organic acids, which kill the bacteria. These organic acids occur naturally, such as lactic or citric acid. This process has no detrimental impact on chicken quality.

Chemical wash

This process involves the meat being either sprayed with or dipped in chemical acids, which kill the bacteria. Chlorinated and other acidic washes are commonly used. This process has no detrimental impact on chicken quality.

Cold plasma treatment

In the process, the chicken is packaged as normal. The package is then passed (briefly) through a magnetic field. This temporarily changes the atmosphere in the package, resulting in bacteria destruction. When the package comes out of the magnetic field, the atmosphere inside the package returns to normal. This process has no detrimental impact on chicken quality.

The findings bring to light that forced air chilling, at 55%, is the most widely accepted meat decontamination treatment out of the six presented to respondents (Figure 19). It is consistently ranked first across all demographics and variables, and the highest incidence of its acceptability is noticed among ABC1s (61%), those who claim to be aware of *Campylobacter* (60%) and those who show preference for seeing the treatment information on the meat packaging (60%).

Figure 19: Consumer acceptability of six meat decontamination treatments
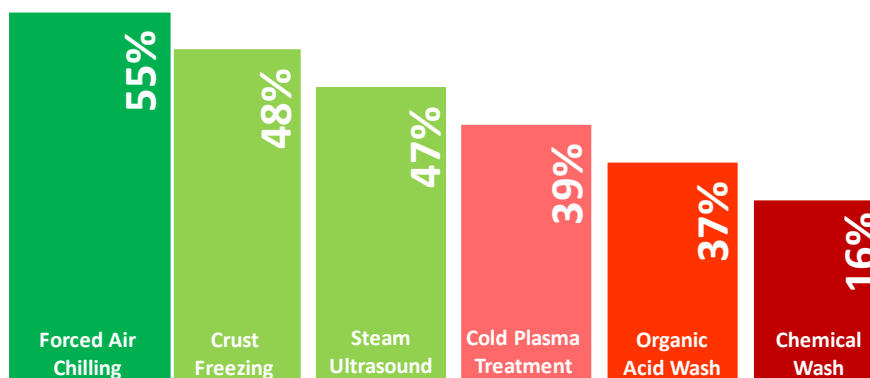
Crust freezing and steam ultrasound follow as second and third most accepted treatments (at just under half of respondents, 48% and 47% respectively). Crust freezing appears more accepted than steam ultrasound across most demographics, with the exception of both the youngest and the oldest age groups. These show marginally more acceptance of steam ultrasound.

Cold plasma and organic acid wash both show similar levels of acceptability, at 39% and 37% respectively. Cold plasma treatment is consistently ranked fourth across all demographics, with the exception of those respondents who have people in their household under four or over 65 years of age, or with long-term illness, for whom they take special measures cooking. This subgroup showed slightly higher acceptance of organic washing.

Perhaps unsurprisingly, given the qualitative findings, chemical wash is the least accepted meat decontamination treatment, significantly behind others at 16%. Only those aware of *Campylobacter* appear to show a relatively higher level of acceptance of this treatment (22%).

Forced air chilling

Over half of all those interviewed consider forced air chilling an acceptable treatment for meat decontamination (Figure 20). In particular, two in 10 (21%) find the treatment *definitely* acceptable, with an additional third of respondents (34%) who find it *somewhat* acceptable.

At the other end of the spectrum, there are two in 10 consumers (21%) for whom this treatment is unacceptable. A quarter of the population remain neutral on the subject (25%).

Figure 20: Consumer acceptability of forced air chilling as a method of meat decontamination
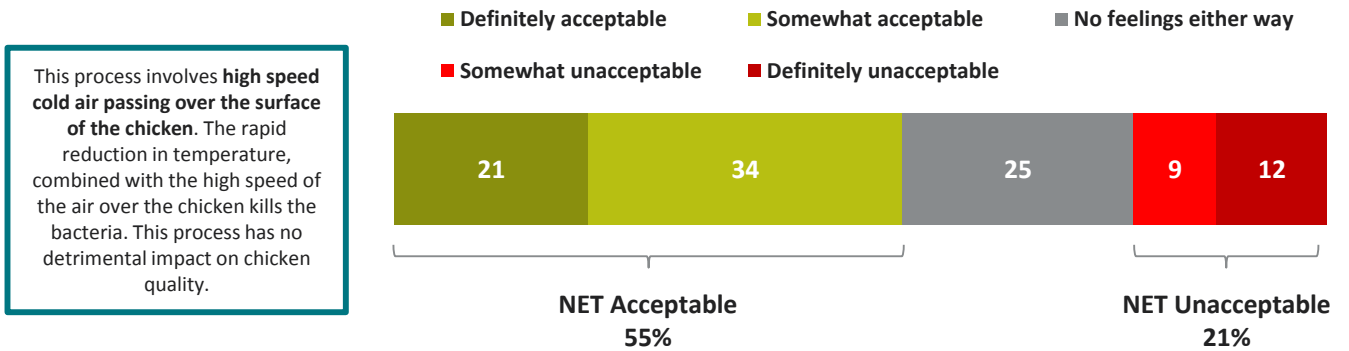
| Definitely acceptable | Somewhat acceptable | No feelings either way |
| Somewhat unacceptable | Definitely unacceptable |

This process involves **high speed cold air passing over the surface of the chicken**. The rapid reduction in temperature, combined with the high speed of the air over the chicken kills the bacteria. This process has no detrimental impact on chicken quality.

| 21 | 34 | 25 | 9 | 12 |

NET Acceptable 55%

NET Unacceptable 21%

Q.8   Based on what you have just heard about forced air chilling, can you tell me how acceptable or unacceptable you think it would be to treat meat in this way to reduce the risk of food poisoning?
Base: All Respondents: 2,011

When looking at results by demographics (Figure 21), the findings underline a higher incidence of acceptance of forced air chilling among ROI residents (61%) compared with NI residents (48%). As mentioned in the first few pages of the report, the difference between ROI and NI consumers in their treatment acceptability levels – in that ROI shows a significantly higher incidence of accepting the proposed treatments – is one of the main patterns or key learnings from the research (validated in five out of the six instances).

Figure 21: Acceptability of forced air chilling as a method of meat decontamination by region, gender, age and social class

	Total %	REGION		GENDER		AGE				SOCIAL CLASS	
		ROI	NI	Male	Female	15-24	25-44	45-64	65+	ABC1	C2DE
		(1,001)	(1,010)	(969)	(1,042)	(294)	(641)	(622)	(454)	(865)	(1,090)
		%	%	%	%	%	%	%	%	%	%
NET Acceptable	55	61	48	57	53	57	59	56	43	61	48
No feelings	25	22	27	24	25	29	23	23	28	22	27
NET Unacceptable	21	17	25	19	23	14	18	22	30	17	24

Q.8   Based on what you have just heard about forced air chilling, can you tell me how acceptable or unacceptable you think it would be to treat meat in this way to reduce the risk of food poisoning?
Base: All Respondents: 2,011

The incidence of finding forced air chilling acceptable increases to six in 10 respondents when aware of *Campylobacter* (Figure 22). It is noteworthy, however, that when unaware of the bacteria it is the proportion of those who are neutral on the subject that increases (27%), rather than the proportion finding the treatment unacceptable.

Figure 22: Changes in perceived acceptability of forced air chilling, with and without awareness of *Campylobacter*
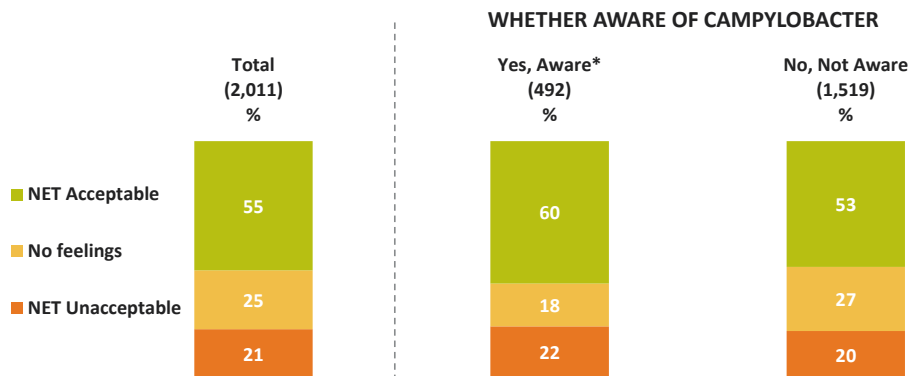
Q.8   Based on what you have just heard about forced air chilling, can you tell me how acceptable or unacceptable you think it would be to treat meat in this way to reduce the risk of food poisoning?
Base: All Respondents: 2,011

*Spontaneous or Prompted

Crust freezing

The second most accepted treatment (albeit closely followed by steam ultrasound), crust freezing receives approval from just under half of the audience surveyed (48%). While a quarter (25%) continue to stay neutral on the subject, 15% of respondents find the treatment *definitely* unacceptable for meat decontamination (Figure 23).

Figure 23: Consumer acceptability of crust freezing as a method of meat decontamination

In this process, the skin and approx. **3mm of the surface of the chicken are reduced to -2 degrees temporarily and the chicken is then very quickly returned to a normal chilled temperature**. During this short time, **the rapid freezing kills the bacteria**. This process has no detrimental impact on chicken quality.

Q.6   Based on what you have just heard about crust freezing, can you tell me how acceptable or unacceptable you think it would be to treat meat in this way to reduce the risk of food poisoning?
Base: All Respondents: 2,011

76

The difference between the ROI and NI in opinion is notable: 55% of ROI respondents find the treatment acceptable compared with 41% of NI residents (Figure 24). Within the ROI sample, the incidence of finding crust freezing acceptable is particularly high among the younger age group (18 to 24 years old, at 69%) and male respondents (59%, compared with females at 51%).

Figure 24: Acceptability of crust freezing as a method of meat decontamination by region, gender, age and social class

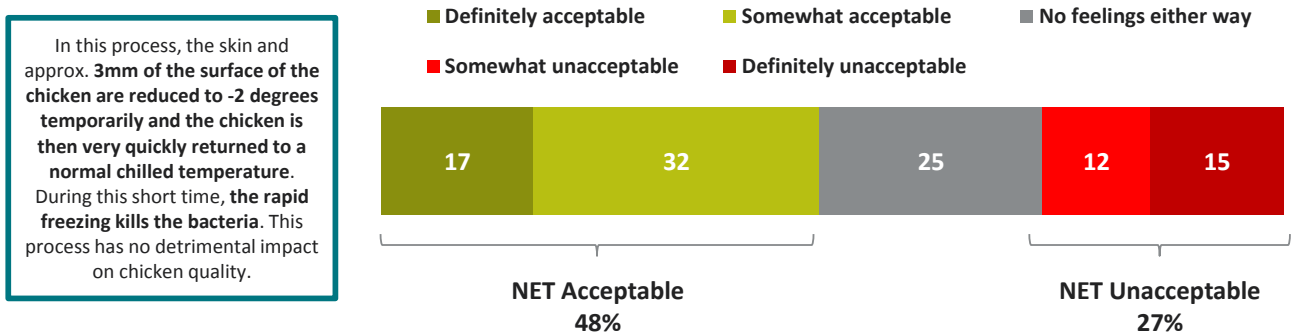|	Total %	REGION		GENDER		AGE				SOCIAL CLASS	
		ROI	NI	Male	Female	15-24	25-44	45-64	65+	ABC1	C2DE
		(1,001)	(1,010)	(969)	(1,042)	(294)	(641)	(622)	(454)	(865)	(1,090)
		%	%	%	%	%	%	%	%	%	%
NET Acceptable	48	55	41	51	45	52	53	47	38	52	44
No feelings	25	21	29	25	25	30	22	23	29	24	26
NET Unacceptable	27	24	30	24	30	18	25	30	33	24	29

Q.6   Based on what you have just heard about crust freezing, can you tell me how acceptable or unacceptable you think it would be to treat meat in this way to reduce the risk of food poisoning?
Base: All Respondents: 2,011

While other variables do not present significant differences, looking at purchasing behaviour shows a higher incidence of acceptance of crust freezing, particularly among those who buy raw meat from the supermarket (54% acceptability) (Figure 25).

Figure 25:   Purchasing behaviour associated with crust freezing, and preference for seeing treatment information on food labels
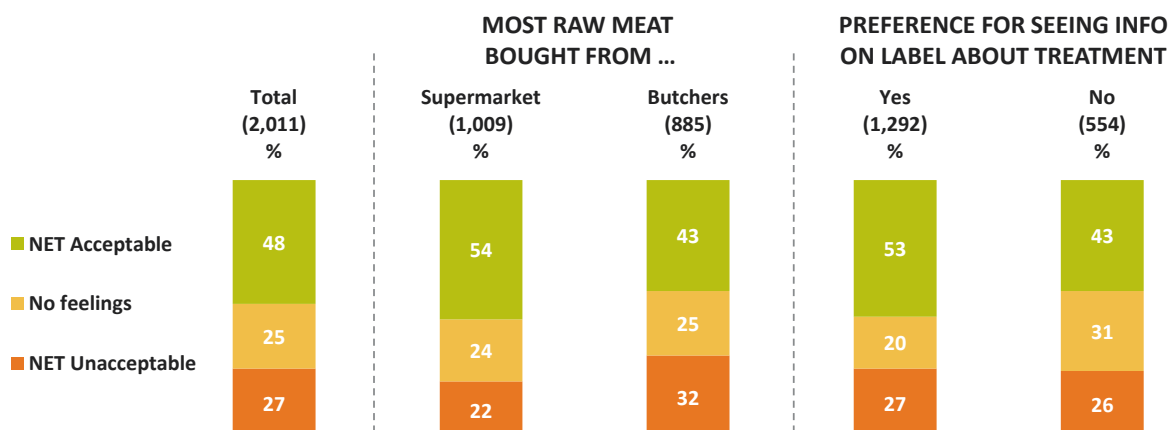
	Total (2,011) %	MOST RAW MEAT BOUGHT FROM …		PREFERENCE FOR SEEING INFO ON LABEL ABOUT TREATMENT	
		Supermarket (1,009) %	Butchers (885) %	Yes (1,292) %	No (554) %
NET Acceptable	48	54	43	53	43
No feelings	25	24	25	20	31
NET Unacceptable	27	22	32	27	26

Q.6   Based on what you have just heard about crust freezing, can you tell me how acceptable or unacceptable you think it would be to treat meat in this way to reduce the risk of food poisoning?
Base: All Respondents: 2,011

Moreover, those who prefer seeing treatment information on the meat packaging show higher acceptability of crust freezing (53%), compared with 43% among those who do not want to see this information displayed, where feelings of indifference are more prominent (31%).

Steam ultrasound

Following very closely behind crust freezing, steam ultrasound is considered an acceptable meat decontamination treatment by 47% of respondents; 27% find it unacceptable and a quarter of the audience remains neutral (Figure 26).

Figure 26: Consumer acceptability of steam ultrasound as a method of meat decontamination

This process combines **the use of ultrasound and steam at high pressure. Ultrasound disturbs the very thin outer layer of the chicken, which allows the steam to penetrate and kill the bacteria** before the heat affects the chicken itself. This process has no detrimental impact on chicken quality.

Legend: ■ Definitely acceptable ■ Somewhat acceptable ■ No feelings either way ■ Somewhat unacceptable ■ Definitely unacceptable

15 | 31 | 26 | 12 | 15

NET Acceptable 47%

NET Unacceptable 27%

Q.7   Based on what you have just heard about steam ultrasound, can you tell me how acceptable or unacceptable you think it would be to treat meat in this way to reduce the risk of food poisoning?
Base: All Respondents: 2,011

Demographically, the proportion of those who find the treatment acceptable is higher among males (52%). The gender difference is more notable within the ROI sample where six in 10 (60%) males accept crust freezing, compared with 47% females. Overall, the two younger age groups appear more willing to accept this treatment than the older groups (Figure 27).

Figure 27: Acceptability of steam ultrasound as a method of meat decontamination by region, gender, age and social class

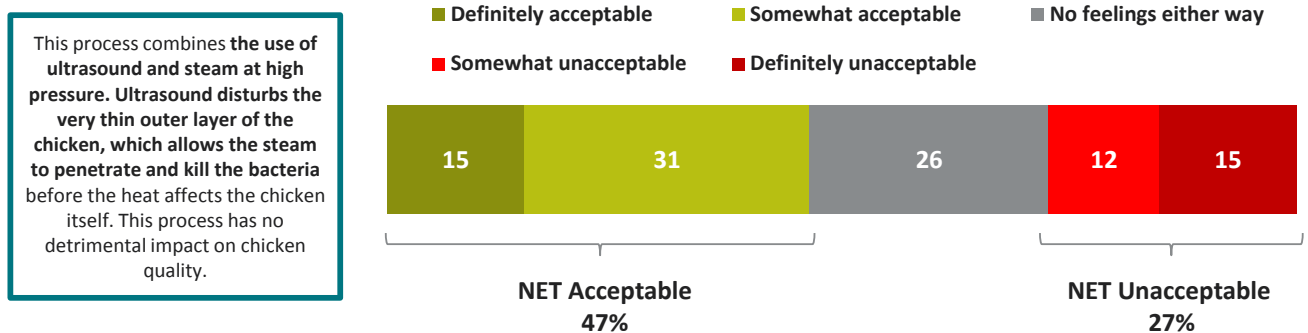|	Total %	REGION		GENDER		AGE				SOCIAL CLASS	
		ROI	NI	Male	Female	15-24	25-44	45-64	65+	ABC1	C2DE
		(1,001)	(1,010)	(969)	(1,042)	(294)	(641)	(622)	(454)	(865)	(1,090)
		%	%	%	%	%	%	%	%	%	%
NET Acceptable	47	53	40	52	42	53	52	42	40	51	43
No feelings	26	24	28	25	27	32	24	25	29	25	27
NET Unacceptable	27	23	31	23	31	15	25	32	32	24	30

Q.7 Based on what you have just heard about steam ultrasound, can you tell me how acceptable or unacceptable you think it would be to treat meat in this way to reduce the risk of food poisoning?
Base: All Respondents: 2,011

Similar to crust freezing, purchasing behaviour is the only variable that shows a few differences in perception: those who shop for meat at supermarkets show higher levels of acceptance (52%) of steam ultrasound for meat decontamination purposes (Figure 28).

Figure 28: Purchasing behaviour associated with steam ultrasound, and preference for seeing treatment information on food labels
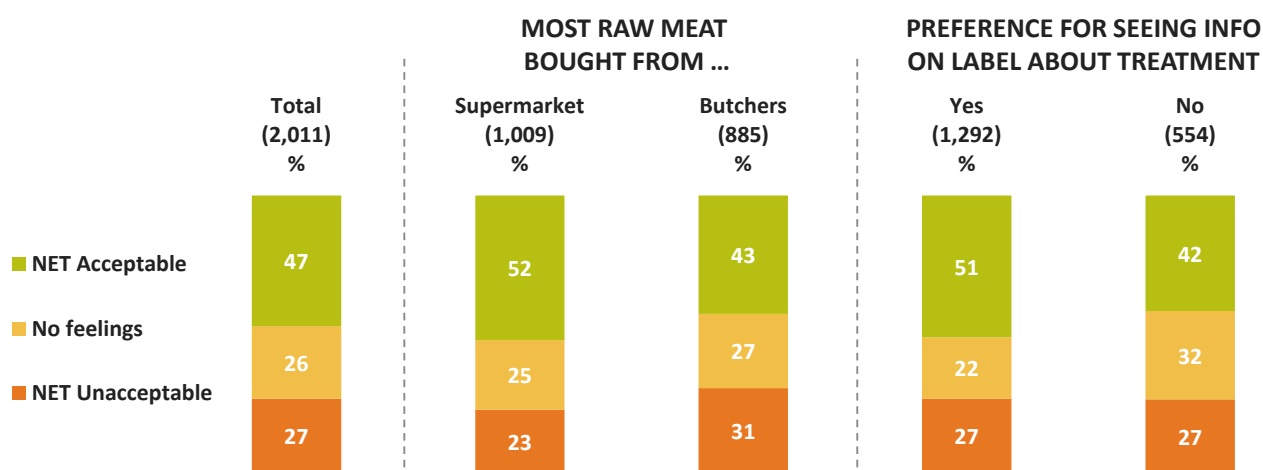
	Total (2,011) %	MOST RAW MEAT BOUGHT FROM ...		PREFERENCE FOR SEEING INFO ON LABEL ABOUT TREATMENT	
		Supermarket (1,009) %	Butchers (885) %	Yes (1,292) %	No (554) %
NET Acceptable	47	52	43	51	42
No feelings	26	25	27	22	32
NET Unacceptable	27	23	31	27	27

Q.7 Based on what you have just heard about steam ultrasound, can you tell me how acceptable or unacceptable you think it would be to treat meat in this way to reduce the risk of food poisoning?
Base: All Respondents: 2,011

Cold plasma treatment

After the three treatments that qualitative research found to be perceived as more natural and less invasive, cold plasma gathered more mixed reactions and its overall acceptability is at 39% (Figure 29). One in 10 respondents found it *definitely* acceptable compared with two in 10 for whom cold plasma is unacceptable.

Similar to the other cases so far, a quarter of respondents (26%) have no feelings either way on the subject.

Figure 29: **Consumer acceptability of cold plasma treatment as a method of meat decontamination**

In the process, the chicken is packaged as normal. **The package is then passed (briefly) through a magnetic field. This temporarily changes the atmosphere in the package resulting in bacteria destruction.** When the package comes out of the magnetic field, the atmosphere inside the package returns to normal. This process has no detrimental impact on chicken quality.

- ■ Definitely acceptable
- ■ Somewhat acceptable
- ■ No feelings either way
- ■ Somewhat unacceptable
- ■ Definitely unacceptable

11	28	26	15	20

NET Acceptable
39%

NET Unacceptable
35%

Q.11   Based on what you have just heard about cold plasma treatment, can you tell me how acceptable or unacceptable you think it would be to treat meat in this way to reduce the risk of food poisoning?
Base: All Respondents: 2,011

Acceptability among ROI respondents is higher, at 46%, compared with 33% of NI residents. While there are no differences in terms of gender, analysis by age shows that acceptability of cold plasma treatment is higher among younger respondents (Figure 30).

Figure 30: Acceptability of cold plasma treatment as a method of meat decontamination by region, gender, age and social class

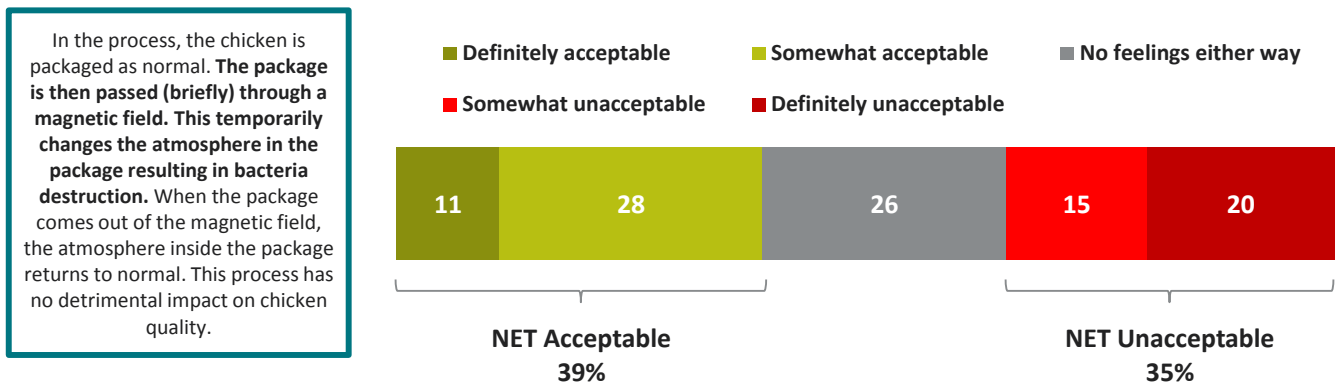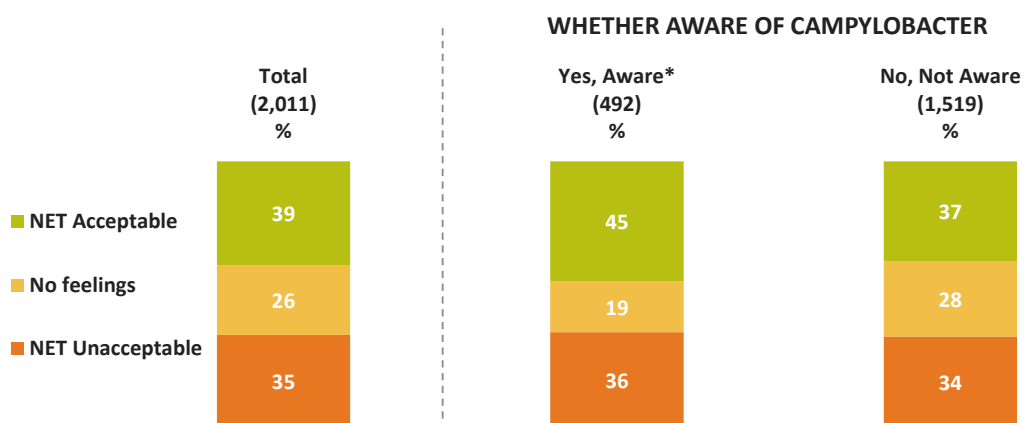|	Total %	REGION		GENDER		AGE				SOCIAL CLASS	
		ROI (1,001) %	NI (1,010) %	Male (969) %	Female (1,042) %	15-24 (294) %	25-44 (641) %	45-64 (622) %	65+ (454) %	ABC1 (865) %	C2DE (1,090) %
NET Acceptable	39	46	33	41	37	47	43	36	33	42	37
No feelings	26	24	28	28	24	29	24	24	30	25	27
NET Unacceptable	35	30	39	31	39	24	33	40	36	33	37

Q.11   Based on what you have just heard about cold plasma treatment, can you tell me how acceptable or unacceptable you think it would be to treat meat in this way to reduce the risk of food poisoning?
Base: All Respondents: 2,011

Those who claim to be aware of *Campylobacter* appear more inclined to find this treatment acceptable, at 45% (Figure 31).

Figure 31: Changes in perceived acceptability of cold plasma treatment, with and without awareness of *Campylobacter*

WHETHER AWARE OF CAMPYLOBACTER

	Total (2,011) %	Yes, Aware* (492) %	No, Not Aware (1,519) %
NET Acceptable	39	45	37
No feelings	26	19	28
NET Unacceptable	35	36	34

Q.11   Based on what you have just heard about cold plasma treatment, can you tell me how acceptable or unacceptable you think it would be to treat meat in this way to reduce the risk of food poisoning?
Base: All Respondents: 2,011

Spontaneous or Prompted

The organic and chemical wash treatments are the lowest ranked meat decontamination treatments. However, the difference between how the two are perceived is significant: organic acid wash is deemed acceptable by almost four in 10 consumers (37%), very closely behind the cold plasma option, while chemical wash gathers much less approval (Figure 32).

Four in 10 of those interviewed feel organic acid is not an acceptable method of meat decontamination.

Figure 32: Consumer acceptability of organic acid wash as a method of meat decontamination

This process involves **the meat being either sprayed with or dipped in organic acids which kill the bacteria.** These organic acids occur naturally, such as lactic or citric acid. This process has no detrimental impact on chicken quality.

■ **Definitely acceptable** ■ **Somewhat acceptable** ■ **No feelings either way**
■ **Somewhat unacceptable** ■ **Definitely unacceptable**

| 12 | 25 | 22 | 18 | 23 |

NET Acceptable 37% **NET Unacceptable 40%**

Q.9   Based on what you have just heard about organic acid washes, can you tell me how acceptable or unacceptable you think it would be to treat meat in this way to reduce the risk of food poisoning?
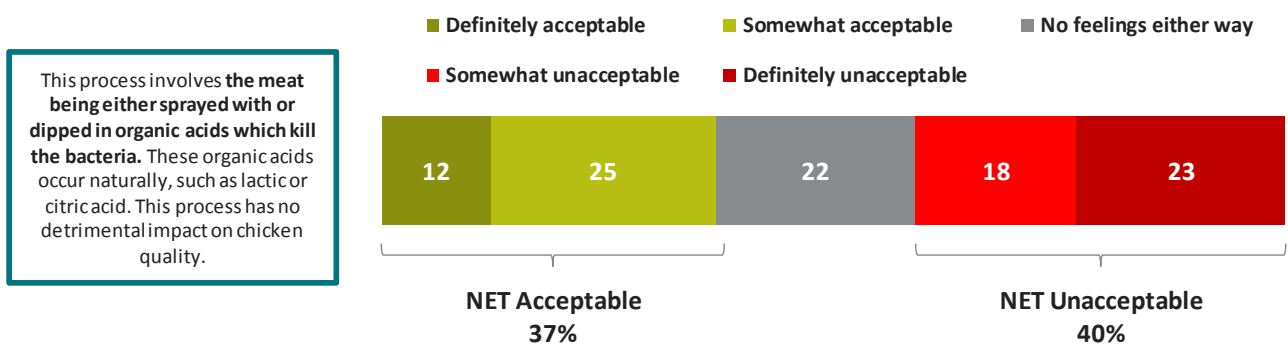Base: All Respondents: 2,011

Across the demographic cohorts, the younger groups and ABC1s appear more likely to find organic acid wash acceptable (Figure 33).

As noticed with the other treatments so far, the likelihood to accept this option in the ROI is significantly higher (43%), compared with NI (31%). An analysis within each of the two samples shows that age is a leading factor in this difference, with the highest incidence of acceptance recorded by the two younger groups at 51%. Meanwhile, in NI those aged 65 years or older show a significantly lower approval of the treatment, at 24%.
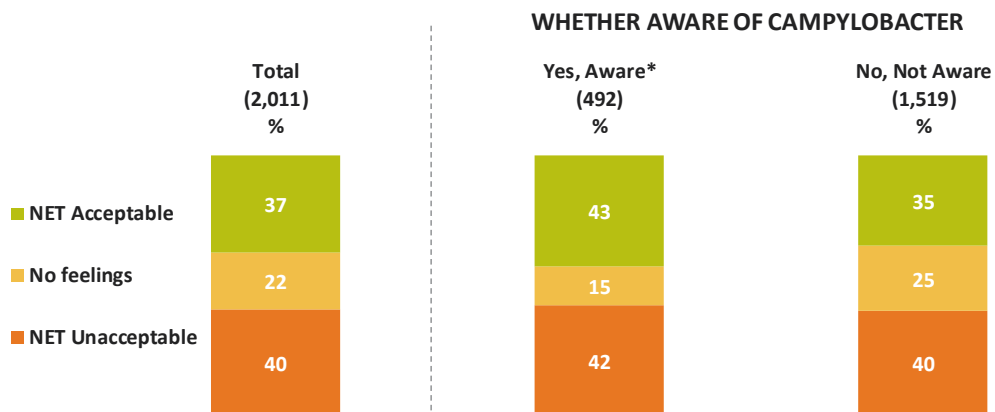
Figure 33: Acceptability of organic acid wash as a method of meat decontamination by region, gender, age and social class

	Total %	REGION		GENDER		AGE				SOCIAL CLASS	
		ROI (1,001) %	NI (1,010) %	Male (969) %	Female (1,042) %	15-24 (294) %	25-44 (641) %	45-64 (622) %	65+ (454) %	ABC1 (865) %	C2DE (1,090) %
NET Acceptable	37	43	31	38	36	42	43	33	29	41	34
No feelings	22	19	26	23	22	27	20	21	24	22	23
NET Unacceptable	40	38	43	39	42	31	37	46	47	36	43

Q.9 Based on what you have just heard about organic acid washes, can you tell me how acceptable or unacceptable you think it would be to treat meat in this way to reduce the risk of food poisoning?
Base: All Respondents: 2,011

At 43%, those aware of *Campylobacter* seem more likely to find organic wash acceptable (Figure 34). Not being aware of the bacteria appears to influence the proportion of those with no feelings on the subject rather than those who oppose it.

Figure 34: Changes in perceived acceptability of organic acid wash, with and without awareness of *Campylobacter*

WHETHER AWARE OF CAMPYLOBACTER

	Total (2,011) %	Yes, Aware* (492) %	No, Not Aware (1,519) %
NET Acceptable	37	43	35
No feelings	22	15	25
NET Unacceptable	40	42	40

Q.9 Based on what you have just heard about organic acid washes, can you tell me how acceptable or unacceptable you think it would be to treat meat in this way to reduce the risk of food poisoning?
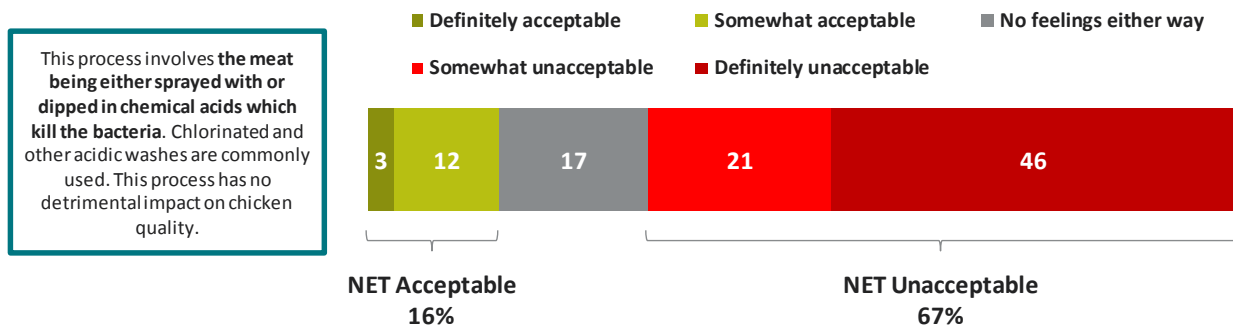Base: All Respondents: 2,011

*Spontaneous or Prompted

Chemical wash

By far the least acceptable meat decontamination treatment from the options presented, chemical wash is disapproved of by two-thirds of the population (67%), with a majority (46%) finding the treatment *definitely* unacceptable (Figure 35).

Only 16% of respondents find this intervention acceptable, most of which (12%) only find it *somewhat* acceptable.

Figure 35: Consumer acceptability of chemical wash as a method of meat decontamination

Legend: ■ Definitely acceptable ■ Somewhat acceptable ■ No feelings either way ■ Somewhat unacceptable ■ Definitely unacceptable

This process involves **the meat being either sprayed with or dipped in chemical acids which kill the bacteria**. Chlorinated and other acidic washes are commonly used. This process has no detrimental impact on chicken quality.

| 3 | 12 | 17 | 21 | 46 |

NET Acceptable 16%   NET Unacceptable 67%

Q.10 Based on what you have just heard about chemical washes, can you tell me how acceptable or unacceptable you think it would be to treat meat in this way to reduce the risk of food poisoning?
Base: All Respondents: 2,011

For all other treatments, an evident difference between the ROI and NI was noticed in that residents appeared more likely to find the interventions acceptable. Chemical wash is the only example where unacceptability was higher among ROI respondents, with more NI residents (21%) showing no feelings towards it (Figure 36).

Figure 36: Acceptability of chemical wash as a method of meat decontamination by region, gender, age and social class

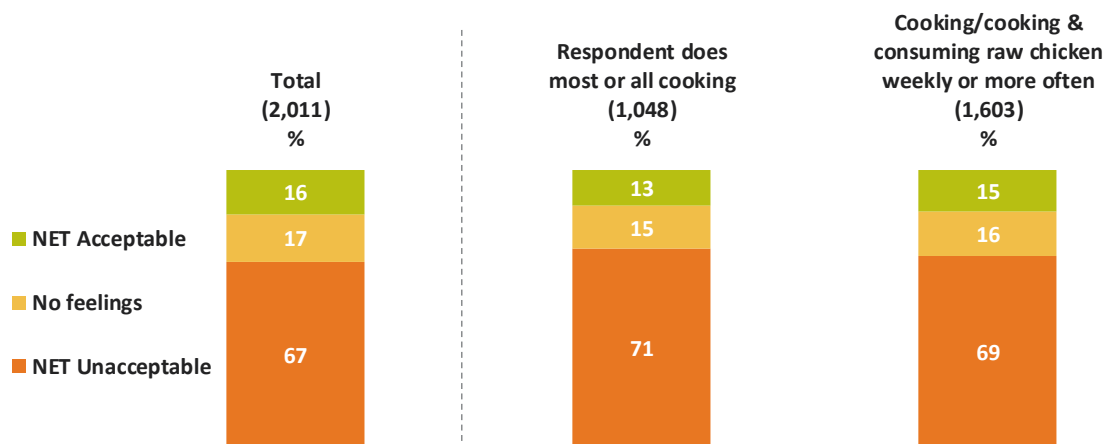|	Total %	REGION		GENDER		AGE				SOCIAL CLASS	
		ROI (1,001) %	NI (1,010) %	Male (969) %	Female (1,042) %	15-24 (294) %	25-44 (641) %	45-64 (622) %	65+ (454) %	ABC1 (865) %	C2DE (1,090) %
NET Acceptable	16	16	15	18	13	19	16	15	12	16	15
No feelings	17	14	21	19	15	22	16	15	19	17	18
NET Unacceptable	67	70	64	63	71	59	68	69	69	67	67

Q.10 Based on what you have just heard about chemical washes, can you tell me how acceptable or unacceptable you think it would be to treat meat in this way to reduce the risk of food poisoning?
Base: All Respondents: 2,011

In the ROI, unacceptability of chemical wash is highest among those aged 45 to 64 years old, while among the NI sample it is females who feel strongest against this intervention (seven in 10).

Seven in 10 (71%) of those who hold most of the cooking responsibility in the household consider the intervention unacceptable, while no significant differences are noticed among those who cook or consume chicken frequently.
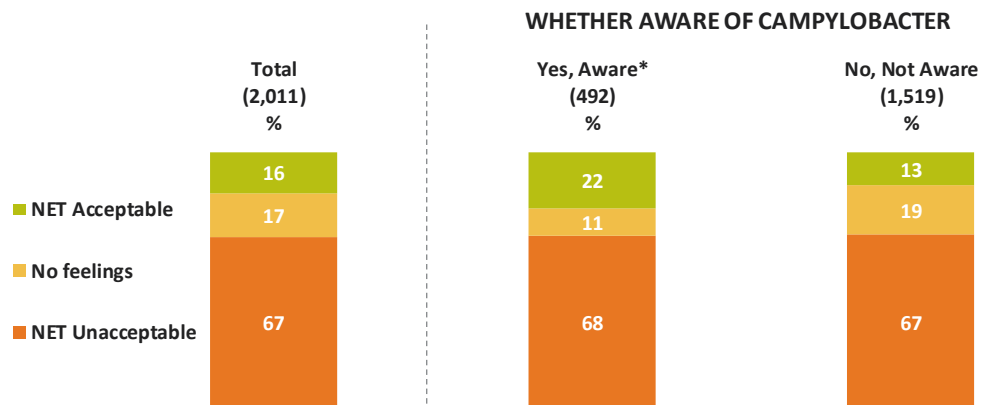
Figure 37: Changes in perceived acceptability of chemical wash, and frequency of cooking or consuming raw meat

	Total (2,011) %	Respondent does most or all cooking (1,048) %	Cooking/cooking & consuming raw chicken weekly or more often (1,603) %
NET Acceptable	16	13	15
No feelings	17	15	16
NET Unacceptable	67	71	69

Q.10   Based on what you have just heard about chemical washes, can you tell me how acceptable or unacceptable you think it would be to treat meat in this way to reduce the risk of food poisoning?
Base: All Respondents: 2,011

As shown in Figure 38, those who claim to be aware of *Campylobacter* appear more inclined to find chemical wash acceptable (22%), while those not aware are more indifferent to the treatment (19%).

Figure 38: Changes in perceived acceptability of chemical wash, with and without awareness of *Campylobacter*

WHETHER AWARE OF CAMPYLOBACTER

Total (2,011) %
Yes, Aware* (492) %
No, Not Aware (1,519) %

- NET Acceptable
- No feelings
- NET Unacceptable

Q.10   Based on what you have just heard about chemical washes, can you tell me how acceptable or unacceptable you think it would be to treat meat in this way to reduce the risk of food poisoning?
Base: All Respondents: 2,011

*Spontaneous or Prompted

5 Cluster analysis

Chapter 5 in this publication explores general attitudes towards the six meat decontamination methods by looking at four distinct groups of people identified through cluster analysis. "Cluster analysis" is a methodology used to classify respondents into groups that are as similar as possible within themselves but as different as possible to the other groups identified. The classification is made on the basis of a set of variables used as clustering criterion. In this case, the 2,011 respondents from the quantitative research have been segmented into four distinct clusters based on their levels of acceptance of the six meat decontamination techniques. Finally, a set of demographics was used to profile the segments and understand the key features of each one.

The final four clusters solution was obtained running hierarchical clustering that helps with detecting the natural number of groups in the data and successively applying "k-means" clustering, which assigns respondents to the four segments. Using Ward's linkage method, the hierarchical stage identified two solutions, one with three clusters and the other with four. This last option was deemed most appropriate as it brought more differentiation among the groups.

In the second stage of the analysis, k-means clustering was applied to redistribute cases to each segment, based in the smallest distance of each respondent to the average (or centroid) of each cluster.

The cluster analysis identified the presence of four groups of people. Among the methods outlined, chemical wash is the one that generates the lowest level of acceptance. Additionally, cooking and shopping habits may have an impact on people's opinions towards the different decontamination techniques presented in the survey.

Cluster analysis findings

Table 6: Consumer reactions to meat decontamination techniques by segment

	Segment label	No. of respondents	%
Segment 1	Partly accept	413	21%
Segment 2	Against every method	375	19%
Segment 3	Acceptance	549	27%
Segment 4	Tend to be indifferent	663	33%
Total		2011	100%

Base: Total sample (2,011), weighted frequencies

Segments 2 and 3 show opposite reactions to meat decontamination techniques, the first being against each method and the second instead welcoming every technique. In between these positions there are segments 4 and 1, where respondents prove to be either indifferent to the topic or selectively accept only some techniques.

Table 7 reports the average level of acceptance for each decontamination technique split by segment, where 1 is "definitely acceptable" and 5 is "definitely unacceptable".

Table 7: Level of acceptance of decontamination techniques by segment

	Cluster			
	Partly accept	Against every method	Acceptance	Tend to be indifferent
Crust Freezing	2.26	4.45	1.69	3.07
Stream Ultrasound	2.55	4.38	1.73	2.92
Forced Air	2.00	4.31	1.65	2.72
Organic Acid	4.41	4.61	1.82	2.60
Chemical Acid	4.70	4.80	3.01	3.76
Cold Plasma	2.85	4.52	1.87	3.28

Cluster profiles

Partly accept

This group of people selectively accepts some of the decontamination methods proposed, with preference showed for crust freezing and forced air treatment. Chemical wash and organic acid wash are considered highly unacceptable.

Against

Key metrics

- 52% women, 48% men
- 32% from "DE" social demographic grades, a significantly higher proportion compared with segment 3
- 53% do most or all of the cooking
- Highest proportion that would want treatment information on the food label – 74%
- 51% buy meat in supermarkets, a significantly higher percentage compared with segment 2

This segment of respondents rates every method "4" or above, showing a strong aversion to meat decontamination in general. As for the other segments, chemical wash is particularly opposed.

<div>

Key metrics

- Highest proportion of females – 57%
- 38% from "DE" social demographic grades, a significantly higher proportion compared with segment 3
- Highest proportion that does most or all of the cooking – 60%
- Highest proportion that does not know about *Campylobacter* – 80%
- 60% buys meat from butchers, a significantly higher percentage compared with segments 1, 3 and 4

</div>

Acceptance

Opposite to segment 2, segment 3 shows high tolerance for the meat decontamination techniques. Respondents appear indifferent to chemical wash.

<div>

Key metrics

- Highest proportion of males – 55%
- 35% from "C1" social demographic grade, a significantly higher proportion compared with segment 2
- Highest proportion that does some cooking – 40%
- 21% are between 25 and 34 years old
- 54% have completed third level education

</div>

Tend to be indifferent

People in segment 4 appear indifferent to all decontamination methods, with the exception of chemical wash. This is rated as "unacceptable".

Key metrics

- 48% males, 52% females
- 32% from "DE" social demographic grades, a significantly higher proportion compared with segment 3
- 50% do most or all of the cooking
- Second highest proportion that does not know about *Campylobacter* – 78%
- 52% buy meat in supermarkets, a significantly higher percentage compared with segment 2

6 Conclusions

Focus group findings

- Despite *Campylobacter* being a major cause of food poisoning on the IOI there was no awareness or recall of *Campylobacter* even when specifically prompted.

- *Salmonella* and *E. coli* were the only bacteria commonly mentioned across all groups and were associated with chicken and fish.

- There was no knowledge of how bacteria can enter the poultry supply chain or potential interventions to control bacteria. It would appear that consumers on the IOI are detached from modern practices in poultry production.

- Consumers on the IOI appear to place their trust in retailers to sell them safe food.

- Consumers' reaction to any decontamination process is strongly influenced by the vocabulary used in describing them.

- When consumers from the IOI were asked about possible interventions they exhibited a preference for what they perceived as "natural" and non-invasive processes.

- Irradiation and organic and chemical washes were considered invasive.

Quantitative survey findings

- 73% of respondents think of chicken as the most common cause of food poisoning.

- Salmonella was spontaneously mentioned as a bug that causes food poisoning by 54% of respondents, whereas only 5% mentioned *Campylobacter.*

- An additional two in 10 respondents claimed to be aware of *Campylobacter* when prompted.

- 67% of respondents would like to see information on the product label about treatments used in the processing plant to kill bacteria.

- Forced air chilling ranked as the most acceptable intervention followed by crust freezing, steam ultrasound, cold plasma and organic acid washes.

- Chemical washes were the least acceptable.

- 33% of respondents were indifferent to interventions of any type, 27% found some acceptable, 21% found some partially acceptable and 19% were against every method.

The survey established that the public have clear negative views about chemical forms of treatment, with more positive views of physical treatments. Given sufficient information people become more positive about some forms of treatment.

It would appear that the language used in the explanations given to the respondents was not sufficiently convincing for many consumers, even though the wording was considered to be clear by the food scientists who developed the explanations.

This highlights the gap that exists between the public and professional views and presents a challenge for *safe*food and other communicators to deliver food safety messages in a format that the public can understand.

Work needs to be done by the industry and the authorities to inform consumers about the risk of *Campylobacter* and the risk management initiatives that are and can be undertaken to reduce this risk.

More innovative communication strategies are needed.

Confidence in the efficacy of the interventions is needed before communicating them as solutions to the public. Therefore, more field trials are needed to collect the appropriate data.

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8 Appendices

Appendix 1: Focus groups discussion guide

16-024405 - Poultry Research

Discussion Guide (final)

1.0 Introduction – 5 minutes

Introduce Ipsos MRBI, the overall aim of the research, how the session will run, confidentiality, reassurance, explanation of taping.

- No right or wrong answers
- Researchers have no vested interest in the outcome of the research
- Mobiles off
- Reassure respondents of adherence to MRS code of conduct and confidentiality of individual responses
- Explain nature of research
- Respondent introduction
  - Name
  - Family status
    - Number of children (if any) – ages, who has the next birthday
  - Favourite meal and why?

2.0 Warm up: Meals (10 Minutes)

This phase of the discussion is designed to get respondents opening up and thinking about the different types of protein sources they use in the meals that they prepare in the home.

- What's your favourite meal to cook for dinner/ lunch? Which of the following meats are these meals typically based on?
  - Chicken
  - Turkey
  - Beef
  - Fish
  - Lamb
- Using a series of cards with the different protein sources to aid discussion in the groups.
- Taking each of these meats in turn what are the benefits of using each for the meals you prepared? Sort them in terms of each of the following binary options?

- o More/ less taste
- o More/ less convenience
- o More/ less versatility
- o Easy to use/ difficult to use
- o More/ less natural
- o Good value/ poor value
- o Etc.
- What are your priorities when you are:
  - o Buying meat/ poultry
  - o Cooking meat/poultry

3.0 Food purchase behaviour (15 Minutes)

In the section, we will briefly discuss the elements of the decision making process in terms of meat purchase and explore the role that quality of the meat/processing has. In addition we'll explore how much information consumers want about the processes that go into the meat that they purchase?

- When you are buying different types of meat, what do you take into account when considering which to buy? Probe particularly in relation to poultry
  - o Taking each in turn: Chicken, Beef, Lamb
    - ▪ Best before date
    - ▪ Value
    - ▪ Quality assurance
    - ▪ Packaging
    - ▪ Weight/ size
    - ▪ Origin
      - Explore what they understand by origin.
      - Any particular sensitivities towards a particular protein source in terms of origin?
    - ▪ Brand
    - ▪ Free Range/ Organic
    - ▪ Farmer names/ process name
    - ▪ Etc.

- Where do you normally buy each?
  - o Taking each in turn: Chicken, Beef, and Lamb. Prompt and then explore reasons.
    - ▪ Supermarkets
    - ▪ Butchers
    - ▪ Farmers Markets
    - ▪ Other.

- How much information about the meat would you like to know about more generally/see on packaging?
  - Processor name?
  - Origin?
  - Specifics of the processing process?
  - Information in relation to the processes involved in making sure the product is clean, safe and hygienic?
  - Processes to demonstrate the quality of the meat?
- Is there information that you would not want to see/know more about?
  - Probe areas that the customer would not like to see.
  - Of all the elements discussed above, which should be…
    - A. Clearly stated on the packaging/in-store?
    - B. Be included in the overall quality assurance/food safety brand e.g. Q Mark but not specifically referenced?

4.0 Meat and Food Poisoning (10 Minutes)

This section explores consumer understanding and associations between the meat they eat, the potential causes of food poisoning and where they think the bacteria is most at risk of developing.

- What hygiene procedures would you adhere to when preparing food in the home?
  - Storage?
  - Washing meat/ poultry?
    - Wash packaging before disposal?
  - Washing hands before/after preparing food?
  - Washing down countertops?
  - Washing fridge?
  - Changing dish cloth regularly?

- Which bacteria have you heard of/do you most associate with food poisoning / getting sick?
  - Record names of the different suspected bacteria.
  - Which are the most common? Which is most dangerous?
    - Rank in terms of which is most common?

- Which types of meats do you most associate with potential for food poisoning/ getting sick from?
  - Spontaneous and then probe:
    - Beef
    - Fish
    - Lamb
    - Turkey
    - Chicken
- And which bacteria do you most commonly associate with food poisoning?
  - Probe and explore links between.
    - Salmonella

- - Campylobacter
  - Norovirus
  - E. coli
  - Listeria
  - Would you associate one or more of these with specific meats?
    - Probe which meats ESP, chicken.
- In general, do you think that the bacteria that causes food poisoning is present on the meat when you buy it or developed overtime e.g. in the fridge/storage?
  - Does this vary depending on the types of meat?
    - Chicken vs. Beef?
  - If yes, why? If not, why not?

5.0 Discussion of Campylobacter & Processing   (45 Minutes)

This section will explain the presence of campylobacter and explore consumer responses to different methods of reducing incidence in the supply chain. A series of slides will be used to explore each of these – the stimulus accompanies this guide separately.

This section will be introduced with two slides explaining the issue with campylobacter and the requirement for additional processing of poultry.

- Exploring each of the processes in turn. These will be rotated across the groups to avoid any research effect.
  - Crust Freezing
  - Steam Ultrasound
  - Chicken Washes
    - Organic Acid
    - Chemical Washes
  - Forced Air Chilling
  - Light Technology
  - Irradiation
  - Ozone treatment
  - Electrolyzed Oxidising Water
  - Cold Plasma Treatment

- Explore each in terms of:
  - Understanding
  - Association

- o Acceptability
- o Perceived impact on the quality of the meat
- Please rank these in terms of most acceptable to least acceptable?
  - o Each will be ranked and rationale for ranking is developed.
- Returning to a question asked earlier in relation to how much information should be made available to consumer –
  - o Information in relation to the processes involved in making sure the product is clean, safe and hygienic?
- Should this information be included on packaging?
  - o Explore reasons for inclusion/ exclusion on packaging information
- Potential to include packaging examples if required at this point.

6.0 Conclusion (5 Minutes)

- Key learning from today's session?
- Thanks and close

Appendix 2: Quantitative survey questionnaire

16-024405 UCD/Safefood
Consumers' Attitudes towards Raw Meat Decontamination Treatments
FINAL Questionnaire 9-06-2016

I'd like to start with some questions about your attitudes to food in general…

Q.1 Are you the person who usually does most of the cooking in this household, or do you just do some of the cooking, or do you not usually do any cooking at all?

Does most or all of the cooking

Does some cooking
Does no cooking

Q.2 How often do you cook/consume any kind of raw chicken, including chicken fillets or things like chicken Kiev? Would it be ... READ OUT

Most days
At least once a week
At least once a fortnight
At least once a month
Less than once a month
Never

Q.3 In your opinion, what is the <u>one</u> category of meat, poultry or fish that causes food poisoning most often?
SINGLE CODE. DO NOT READ OUT.

Pork
Beef
Lamb
Chicken
Turkey
Salmon
Shellfish
Other
Don't know

Spontaneous awareness of Campylobacter
Q.4 What bacteria would you be aware of that causes food poisoning? DO NOT READ OUT.

Campylobacter
Salmonella
E-coli
Listeria
Shigella
Botulism
Norovirus
Other

Prompted awareness of Campylobacter
<u>IF Campylobacter not spontaneously mentioned at Q.4:</u>
Q.5 Have you ever heard of Campylobacter?

Yes
No

Read out: One of the main causes of food poisoning is bacteria on raw meat. It is possible to remove most of the bacteria on raw meat by treating it when the meat is being cut up in the slaughterhouse before being sent to butchers and supermarkets. There are a number of different treatments that could be introduced for use in the slaughterhouse, and I am going to go through some of these with you.

INTERVIEWER NOTE:
- *If respondent raises concern about lactic acid and lactose/dairy intolerance explain that this treatment does not involve milk in any way and there is no risk for anyone lactose/dairy intolerant.*

- *If respondent asks if treatments are currently used, explain that at present the only thing that can be done is to wash the meat in water in the slaughterhouse. NONE of these treatments are currently in use in Ireland, but could be introduced.*

SCRIPTOR NOTE: ROTATE Q6-Q11 BUT WITH Q.10 ALWAYS FOLLOWING Q.9

CRUST FREEZING
Read out: In this process, the skin and approx. 3mm of the surface of the chicken are reduced to -2 degrees temporarily and the chicken is then very quickly returned to a normal chilled temperature. During this short time, the rapid freezing kills the bacteria. This process has no detrimental impact on chicken quality.

Q.6 Based on what you have just heard about crust freezing, can you tell me how acceptable or unacceptable you think it would be to treat meat in this way to reduce the risk of food poisoning?

Definitely acceptable
Somewhat acceptable
No feelings either way
Somewhat unacceptable
Definitely unacceptable

STEAM ULTRASOUND
Read out: This process combines the use of ultrasound and steam at high pressure. Ultrasound disturbs the very thin outer layer of the chicken, which allows the steam to penetrate and kill the bacteria before the heat affects the chicken itself. This process has no detrimental impact on chicken quality.

Q.7 Based on what you have just heard about steam ultrasound, can you tell me how acceptable or unacceptable you think it would be to treat meat in this way to reduce the risk of food poisoning?

Definitely acceptable
Somewhat acceptable
No feelings either way
Somewhat unacceptable
Definitely unacceptable

FORCED AIR CHILLING

Read out: This process involves high speed cold air passing over the surface of the chicken. The rapid reduction in temperature, combined with the high speed of the air over the chicken kills the bacteria. This process has no detrimental impact on chicken quality.

Q.8 Based on what you have just heard about forced air chilling, can you tell me how acceptable or unacceptable you think it would be to treat meat in this way to reduce the risk of food poisoning?

Definitely acceptable
Somewhat acceptable
No feelings either way
Somewhat unacceptable
Definitely unacceptable

ORGANIC ACID WASH

Read out: This process involves the meat being either sprayed with or dipped in organic acids which kill the bacteria. These organic acids occur naturally, such as lactic or citric acid. This process has no detrimental impact on chicken quality.

Q.9 Based on what you have just heard about organic acid washes, can you tell me how acceptable or unacceptable you think it would be to treat meat in this way to reduce the risk of food poisoning?

Definitely acceptable
Somewhat acceptable
No feelings either way
Somewhat unacceptable
Definitely unacceptable

CHEMICAL WASH

Read out: This process involves the meat being either sprayed with or dipped in chemical acids which kill the bacteria. Chlorinated and other acidic washes are commonly used. This process has no detrimental impact on chicken quality.

Q.10 Based on what you have just heard about chemical washes, can you tell me how acceptable or unacceptable you think it would be to treat meat in this way to reduce the risk of food poisoning?

Definitely acceptable
Somewhat acceptable
No feelings either way
Somewhat unacceptable
Definitely unacceptable

COLD PLASMA TREATMENT

Read out: In the process, the chicken is packaged as normal. The package is then passed (briefly) through a magnetic field. This temporarily changes the atmosphere in the package resulting in bacteria destruction. When the package comes out of the magnetic field, the atmosphere inside the package returns to normal. This process has no detrimental impact on chicken quality.

Q.11 Based on what you have just heard about cold plasma treatment, can you tell me how acceptable or unacceptable you think it would be to treat meat in this way to reduce the risk of food poisoning?

Definitely acceptable
Somewhat acceptable
No feelings either way
Somewhat unacceptable
Definitely unacceptable

Q.12 Do you buy most of your raw meat from a supermarket, a butcher's, a market, or some other kind of shop?

Supermarket
Butchers
Market
Other

Q.13 When buying raw meat in the supermarket, would you want to see information on the label about the treatment used in the slaughterhouse to kill bacteria?

Yes
No
Don't know

Q.14 Are there any people from the below groups residing in your household?

0-4 years of age
65+ years of age
With Diabetes or other long term illness

IF YES at any of the groups from Q.14:
Q.15 And would you typically take any special measures when preparing food for them?

Yes
No
N/A

*safe*food:
7 Eastgate Avenue, Eastgate, Little Island, Co. Cork
7 Ascaill an Gheata Thoir, An tOiléan Beag, Co. Chorcaí
7 Aistyett Avenue, Aistyett, Wee Isle, Co. Cork
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