Food by-products as natural source of bioactive compounds against *Campylobacter*

Jose Manuel Silván & Adolfo J. Martinez-Rodríguez*

Grupo de Microbiología y Biocatálisis de Alimentos, Departamento de Biotecnología y Microbiología de Alimentos, Instituto de Investigación en Ciencias de la Alimentación (CIAL), CSIC-UAM, C/ Nicolás Cabrera, 9. Campus de Cantoblanco, Universidad Autónoma de Madrid, 28049, Madrid, Spain

*Corresponding author at: Departamento de Biotecnología y Microbiología de Alimentos, Instituto de Investigación en Ciencias de la Alimentación (CIAL), CSIC-UAM - C/ Nicolás Cabrera, 9. Campus de Cantoblanco, Universidad Autónoma de Madrid, 28049, Madrid, Spain.

E-mail addresses: jm.silvan@csic.es (J. M. Silván); adolfo.martinez@csic.es (A. J. Martinez-Rodriguez)

Keywords: food by-products, *Campylobacter*, foodborne pathogen, bioactive compounds, phenolic compounds, citrus peel extract, citrus essential oils, pectic oligosaccharides, olive mill wastes (OMW), winemaking waste, grape seed extract, berry pomace, cereal by-products, chitosan, lactic acid.

20 **Synopsis**

21 This review describes the role of different food by-products as alternative tool to
22 the use of antibiotics and disinfectants in the control of *Campylobacter*, the main bacterial
23 foodborne pathogen associated to human gastroenteritis. These by-products are a source
24 of bioactive compounds potentially applicable at all stages of the food chain where
25 *Campylobacter* is present. Therefore, the use of industrial food by-products in the
26 mitigation of *Campylobacter* contamination may contribute to its revalorization and the
27 sustainability of different production processes, which is a cause of global concern
28 nowadays.

29 **Abstract**

30 *Campylobacter* is the leading cause of human bacterial gastroenteritis worldwide.
31 This microorganism may be present throughout the entire food chain. For this reason, it
32 is of particular interest to find natural alternatives environmentally sustainable to the use
33 of antibiotics and chemical disinfectants. Industrial food by-products are an economical
34 and sustainable alternative as a source of useful bioactive compounds against
35 *Campylobacter*. The food industry generates a large quantity of by-products and wastes
36 rich in organic matter that contribute significantly to environmental pollution. Therefore,
37 food industries are currently focusing on solving the problems of waste management and
38 recycling by utilization of the by-products. In the present review, the efficacy in the
39 control of *Campylobacter* of several by-products from the food industry, both of plant
40 and animal origin, has been summarized. The effect of the bioactive compounds present
41 in these by-products against *Campylobacter* is discussed, both in inhibiting growth and
42 the adhesion and invasion to intestinal epithelial cells, as well as their ability to reduce
43 biofilm formation on biotic and abiotic surfaces.

1. *Campylobacter*: significance and microbiological aspects

Campylobacter has been recognized as the leading cause of human bacterial gastroenteritis worldwide (Kaakoush et al., 2015). Being the most common bacterial cause of diarrhoea in many industrialized countries, *Campylobacter* infection is consequently responsible for a major public health and economic burden.

The genus *Campylobacter* is Gram-negative, non-saccharolytic bacteria with microaerobic growth requirements. Its catabolic capability is highly restricted. They do not ferment or oxidize carbohydrates neither complex substances. Energy is obtained from amino acids or tricarboxylic acid cycle intermediates. In morphological terms, campylobacters are usually S-shaped or spiral rods with tapering ends (0.2-0.8 µm-wide by 0.5-5 µm-long) (Figure 1). *Campylobacter* commonly possesses a polar flagellum at one or both ends of the cell and this, presumably aided by its spiral morphology, imparts a high degree of motility to the cell. This bacterium has quite stringent requirements for its growth. *Campylobacter* species are microaerophilic, requiring a reduced O₂ concentration of 5-8% and an elevated CO₂ concentration of 3-10%. Most relevant species are also thermophilic, growing best among 40-42°C. Table 1 shows some of the main features of the genus *Campylobacter*. At present, the genus *Campylobacter* contains 27 species and 8 subspecies, and *C. jejuni* and *C. coli* are the most important human enteropathogens among the campylobacters, being usually responsible of around the 80-90% of the diagnosed cases of *Campylobacter* infections (EFSA, 2017).

2. Epidemiology and reservoirs

Campylobacters are widespread in the natural environment, and can survive for long periods of time outside and inside of a given host (Poly & Guerry, 2008). As a major reservoirs, campylobacters are part of the natural intestinal microbiota of a wide range of

domestic and wild animals as well as various agriculturally important mammals (cattle, swine, and birds), especially poultry, whose intestines offer a suitable biological niche for their survival and dissemination. Particularly, *C. jejuni* is often the predominant species in poultry, and *C. coli* is most prevalent in swine. However, chickens are the most important reservoir and source of human infection. In Europe, broiler meat was the most important single source of human campylobacteriosis in 2016, and 36.7% of the 11,495 samples of fresh broiler meat were found to be *Campylobacter*-positive (EFSA and ECDC, 2017). In fact, campylobacteriosis was the most commonly reported zoonoses in the EU in 2016, the number of reported confirmed cases of human campylobacteriosis was 246,307 (Figure 2).

In developed countries, the most recognized route of *Campylobacter* transmission to humans occurs commonly by handling, preparation, and consumption of contaminated chicken meat or chicken meat products. Chicken carcasses use to be contaminated by the bacteria during slaughter and further processing (Bronowski et al., 2014; Kaakoush et al., 2015), since bacterial multiplication in food is not possible. Other reported sources contributing to *Campylobacter* infection in humans are the consumption of untreated water, unpasteurized dairy products, eating at restaurants, as well as foreign travel (Bronowski et al., 2014; Doorduyn et al., 2010; Mughini Gras et al., 2013). Contamination of the environment by domestic and wild animal feces presents an alternative exposure pathway for human infection, for example, soil, beach sand, sewage, groundwater, and drinking water. Figure 3 shows the main sources of *Campylobacter jejuni* infection.

However, the most cases appear to be sporadic and show a consistent seasonality. Given the sporadic nature of *Campylobacter* infections, source attribution based on outbreak investigations has had limited value. This is largely because, unlike for

salmonellosis (Wagenaar et al., 2013), campylobacteriosis outbreaks are rarely reported. Although most outbreaks (~64%) were not attributable to known sources, ~12% were attributed to meat products in general, and ~10% specifically to chicken meat (Newell et al., 2016).

3. Pathogenesis and virulence factors

Infection begins with an infectious dose of a few hundred bacteria (5-800 organisms) which is sufficient to overcome the so-called “colonization resistance barrier” in humans (Backert et al., 2016). During infection of humans, *Campylobacter* enters the host intestine via the oral route (in association with food or water) and colonizes the distal ileum and colon. Following colonization of the mucus and adhesion to intestinal cell surfaces, campylobacters perturb the normal absorptive capacity of the intestine by damaging epithelial cell function either directly, by cell invasion or the production of toxin(s), or indirectly, following the initiation of an inflammatory response (Silvan et al., 2013). Figure 4 shows the hypothetical model for *C. jejuni* mechanisms of human infection. The clinical spectrum ranges from severe inflammatory diarrhoea (patients in developed nations) to generally mild, non-inflammatory, watery diarrhoea (patients in developing nations). The incubation period prior to the appearance of symptoms usually ranges from 1 to 7 days. Although infection can result in a severe illness lasting more than a week, it is generally self-limiting and complications are uncommon, although it can in a small number of cases result in severe complications, such as Guillain-Barre syndrome and reactive arthritis (Esan et al., 2017).

4. Treatment and antibiotic-resistance

Treatment with antibiotics for uncomplicated *Campylobacter* infection is rarely indicated. Most humans suffering campylobacteriosis recover without therapeutic

intervention other than fluid and electrolyte replacement. Antimicrobial treatment is usually required in patients with severe or prolonged enteritis, especially in infants or the elderly, immunocompromised individuals and in cases of extra-intestinal manifestations (Ganan et al., 2012). In the past, fluoroquinolones were commonly used when antibiotic treatment was needed for campylobacteriosis. However, nowadays the level of acquired resistance to fluoroquinolones precludes the use of these antimicrobial agents for routine empirical treatment of human campylobacteriosis (EFSA & ECDC, 2017). In fact, there is strong evidence linking the indiscriminate usage of antibiotics in animal production to the emergence and spread of antibiotic resistance in *Campylobacter* (Silva et al., 2011). Increases in the incidence of infection caused by antibiotic-resistant strains of *Campylobacter* make these illnesses increasingly difficult to treat (Zhang & Plummer, 2008). In view of the continuing relatively high incidence of fluoroquinolone resistance in *Campylobacter* from human cases, macrolides such as erythromycin and azithromycin are considered the drugs of choice for treatment of human campylobacteriosis (CDC, 2014). However, the efficacies of such treatments are currently compromised by the increasing resistance to these antibiotics in *C. jejuni* and *C. coli* (Alfredson & Korolik, 2007). Figure 5 shows the antimicrobial resistance in *Campylobacter* to different antibiotics in humans. Furthermore, it would be necessary to achieve alternative strategies to the use of antibiotics to reduce the presence or to eradicate *Campylobacter* from the human food chain.

5. Alternative control strategies

The application of stricter hygiene measures has been found to reduce or delay *Campylobacter* infection in chickens, but is not sufficient to eradicate the pathogen. Also, the use of chemical agents could be an effective strategy to control *Campylobacter*, however, this procedure are not well accepted by the consumer and can result in the

accumulation of chemical wastes, so cannot really be described as environmentally-friendly practises (Vandeplas et al., 2008). On the other hand, a number of physical decontamination techniques have been successfully investigated to control the level of *Campylobacter* on poultry products including ozonation, irradiation, forced air chilling, steam pasteurisation, stem-ultrasound or freezing (Boysen & Rosenquist, 2009; Whyte et al., 2003). Each method has its advantages and disadvantages with relation to appearance of the final product, consumer acceptance, price, etc. Several other treatments have been evaluated, with more or less success, as alternatives to the use of chemicals and antibiotics against *Campylobacter*. Table 2 shows a summary of some of the most commonly used methods for controlling *Campylobacter* infection in the poultry industry.

6. Food by-products as alternative for controlling *Campylobacter*

Food industries are growing rapidly due to globalization and population increase and are providing a wider range of food products to satisfy the needs of the consumers. The major food industries of the developed countries include dairy, fruits and vegetables, meat and poultry, seafood and cereal. However, these industries generate huge amounts of food-processing wastes and by-products, which consist of high amounts of organic matter, which have not already been used for other purposes and have not been recycled, leading to problems regarding disposal, environmental pollution and sustainability. However, food industries are currently focusing on solving the problems of waste management and recycling by utilization of the by-products. These by-products can contain valuable nutrients or bioactive compounds that can be used for developing novel value-added products.

Traditional methods of waste utilization include their use as animal feed, fertilizer or disposal (Jayathilakan et al., 2012). However, their use has been limited due to legal restrictions, ecological problems and cost issues. Therefore, efficient, cheap, and

ecologically sound methods for utilization of wastes are being focused upon, which can minimize the quantities of wastes exposed to the environment and the subsequent health hazards. Wastes from the food industries generally comprise of dietary fibers, proteins and peptides, lipids, fatty acids and phenolic compounds, depending on the nature of the product produced. The different types of wastes produced by the different processing industries with potential revalorisation uses are listed in Table 3. Some of these by-products have been the subject to investigations and have proven to be effective sources of antimicrobial compounds against *Campylobacter*.

6.1. Fruits by-products

The world production of fruits has increased rapidly in recent years and thereby there has been a concomitant increase in the quantity of fruits by-products (FAO, 2009). The fruit processing by-products are regarded as waste and disposed of in the environment, which causes ecosystem problems as they are prone to microbial degradation. However, important efforts are being made to reuse by-products from the fruits processing industries because are enrich-sources of bioactive compounds, such as phenolic compounds. These phenolic compounds are secondary metabolites in plants and play an important role in their growth and reproduction, providing protection against several pathogens. The phenolic compounds possess potent antioxidant and antibacterial activities (Khao & Chen, 2013). In this regard, the antibacterial activity against *Campylobacter* has been studied reusing several fruits by-products enriched in phenolic compounds.

Citrus industry

Citrus is one of the world's major fruit crops with global availability and popularity that contributes to human diets (FAO, 2009). Global production of citrus fruit has significantly increased during the past few years and has reached ~92 million tons in the

years 2016-2017 (USDA, 2017). Although many citrus fruits can be eaten fresh, approximately a third of citrus fruits worldwide are utilised after processing and juice production, yielding about 44% peel as by-product (Li et al., 2006). Therefore, the citrus industry (grapefruits, lemons, limes, oranges, and tangerines) produces annually large quantities of waste or by-products (peels, seeds, and pulps), which can represent up to 50% of the raw processed fruit (Khao & Chen, 2013). It has been proven that citrus peels and seeds contain higher amounts of total phenolic compounds than edible portions (Gorinstein et al., 2001), mainly phenolic acids and flavonoids (Castillo et al., 2017). This rich polyphenolic composition has encouraged the use of these by-products to study their potential antimicrobial capacity.

Citrus extracts obtained from peels and seeds have been successfully tested for their ability to inhibit the growth and to affect other virulence factors of *C. jejuni* (Castillo et al., 2014 and 2017). *Citrus* peel extracts showed significant inhibitory activities; with inhibition zones ranging from 1.8 to 2.4 cm when the disinfectant used as positive control produced inhibition zones ranging from 2.7 to 3.0 cm. Treatment with these *Citrus* peel extracts were also able to reduce *Campylobacter* swarm motility 44-59%. The beneficial effects of *Citrus* by-product extracts on the adherence and invasion to human intestinal cells in *Campylobacter* have been also investigated. Castillo et al. (2017) confirmed the reduction of adherence and invasion using different *Campylobacter* strains by treatment with *Citrus* by-product extracts. The percentage reduction was noticeably high for both processes, reaching up to 90% inhibition almost in all tested strains. Reductions in adherence and motility of *Campylobacter* by treatment with citrus peel extract have been also successfully achieved (Castillo et al., 2014). However, *Campylobacter* did not show complete loss in the motility. This effect is an important contribution because adherence and motility are crucial for bacterial pathogenesis. Biofilm formation is another important

survival mechanism for *Campylobacter*, because *Campylobacter* biofilms has demonstrated resistance to environmental stress and pharmacological treatments (Gunther & Chen, 2009). This virulence factor was also effectively reduced in 60-75%, depending on extract concentration and/or strain tested, by treatment with *Citrus* peel extract (Castillo et al., 2014).

Citrus essential oils (EOs) mainly exist in fruit peels which are usually discarded as waste. EOs are a complex mixture of different components and their content as well as composition depends on species, variety, cultivation and extraction methods (Mahato et al., 2017). Their most common constituents are terpenes, aromatic and aliphatic compounds (Dugo et al., 2011). Besides being used as a fragrance, citrus essential oils have been reported to possess biological activities, such as antifungal, antioxidant, and antimicrobial activities (Mitropoulou et al., 2017; Singh et al., 2010; Torres-Alvarez et al., 2016). In this regard, limonene, citral, and linalool are ones of the major compounds of citrus fruit oils identified as active antimicrobial components (Geraci et al., 2016). Little research has been carried out on *Campylobacter* spp. in terms of the effects of EOs on growth and survival, but the few studies reported indicate that citrus EOs could be an effective tool to inhibit the growth of this pathogen. In this regard, EOs extracted from bergamot (*Citrus bergamia*) and lemon (*Citrus limon*) were effective to inhibit *C. jejuni* growth (Fisher et al., 2006). Antibacterial activity of the main components of these EOs, citral, linalool and limonene, were also evaluated resulting linalool oil the most effective anti-bacterial component against *C. jejuni*. This active terpene compound was found more abundant in the bergamot EOs (15%) postulating that the inhibitory effect was due to linalool. Sweet orange oil has been also found effective to inhibit both *C. jejuni* and *C. coli* (Nannapaneni et al., 2009; Thanissery et al., 2014), where linalool appeared to be a dominant component (20.2%) of this tested citrus oil (Nannapaneni et al., 2009). Sour

orange peel extract has been also reported to be effective against both *C. jejuni* and *C. coli* reducing the viability in a chicken skin model by >4 log and *in vitro* assays (MBC 2 mg/mL) diminishing population of *Campylobacter* to undetectable levels (Valtierra et al., 2010). Therefore, utilization of EOs from citrus by-products as antimicrobials may provide a good solution for industry and environmental sustainability.

Other valuable by-products that can be obtained from citrus fruit wastes are pectin and pectic oligosaccharides obtained by chemical and/or enzymatic pectin processing. Pectins are obtained from citrus peel powder, which is the waste of citrus juice processing industry. The main use for pectin is as a gelling and thickening agent and stabilizer in food. However, it was observed that pectic oligosaccharides extracted from *Citrus sinensis* inhibit *C. jejuni* invasion to human intestinal cells (Ganan et al., 2010). Pectic oligosaccharides seem to interfere with cell invasion by affecting the efficacy of cell adhesion as is shown in Figure 6. Effective adhesion is a prerequisite for cell invasion, which is one of the main factors that allow the initiation of successful colonization. The ability of *C. jejuni* to induce symptoms involves binding and colonization of the intestinal cells. Thus, these results suggest that pectic oligosaccharides could be potentially useful as alternatives to antibiotics in the control of *C. jejuni*.

Olive industry

The by-products of the olive industry have attracted considerable interest as a source of phenolic compounds, with much attention focused on the olive mill wastes (OMW). The phenolic compounds present in the olive fruits are distributed into the olive oil, the aqueous phase wastewater, or the solid phase pomace, but these last olive by-products retain the great amount of total phenolic compounds (~98%) that are not transferred to olive oil (Araujo et al., 2015). Therefore, OMW are a potential source of phenolics, particularly in consideration that olive oil production results in an annual

generation of more than 30 million m³ of OMW (Doula et al., 2017). More than 50 different phenolic compounds have been identified in OMW. The most representative phenolic compounds have been classified into three groups: compounds related to tyrosol (tyrosol and hydroxytyrosol), derivatives of benzoic acids and cinnamic acids (Torrecilla, 2010). Several studies reported antibacterial effects of phenolic enriched fractions obtained from OMW on bacterial pathogens, including Gram positive and Gram negative bacteria (Aissa et al., 2017). However, studies about the antibacterial effects of OMW on *Campylobacter* are scarce, despite the epidemiological importance of this bacterium as a foodborne pathogen. Branciari et al. (2016) found that supplementing the diet of broilers with different amounts of OMW extract results in a significant decrease in *Campylobacter* contamination. The higher amounts of polyphenols contained in the OMW diets were likely responsible for the observed effects on *Campylobacter* spp. shedding. These results suggest that olive waste by-products could be useful to reduce the risk of *Campylobacter* diffusion in the chicken flock and consequently in processed poultry meat. Recently, our research group has successfully evaluated the response of *C. jejuni* and *C. coli* species isolated from chicken food chain and clinical patients to OMW fractions (Silvan et al., 2018). The most active OMW fraction was bactericidal reducing the *Campylobacter* growth in 8 logarithms. Moreover, this bactericidal fraction markedly inhibited inflammation on macrophage cell line. These findings suggest the potential biological properties of OMW as precursor of polyphenol compounds with antibacterial and anti-inflammatory properties, which might ameliorate the infection and inflammation process induced by *Campylobacter*. This beneficial effect of OMW on campilobacteriosis supports the idea for increasing its revalorisation.

Besides OMW, olive leaves represent another by-product of the olive industry obtained in high amounts during the olive harvest for olive oil production and have been

explored as a source of phenolic compounds, albeit to a lesser extent. *Campylobacter jejuni* was found to be very susceptible *in vitro* to leaf extracts, where oleuropein was the most abundant compound (Šikić Pogačar et al., 2016; Sudjana et al., 2009). Phytochemicals present in food by-products can also prevent the attachment of several pathogens to abiotic surfaces. In this regard, olive leaf extracts were successful proved to inhibit *C. jejuni* adhesion to the abiotic and biotic surfaces to prevent colonization in poultry and to reduce transmission to humans (Šikić Pogačar et al., 2016). However, the concentrations of olive leaf extract that had anti-adhesion activities did not measurably alter *C. jejuni* growth. Therefore, authors suggest that the olive leaf extract tested could be considered as new antimicrobial that inhibit bacterial adhesion rather than bacterial growth.

Grape and winery industry

Grapes are one of the world's most commonly produced fruit crops, with approximately 75 million tons generated annually worldwide, and with the highest total value of production in the world (FAO-OIV, 2016). Grapes and winery industries produce a great variety of wines, grape juices, and raisins. But its production process generates high amounts of by-products, such as grape pomace, seeds, skins, stems, leaves and lees. For instance, production of wines, up to 40% of the grapes ends up as by-products (Friedman et al., 2014). This residue is generally used in the production of ethanol by fermentation/distillation, in the extraction of tartaric acid, as organic fertilizer or for animal feed (Brenes et al., 2016). However, these grape by-products contain numerous bioactive compounds, such as dietary fibre and phenolic compounds (Hogervorst et al., 2017; Teixeira et al., 2014; Zhu et al., 2012), with potentially antibacterial action against foodborne pathogens (Friedman et al., 2014; García-Lomillo et al., 2017).

The largest fraction of winery waste is the winemaking waste (WW) consisting of the skins, seeds, and stems left after juice or wine is pressed. This grape by-product is a complex mixture of polysaccharides, fermentation by-products, dietary fiber, and polyphenols amongst others (Yu & Ahmedna, 2013). The feasibility of WW extract as source of active phenolic compounds against *Campylobacter* has been recently evaluated (Mingo et al., 2016). WW extract was active against all *C. jejuni* and *C. coli* strains tested, and most of them were inhibited at concentrations between 0.04 and 0.1 mg gallic acid equivalents/mL. Phenolic characterization of WW extract showed that catechins and proanthocyanidins were the main families involved in the antibacterial effect, and epicatechin gallate and resveratrol the most active compounds against *Campylobacter*.

Grape seed extracts (GSE) have showed anti-*Campylobacter* effect in several studies. Silvan et al. (2013) confirmed strong bactericidal effect of GSE against different *Campylobacter* strains obtaining a reduction of up to 7 logs colony forming unit, being the minimal inhibitory concentration (MIC) lower than 0.02 mg/mL and the minimal bactericidal concentration (MBC) 0.06 mg/mL. In this work, fractionation of the GSE was performed and the most bactericidal fraction showed that phenolic acids, catechins and flavonols were the main responsible of the inhibitory effect. Figure 7 shows the antibacterial activity of grape seed collected fractions against *C. jejuni* and their phenolic composition. Hettiarachchy et al. (2010) also demonstrated inhibition of *C. jejuni* growth after GSE treatment (1%), obtaining a maximum reduction of 6 logs. Recently, Klančnik et al. (2017) observed anti-*Campylobacter* activity of waste grape skins and seeds (GSS) with a MIC of 1.25 mg/mL. This effect reached a growth inhibition in the range of 22%, inducing morphological changes, which would be associated with alterations in the integrity of the cell membrane. Sub-inhibitory concentrations of GSS extract also inhibited *C. jejuni* invasion by up to 20% across the tested concentration range (0.0125

to 0.2 mg/mL). Thus, GSS showed an anti-bacterial, anti-adherent and anti-invasive activity that turned out quite effective, which could help modulate the pathogenicity of *Campylobacter*, and could therefore be used to prevent or treat bacterial infection.

Grape skin extract, other abundant grape by-product, have also showed anti-*Campylobacter* effect. Katalinić et al. (2010) confirmed antimicrobial activity of grape skin extracts of 14 *Vitis vinifera* L. white and red varieties against *C. coli*. This work found that grape skin extract had antimicrobial activity against different Gram-positive and Gram-negative food-borne pathogenic bacteria, but the most susceptible organism to grape skin extracts was *Campylobacter*. These grape skin extracts were rich in flavonoids, catechins and flavanols. Similar antibacterial activity against *C. jejuni* was recently described by Trošt et al. (2016) using freeze-dried grape skin and seed extracts obtained from winery by-product waste of different grape varieties. The phenolic profiles of tested grape skin and seed extracts included mainly flavonols and catechins as described by Katalinić et al. (2010).

Leaves from *Vitis vinifera* also constitute an important waste from grape crops and winery industry. Antibacterial activity of leaf phenolic extracts obtained from six grapevine varieties against *C. jejuni* have been confirmed by Katalanic et al. (2013). The analytical characterization of these leaf extracts confirmed highly content of phenolic compounds, such as flavan-3-ols and flavonols, especially quercetin and its derivatives, as well as the presence of compounds from the resveratrol family.

Berry industry

Berry pomace is a by-product of the juice-pressing industry, which traditionally has been used as an ingredient in animal feed or it has been disposed into soils. Due to its low pH value it may possess significant ecological and environmental problems. Berry pomaces containing the berry skins are, however, very rich sources of phenolic

compounds. Salaheen et al. (2014) evaluated the effect of bioactive compounds extracted from blueberry and blackberry pomaces on the *C. jejuni* growth and its pathogenicity. Results indicated that blackberry and blueberry pomace extracts significantly reduced the growth of *C. jejuni*. MIC and MBC of berry pomaces extract were in a range of 0.4-0.6 mg/mL and 0.5-0.8 mg/mL gallic acid equivalent, respectively. However, bactericidal activity of blueberry pomace extract was stronger than that of blackberry pomace extract. This study also found that several virulence properties of *C. jejuni*, such as autoaggregation, motility, adhesion, invasion, and expression level of virulence genes, were significantly modified due to exposure to berry pomace extracts.

Recently, the same research group carried out a study to evaluate blackberry and blueberry pomaces on *C. jejuni* colonization in broiler cecum (Salaheen et al., 2018). As a water supplement, phenolic extract from berry pomaces reduced *C. jejuni* pre-harvest colonization level in poultry gut in a dose dependent manner. In addition, berry pomaces induced complete inhibition of the *C. jejuni* marker strain in drinking water reducing the potential for horizontal transfer in poultry flocks. Therefore, authors suggest that berry pomace extracts, especially from blackberry and blueberry, might be a feasible alternative as feed additives or water supplements to reduce the colonization level of *C. jejuni* in poultry, and as a natural preservative to control *Campylobacter* growth in the poultry food chain and its final products.

6.2. Cereal by-products

World cereal production in 2016 reached 2,500 million tons (FAO, 2017), thus cereals are a major source of agricultural waste in many countries. The seven principal cereals grown in the world are wheat, maize, rice, barley, oats, rye and sorghum. During grain processing, large quantities of by-products such as bran, germ, husk and straw that are rich in bioactive compounds are produced. To the best of our knowledge, only by-

products obtained from sorghum processing have been evaluated for controlling *Campylobacter*. Sorghum (*Sorghum bicolor*) is a cereal crop in many parts of world and contains high levels of phytochemicals including condensed tannins, phenolic acids, flavonoids, deoxyanthocyanins, phytosterols and policosanols (de Moraes Cardoso et al., 2017). Sorghum is converted to ethanol by yeast fermentation techniques resulting condensed distillers solubles, also referred to as sorghum syrup, as a by-product which contains bioactive compounds. Navarro et al. (2015) confirmed that sorghum syrup, obtained from bioethanol production, were active against *Campylobacter* with MIC values ranging from 0.25% for the concentrated sorghum syrup up to 4% for the methanol and water extractions. All tested syrup extracts showed a dose-dependent response against *Campylobacter* indicating higher the dose tested the higher the inhibition. Recently, the same research group confirmed that sorghum syrup obtained from bioethanol industry was effective as antimicrobial against *Campylobacter* (Navarro et al., 2016). The MIC that inhibited the bacterial growth reached 1% concentration of condensed distillers solubles. In this study, the main phytochemical compounds contributing to the bioactivity were determined founding that flavonol taxifolin, and the phenolic acids, protocatechuic acid, 4-hydroxybenzoic acid, ferulic acid, cinnamic acid and p-coumaric acid, were the main phenolic compounds.

6.3. Animal by-products

Seafood processing industry

As described above in the case of fruits by-products, some industrial by-products of animal origin have demonstrated their effectiveness against *Campylobacter*. One of the most studied has been the effect of chitosan and chitooligosaccharides. Chitosan, a natural carbohydrate polymer derived from the deacetylation of chitin, is the second most abundant natural biopolymer after cellulose (Younes et al., 2015). Chitosan is produced

commercially from crab and shrimp shell wastes with different degrees of deacetylation and molecular masses, thus presenting a variety of properties. Over the past few years, chitosan has received increased attention mainly due to its innocuous nature and bioactivity, and it is used in different applications for foods and pharmaceuticals (Muxica et al., 2017). Chitosan has several biological properties useful for the food industry, but the most attractive is its potential use as a food preservative of natural origin due to its antimicrobial activity against a wide range of foodborne microorganisms (Zhengxin et al., 2017). In a work performed using three chitosans with different molecular masses against six Gram-negative and three Gram-positive bacteria, it was observed that *Campylobacter* was the microorganism most sensitive to chitosan, regardless of their molecular mass (Ganan et al., 2009). The MIC of chitosan for *Campylobacter* ranged from 0.005 to 0.05%, demonstrating the high sensitivity of campylobacters to chitosan. These authors also studied the mechanism of chitosan's action against *Campylobacter*, pointed that chitosan caused a loss in the membrane integrity of *Campylobacter*, measured as an increase in cell fluorescence due to the uptake of propidium iodide, a dye that is normally excluded from cells with intact membranes. Recent years have witnessed great developments in biobased polymer packaging films for the serious environmental problems caused by the petroleum-based nonbiodegradable packaging materials. In this context, chitosan-based materials have been widely applied in various fields for their biological and physical properties of biocompatibility, biodegradability, antimicrobial ability, and easy film forming ability (Wang et al., 2018). Recently, it was observed that the incorporation of ≥ 50 $\mu\text{L/g}$ of allyl isothiocyanate (AITC) or 300 mg/g deodorized oriental mustard extract in κ -carrageenan/chitosan solutions as an edible coating significantly reduced viable numbers of *C. jejuni* on vacuum-packed chicken breasts and thus enhanced its safety (Olaimat et al., 2014). Even though chitosan is known to have

important functional activities, poor solubility makes them difficult to use sometimes in food and biomedical applications. Unlike chitosan, the low viscosity and good solubility of chitosan oligosaccharides (COS) make them especially attractive in an important number of useful applications. Mengibar et al. (2011) observed that *Streptomyces* chitosanase generates more deacetylated products that show higher antibacterial effect against *C. jejuni*. This antimicrobial effect was more pronounced for fractions with molecular weight between 10 and 30 kDa. These results have shown that COS could be useful as antimicrobial in the control of *Campylobacter*. Other related products, such as the antibacterial peptide fractions generated via proteolytic processing of snow crab by-products also exhibited activity against Gram-negative and Gram-positive bacteria, among them *C. jejuni* (Beaulieu et al., 2010).

Dairy industry

Large amounts of wastes emerge from milk processing in dairies, which are one of the largest sources of industrial effluents. The disposal of whey, the liquid remaining after the separation of milk fat and casein from whole milk during cheese processing, is a major problem for the dairy industry, because of the high volumes produced, which demands simple and economical solutions. The most abundant components of whey is the carbohydrate lactose (~70%), follow by proteins and inorganic substances with differing weight proportions. The world whey production amounts to about 82 million metric tons, and especially the acid whey is seen as a waste product. However, the bioconversion of whey to valuable products has been actively explored. For example, since lactose is the major component of whey, the production of lactic acid by using lactose whey through homofermentative lactic acid bacteria is viewed as an alternative process for the management of this abundant dairy by-product. Lactic acid is widely used in food industries as mineral fortifier, preservative, acidulant, and flavouring component, in

addition in the processed meat, hams, fish and poultry industries, lactic acid provides products with a longer shelf life by controlling food-borne pathogens because of its proved antimicrobial activity. Several studies have been confirmed the lactic acid effectiveness against *Campylobacter* bacteria employing different concentrations and contact conditions. Heres et al. (2004) performing an *in vitro* experiment observed a complete reduction of *Campylobacter* in the broiler feed acidified with 5.7% lactic acid. However, when in an *in vivo* experiment was carried out in chickens fed with feed acidified with lactic acid only a limited bacterial reduction was obtained, nevertheless the chickens were less susceptible to the *Campylobacter* infection. Ellerbroek et al. (2007) reported the efficacy of a decontamination method of *C. jejuni* on inoculated poultry carcasses by dipping and spray washing with lactic acid solutions (10% and 15%). The highest bacteria reductions were found after dipping in 15% lactic acid solution reducing 1.5 log₁₀ cfu/g. Riedel et al. (2009) evaluated the effectiveness of a short-time decontamination treatment of *C. jejuni* on inoculated skin and chicken meat through immersion in a 2.5% lactic acid solution. The main results showed a significant reduction of bacterial growth (1.69 log₁₀) after 1 min of immersion which increased to 3.87 log₁₀ after 24 h chilled storage. Subsequent similar studies investigated the effect of dipping inoculated poultry samples with different lactic acid concentrations on the *Campylobacter* growth achieving moderate bacterial reductions and are summarised in Table 4. More efficient results of growth reduction were obtained by Birk et al. (2010) when *C. jejuni* strain was exposed to 0.5% lactic acid solution on chicken meat and in broth causing a 4- and 6-log reduction, respectively, after 24 h of exposure at 4°C.

7. Conclusions

The increasing amount of waste produced by the food industry makes it necessary to create new ways for recycling, developing new technologies for waste processing. This

work summarized the potential of food by-products as a source of bioactive compounds against *Campylobacter*, the main bacterial foodborne pathogen. This putative application would contribute to the sustainability of the food industry, also promoting the valorisation of their by-products. Further studies are required to scale up to industrial applications the best results obtained at laboratory level, in order to increase the interest of the industrial sector in this approach to exploit and revalue the food by-products.

References

Aissa, I., Kharrat, N., Aloui, F., Sellami, M., Bouaziz, M., & Gargouri, Y. (2017). Valorization of antioxidants extracted from olive mill wastewater. *Biotechnology and Applied Biochemistry*, **64**, 579-589.

Alfredson, D. A., & Korolik, V. (2007). Antibiotic resistance and resistance mechanisms in *Campylobacter jejuni* and *Campylobacter coli*. *FEMS Microbiology Letters*, **277**, 123-132.

Araújo, M., Pimentel, F. B., Alves, R. C., & Oliveira, M. B. P. P. (2015). Phenolic compounds from olive mill wastes: Health effects, analytical approach and application as food antioxidants. *Trends in Food Science & Technology*, **45**, 200-211.

Backert, S., & Hofreuter, D. (2013). Molecular methods to investigate adhesion, transmigration, invasion and intracellular survival of the foodborne pathogen *Campylobacter jejuni*. *Journal of Microbiological Methods*, **95**, 8-23.

Backert, S., Tegtmeyer, N., Cróinín, T., Boehm, M., & Heimesaat, M. M. (2016). Human campylobacteriosis. In: Günter Klein (ed). *Campylobacter* features, detection, and prevention of foodborne disease. 1st ed, pp 1-25. Academic Press, Elsevier, Amsterdam.

513 Beaulieu, L., Thibodeau, J., Desbiens, M., Saint-Louis, R., Zatylny-Gaudin, C., &
 514 Thibault, S. (2010). Evidence of antibacterial activities in peptide fractions originating
 515 from Snow Crab (*Chionoecetes opilio*) by-products. *Probiotics and Antimicrobial*
 516 *Proteins*, **2**, 197-209.

517 Bicchi, C. (2012). *Citrus* oils: composition, advanced analytical techniques, contaminants
 518 and biological activity. *Flavour and Fragrance Journal*, **27**, 260–261.

519 Birk, T., Grønlund, A. C., Christensen, B. B., Knøchel, S., Lohse, K., & Rosenquist, H.
 520 (2010). Effect of organic acids and marination ingredients on the survival of
 521 *Campylobacter jejuni* on meat. *Journal of Food Protection*, **73**, 258-265.

522 Boysen, L., & Rosenquist, H. (2009). Reduction of thermotolerant *Campylobacter*
 523 species on broiler carcasses following physical decontamination at slaughter. *Journal of*
 524 *Food Protection*, **72**, 497-502.

525 Branciari, R., Ranucci, D., Ortenzi, R., Roila, R., Trabalza-Marinucci, M., Servili, M.,
 526 Papa, P., Galarini, R., & Valiani, A. (2016). Dietary administration of olive mill
 527 wastewater extract reduces *Campylobacter* spp. prevalence in broiler chickens.
 528 *Sustainability*, **8**, 837.

529 Brenes, A., & Roura, E. (2010). Essential oils in poultry nutrition: main effects and modes
 530 of action. *Animal Feed Science and Technology*, **158**, 1-14.

531 Brenes, A., Viveros, A., Chamorro, S., & Arija, I. (2016). Use of polyphenol-rich grape
 532 by-products in monogastric nutrition. A review. *Animal Feed Science and Technology*,
 533 **211**, 1-17.

534 Bronowski, C., James, C. E., & Winstanley, C. (2014). Role of environmental survival in
 535 transmission of *Campylobacter jejuni*. *FEMS Microbiology Letters*, **356**, 8-19.

536 Buckley, A. M., Wang, J., Hudson, D. L., Grant, A. J., Jones, M. A., Maskell, D. J., &
 537 Stevens, M. P. (2010). Evaluation of live-attenuated *Salmonella* vaccines expressing
 538 *Campylobacter* antigens for control of *C. jejuni* in poultry. *Vaccine*, **28**, 1094-1105.

539 Carvalho, C. M., Gannon, B. W., Halfhide, D. E., Santos, S. B., Hayes, C. M., Roe, J. M.,
 540 & Azeredo, J. (2010). The in vivo efficacy of two administration routes of a phage
 541 cocktail to reduce numbers of *Campylobacter coli* and *Campylobacter jejuni* in chickens.
 542 *BMC Microbiology*, **10**, 232.

543 Castillo, S., Heredia, N., Arechiga-Carvajal, E., & García, S. (2014). *Citrus* extracts as
 544 inhibitors of quorum sensing, biofilm formation and motility of *Campylobacter jejuni*.
 545 *Food Biotechnology*, **28**, 106-122.

546 Castillo, S., Dávila-Aviña, J., Heredia, N., & García, S. (2017). Antioxidant activity and
 547 influence of *Citrus* byproduct extracts on adherence and invasion of *Campylobacter*
 548 *jejuni* and on the relative expression of *cadF* and *ciaB*. *Food Science and Biotechnology*,
 549 **26**, 453-459.

550 CDC (Centers for Disease Control and Prevention) (2014). *Campylobacter*, general
 551 information. Centers for Disease Control and Prevention, Atlanta, GA.
 552 <https://www.cdc.gov/foodsafety/diseases/campylobacter/index.html>.

553 Coşansu, S., & Ayhan, K. (2010). Effects of lactic and acetic acid treatments on
 554 *Campylobacter jejuni* inoculated onto chicken leg and breast meat during storage at 4°C
 555 and -18°C. *Journal of Food Processing and Preservation*, **34**, 98-113.

556 de Moraes Cardoso, L., Pinheiro, S. S., Martino, H. S., & Pinheiro-Sant'Ana, H. M.
 557 (2017). Sorghum (*Sorghum bicolor* L.): Nutrients, bioactive compounds, and potential
 558 impact on human health. *Critical Reviews in Food Science and Nutrition*, **57**, 372-390.

559 Doorduyn, Y., Van Den Brandhof, W. E., Van Duynhoven, Y. T., Breukink, B. J.,
560 Wagenaar, J. A., & Van Pelt, W. (2010). Risk factors for indigenous *Campylobacter*
561 *jejuni* and *Campylobacter coli* infections in The Netherlands: a case-control study.
562 *Epidemiology and Infection*, **138**, 1391-1404.

563 Doula, M. K., Moreno-Ortego, J. L., Tinivella, F., Inglezakis, V. J., Sarris, A., &
564 Komnitsas, K. (2017). Olive mill waste: recent advances for the sustainable development
565 of olive oil industry. In: Charis M. Galanakis (Ed.), *Olive mill waste recent advances for*
566 *sustainable management*. Elsevier Inc., San Diego, pp 29-56.

567 EFSA (European Food Safety Authority) and ECDC (European Centre for Disease
568 Prevention and Control) (2017). The European Union summary report on trends and
569 sources of zoonoses, zoonotic agents and food-borne outbreaks in 2016. *EFSA Journal*,
570 **15**, 5077.

571 El-Shibiny, A., Scott, A., Timms, A., Metawea, Y., Connerton, P., & Connerton, I.
572 (2009). Application of a group II *Campylobacter* bacteriophage to reduce strains of
573 *Campylobacter jejuni* and *Campylobacter coli* colonizing broiler chickens. *Journal of*
574 *Food Protection*, **72**, 733-740.

575 Ellerbroek, L., Lienau, J. A., Alter, T., & Schlichting, D. (2007). Effectiveness of
576 different chemical decontamination methods on the *Campylobacter* load of poultry
577 carcasses. *Fleischwirtschaft*, **4**, 224-227.

578 Esan, O. B., Pearce, M., van Hecke, O., Roberts, N., Collins, D. R. J., Violato, M.,
579 McCarthy, N., Perera, R., & Fanshawe, T. R. (2017). Factors associated with sequelae of
580 *Campylobacter* and non-typhoidal *Salmonella* infections: A systematic review.
581 *EBioMedicine*, **15**, 100-111.

582 Evers, E. G. (2004). Predicted quantitative effect of logistic slaughter on microbial
583 prevalence. *Preventive Veterinary Medicine*, **65**, 31-46.

584 FAO. (2009). Food and Agricultural Organization of the United Nations.
585 <http://faostat.fao.org>

586 FAO. (2017). FAO Cereal supply and demand brief. Bumper crops boost global cereal
587 supplies in 2017/18. <http://www.fao.org/worldfoodsituation/csdb/en/>

588 FAO-OIV (2016). Table and dried grapes. Non-alcoholic products of the vitivinicultural
589 sector intended for human consumption. FAO-OIV Focus 2016, I7042.

590 Fisher, K., & Phillips, C. A. (2006). The effect of lemon, orange and bergamot essential
591 oils and their components on the survival of *Campylobacter jejuni*, *Escherichia coli*
592 O157, *Listeria monocytogenes*, *Bacillus cereus* and *Staphylococcus aureus* *in vitro* and
593 in food systems. *Journal of Applied Microbiology*, **101**, 1232-1240.

594 Friedman, M. (2014). Antibacterial, antiviral, and antifungal properties of wines and
595 winery byproducts in relation to their flavonoid content. *Journal of Agricultural and Food*
596 *Chemistry*, **62**, 6025-6042.

597 FSAI (Food Safety Authority of Ireland) (2011). Recommendations for a practical control
598 programme for *Campylobacter* in the poultry production and slaughter chain. *Report of*
599 *the Scientific Committee of the Food Safety Authority of Ireland*. www.fsai.ie

600 Ganan, M., Carrascosa, A. V., & Martinez-Rodriguez, A. J. (2009). Antimicrobial
601 activity of chitosan against *Campylobacter* spp. and other microorganisms and its
602 mechanism of action. *Journal of Food Protection*, **72**, 1735-1738.

603 Ganan, M., Collins, M., Rastall, R., Hotchkiss, A. T., Chau, H. K., Carrascosa, A. V., &
604 Martinez-Rodriguez, A. J. (2010). Inhibition by pectic oligosaccharides of the invasion
605 of undifferentiated and differentiated Caco-2 cells by *Campylobacter jejuni*. *International*
606 *Journal of Food Microbiology*, **137**, 181-185.

607 Ganan, M., Silván, J. M., Carrascosa, A. V., & Martinez-Rodriguez, A. J. (2012).
608 Alternative strategies to use antibiotics or chemical products for controlling
609 *Campylobacter* in the food chain. *Food Control*, **24**, 6-14.

610 García-Lomillo, J., & González-SanJosé, M. L. (2017). Applications of wine pomace in
611 the food industry: approaches and functions. *Comprehensive Reviews in Food Science*
612 *and Food Safety*, **16**, 3-22.

613 Geraci, A., Di Stefano, V., Di Martino, E., Schillaci, D., & Schicchi, R. (2017). Essential
614 oil components of orange peels and antimicrobial activity. *Natural Product Research*, **31**,
615 653-659.

616 Gorinstein, S., Martin-Belloso, O., Park, Y. S., Haruenkit, R., Lojek, A., Ciz, M., Caspi,
617 A., Libman, I., & Trakhtenberg, S. (2001). Comparison of some biochemical
618 characteristics of different citrus fruits. *Food Chemistry*, **74**, 309–315.

619 Gruntar, I., Biasizzo, M., Kušar, D., Pate, M., & Ocepek, M. (2015). *Campylobacter*
620 *jejuni* contamination of broiler carcasses: population dynamics and genetic profiles at
621 slaughterhouse level. *Food Microbiology*, **50**, 97-101.

622 Guerin, M. T., Sir, C., Sargeant, J. M., Waddell, L., O'Connor, A. M., Wills, R. W.,
623 Bailey, R. H., & Byrd, J. A. (2010). The change in prevalence of *Campylobacter* on
624 chicken carcasses during processing: A systematic review. *Poultry Science*, **89**, 1070-
625 1084.

626 Gunther, N. W., & Chen, C. Y. (2009). The biofilm forming potential of bacterial species
627 in the genus *Campylobacter*. *Food Microbiology*, **26**, 44-51.

628 Hastings, R., Colles, F. M., McCarthy, N. D. and Maiden, M. C. J., & Sheppard, S. K.
629 (2010). *Campylobacter* genotypes from poultry transportation crates indicate a source of
630 contamination and transmission. *Journal of Applied Microbiology*, **110**, 266-276.

631 Heres, L., Engel, B., Urlings, H. A. P., Wagenaar, J. A., & Van Knapen, F. (2004). Effect
632 of acidified feed on susceptibility of broiler to intestinal infection by *Campylobacter* and
633 *Salmonella*. *Veterinary Microbiology*, **99**, 259-267.

634 Hettiarachchy, N., Perumalla, A. V. S., Slavik, M., Kumar, G. S. (2010). Grape seed
635 extract and malic acid effectively inhibit the growth of *Campylobacter jejuni* in broth
636 culture. *Journal of Food Protection*, Supplement A, **73**, p64 (P1-28).

637 Hinton, A. J. R., Cason, J. A., Hume, M. E., & Ingram, K. (2004). Use of MIDI-fatty acid
638 methyl ester analysis to monitor the transmission of *Campylobacter* during commercial
639 poultry processing. *Journal of Food Protection*, **67**, 1610-1616.

640 Hogervorst, J. C., Miljić, U., & Puškaš, V. (2017). Extraction of bioactive compounds
641 from grape processing by-products. In C. M. Galanakis (Ed.) *Handbook of grape*
642 *processing by-products*, pp. 105-135. Academic Press: Elsevier, San Diego, CA, USA.

643 Jayathilakan, K., Sultana, K., Radhakrishna, K., & Bawa, A. S. (2012). Utilization of
644 byproducts and waste materials from meat, poultry and fish processing industries: a
645 review. *The Journal of Food Science and Technology*, **49**, 278-293.

646 Kaakoush, N. O., Castaño-Rodríguez, N., Mitchell, H. M., & Mana, S. M. (2015). Global
647 epidemiology of *Campylobacter* infection. *Clinical Microbiology Reviews*, **28**, 687-720.

648 Katalinic, V., Smole Mozina, S., Generalic, I., Skroza, D., Ljubenkovic, I., & Klanecnik, A.
649 (2013). Phenolic profile, antioxidant capacity, and antimicrobial activity of leaf extracts
650 from six *Vitis vinifera* L. varieties. *International Journal of Food Properties*, **16**, 45-60.

651 Katalinić, V., Smole Možina, S., Skroza, D., Generalić, I., Abramović, H., Miloš, M.,
652 Ljubenković, I., Piskernik, S., Pezo, I., Terpinč, P., & Boban, M. (2010). Polyphenolic
653 profile, antioxidant properties and antimicrobial activity of grape skin extracts of 14 *Vitis*
654 *vinifera* varieties grown in Dalmatia (Croatia). *Food Chemistry*, **119**, 715-723.

655 Khao, T. H., & Chen, B. H. (2013). Fruits and vegetables. In Chandrasekaran, M. (Ed.)
656 *Valorization of food processing by-products*, pp. 517-557. Taylor and Francis Group,
657 Boca Raton, FL, USA.

658 Klančnik, A., Šikić Pogačar, M., Trošt, K., Tušek Žnidarič, M., Mozetič Vodopivec, B.,
659 & Smole Možina, S. (2017). Anti-*Campylobacter* activity of resveratrol and an extract
660 from waste Pinot noir grape skins and seeds, and resistance of *Camp. jejuni* planktonic
661 and biofilm cells, mediated via the CmeABC efflux pump. *Journal of Applied*
662 *Microbiology*, **122**, 65-77.

663 Laisney, M. J., Gillard, M. O., & Salvat, G. (2004). Influence of bird strain on competitive
664 exclusion of *Campylobacter jejuni* in young chicks. *British Poultry Science*, **45**, 49-54.

665 Lehner, Y., Reich, F., & Klein, G. (2014). Influence of process parameter on
666 *Campylobacter* spp. counts on poultry meat in a slaughterhouse environment. *Current*
667 *Microbiology*, **69**, 240-244.

668 Li, S., Lo, C. Y., & Ho, C. T. (2006). Hydroxylated polymethoxy-flavones and methylated
669 flavonoids in sweet orange (*Citrus sinensis*) peel. *Journal of Agricultural and Food*
670 *Chemistry*, **54**, 4176-4185.

671 Mahato, N., Sharma, K., Koteswararao, R., Sinha, M., Baral, E., & Cho, M. H. (2017).
672 Citrus essential oils: Extraction, authentication and application in food preservation.
673 *Critical Reviews in Food Science and Nutrition*, **28**, 1-15.

674 Mengibar, M., Gañan, M., Miralles, B., Carrascosa, A. V., & Martínez-Rodríguez, A. J.
675 (2011). Antibacterial activity of products of depolymerization of chitosans with lysozyme
676 and chitosanase against *Campylobacter jejuni*. *Carbohydrate Polymers*, **84**, 844-848.

677 Meredith, H., Walsh, D., McDowell, D. A., & Bolton, D. J. (2013). An investigation of
678 the immediate and storage effects of chemical treatments on *Campylobacter* and sensory
679 characteristics of poultry meat. *International Journal of Food Microbiology*, **166**, 309-
680 315.

681 Messaoudi, S., Kergourlay, G., Dalgalarondo, M., Choiset, Y., Ferchichi, M., Prévost,
682 H., Pilet, M. F., Chobert, J. M., Manai, M., & Dousset, X. (2012). Purification and
683 characterization of a new bacteriocin active against *Campylobacter* produced by
684 *Lactobacillus salivarius* SMXD51. *Food Microbiology*, **32**, 129-134.

685 Meunier, M., Guyard-Nicodème, M., Hirchaud, E., Parra, A., Chemaly, M., & Dory, D.
686 (2016). Identification of novel vaccine candidates against *Campylobacter* through reverse
687 vaccinology. *Journal of Immunology Research*, **2016**, ID5715790.

688 Mingo, E., Silvan, J. M., & Martinez-Rodriguez, A. J. (2016). Selective antibacterial
689 effect on *Campylobacter* of a winemaking waste extract (WWE) as a source of active
690 phenolic compounds. *LWT - Food Science and Technology*, **68**, 418-424.

691 Mitropoulou, G., Fitsiou, E., Spyridopoulou, K., Tiptiri-Kourpeti, A., Bardouki, H.,
692 Vamvakias, M., Panas, P., Chlichlia, K., Pappa, A., & Kourkoutas, Y. (2017). Citrus

693 medica essential oil exhibits significant antimicrobial and antiproliferative activity. *LWT-*
694 *Food Science and Technology*, **84**, 344-352.

695 Mughini Gras, L., Smid, J. H., Wagenaar, J. A., Koene, M. G., Havelaar, A. H., Friesema,
696 I. H., French, N. P., Flemming, C., Galson, J. D., Graziani, C., Busani, L., & Van Pelt,
697 W. (2013). Increased risk for *Campylobacter jejuni* and *C. coli* infection of pet origin in
698 dog owners and evidence for genetic association between strains causing infection in
699 humans and their pets. *Epidemiology and infection*, **141**, 2526-2535.

700 Muxika, A., Etxabide, A., Uranga, J., Guerrero, P., & de la Caba, K. (2017). Chitosan as
701 a bioactive polymer: processing, properties and applications. *International Journal of*
702 *Biological Macromolecules*, **105**, 1358-1368.

703 Nannapaneni, R., Chalova, V. I., Crandall, P. G., Ricke, S. C., Johnson, M. G., &
704 O'Bryan, C. A. (2009). *Campylobacter* and *Arcobacter* species sensitivity to commercial
705 orange oil fractions. *International Journal of Food Microbiology*, **129**, 43-49.

706 Navarro, M., Sonni, F., Chaliha, M., Netzel, G., Stanley, R., & Sultanbawa, Y. (2016).
707 Physicochemical assessment and bioactive properties of condensed distillers solubles, a
708 by-product from the sorghum bio-fuel industry. *Journal of Cereal Science*, **72**, 10-15.

709 Navarro, M., Stanley, R., Cusack, A., & Sultanbawa, Y. (2015). Combinations of plant-
710 derived compounds against *Campylobacter in vitro*. *The Journal of Applied Poultry*
711 *Research*, **24**, 352-363.

712 Newell, D. G., Elvers, K. T., Dopfer, D., Hansson, I., Jones, P., & James, S. (2011).
713 Biosecurity-based interventions and strategies to reduce *Campylobacter* spp. on poultry
714 farms. *Applied and Environmental Microbiology*, **77**, 8605-8614.

715 Newell, D. G., Mughini-Gras, L., Kalupahana, R. S., & Wagenaar, J. A. (2016).
716 *Campylobacter* epidemiology – sources and routes of transmission for human infection.
717 In Klein, G. (ed) *Campylobacter* features, detection, and prevention of foodborne disease.
718 1st ed, pp 85-110. Academic Press, Elsevier, Amsterdam.

719 Nothaft, H., Davis, B., Lock, Y. Y., Perez-Munoz, M. E., Vinogradov, E., Walter, J.,
720 Coros, C., & Szymanski, C. M. (2016). Engineering the *Campylobacter jejuni* N-glycan
721 to create an effective chicken vaccine. *Scientific Reports*, **6**, 26511.

722 Olaimat, A. N., Fang, Y., & Holley, R. A. (2014). Inhibition of *Campylobacter jejuni* on
723 fresh chicken breasts by κ -carrageenan/chitosan-based coatings containing allyl
724 isothiocyanate or deodorized oriental mustard extract. *International Journal of Food*
725 *Microbiology*, **187**, 77-82.

726 Osiriphun, S., Iamtaweelaloen, P., Kooprasertying, P., Koetsinchai, W., Tuitemwong, K.,
727 Erickson, L. E., & Tuitemwong, P. (2011). Exposure assessment and process sensitivity
728 analysis of the contamination of *Campylobacter* in poultry products. *Poultry Science*, **90**,
729 1562-1573.

730 Oyarzabal, O. A., & Carrillo, C. D. (2016). Isolation, identification, and typing of
731 *Campylobacter* strains from food samples. In Klein, G. (ed) *Campylobacter* features,
732 detection, and prevention of foodborne disease. 1st ed, pp 61-83. Academic Press,
733 Elsevier, Amsterdam.

734 Poly, F., & Guerry, P. (2008). Pathogenesis of *Campylobacter*. *Current Opinion in*
735 *Gastroenterology*, **24**, 27-31.

736 Potturi-Venkata, L. P., Backert, S., Vieira, S. L., & Oyarzabal, O. A. (2007). Evaluation
 737 of logistic processing to reduce cross-contamination of commercial broiler carcasses with
 738 *Campylobacter* spp. *Journal of Food Protection*, **70**, 2549-2554.

739 Rajkovic, A., Smigic, N., Uyttendaele, M., Medic, H., de Zutter, L., & Devlieghere, F.
 740 (2009). Resistance of *Listeria monocytogenes*, *Escherichia coli* O157:H7 and
 741 *Campylobacter jejuni* after exposure to repetitive cycles of mild bactericidal treatments.
 742 *Food Microbiology*, **26**, 889-895.

743 Rajkovic, A., Tomic, N., Smigic, N., Uyttendaele, M., Ragaert, P., & Devlieghere, F.
 744 (2010). Survival of *Campylobacter jejuni* on raw chicken legs packed in high-oxygen or
 745 high-carbon dioxide atmosphere after the decontamination with lactic acid/sodium lactate
 746 buffer. *International Journal of Food Microbiology*, **140**, 201-206.

747 Rao, D. G. (2010). Cleaning and sanitation of process plants. In Fundamentals of food
 748 engineering, pp. 521-539. PHI Learning Pvt. Ltd., New Delhi.

749 Ridley, A., Morris, V., Gittins, J., & Cawthraw, S. (2011). Potential source of
 750 *Campylobacter* infection on chicken farm: contamination and control of broiler
 751 harvesting equipments, vehicles and personnels. *Journal of Applied Microbiology*, **111**,
 752 233-244.

753 Riedel, C. T., Brøndsted, L., Rosenquist, H., Haxgart, S. N., & Christensen, B. B. (2009).
 754 Chemical decontamination of *Campylobacter jejuni* on chicken skin and meat. *Journal*
 755 *of Food Protection*, **72**, 1173-1180.

756 Rosenquist, H., Sommer, H. M., Nielsen, N. L., & Christensen, B. B. (2006). The effect
 757 of slaughter operations on the contamination of chicken carcasses with thermotolerant
 758 *Campylobacter*. *International Journal of Food Microbiology*, **108**, 226-232.

759 Salaheen, S., Nguyen, C., Hewes, D., & Biswas, D. (2014). Cheap extraction of
760 antibacterial compounds of berry pomace and their mode of action against the pathogen
761 *Campylobacter jejuni*. *Food Control*, **46**, 174-181.

762 Salaheen, S., Tabashsum, Z., Gaspard, S., Dattilio, A., Tran, T. H., & Biswas, D. (2018).
763 Reduced *Campylobacter jejuni* colonization in poultry gut with bioactive phenolics. *Food*
764 *Control*, **84**, 1-7.

765 Šikić Pogačar, M., Klančnik, A., Bucar, F., Langerholc, T. & Smole Možina, S. (2016).
766 Anti-adhesion activity of thyme (*Thymus vulgaris* L.) extract, thyme post-distillation
767 waste, and olive (*Olea europea* L.) leaf extract against *Campylobacter jejuni* on
768 polystyrene and intestine epithelial cells. *Journal of the Science of Food and Agriculture*,
769 **96**, 2723-2730.

770 Silva, J., Leite, D., Fernandes, M., Mena, C., Gibbs, P. A., & Teixeira, P. (2011).
771 *Campylobacter* spp. as a foodborne pathogen: a review. *Frontiers in Microbiology*, **200**.

772 Silvan, J. M., Mingo, E., Hidalgo, M., de Pascual-Teresa, S., Carrascosa, A. V., &
773 Martinez-Rodriguez, A. J. (2013) Antibacterial activity of a grape seed extract and its
774 fractions against *Campylobacter* spp. *Food Control*, **29**, 25-31.

775 Silvan, J. M., Pinto-Bustillos, M. A., Vasquez-Ponce, P., Prodanov, M., & Martinez-
776 Rodriguez, A. J. (2018). Olive mill wastewater as potential source of antibacterial and
777 anti-inflammatory compounds against the food-borne pathogen *Campylobacter*.
778 *Innovative Food Science and Emerging Technologies*. Sent for publication.

779 Singh, P., Shukla, R., Prakash, B., Kumar, A., Singh, S., Mishra, P. K., & Dubey, N. K.
780 (2010). Chemical profile, antifungal, antiaflatoxic and antioxidant activity of *Citrus*

781 *maxima* Burm. and *Citrus sinensis* (L.) Osbeck essential oils and their cyclic
782 monoterpene, d-limonene. *Food and Chemical Toxicology*, **48**, 1734-1740.

783 Sudjana, A. N., D'Orazio, C., Ryan, V., Rasool, N., Ng, J., Islam, N., Riley, T. V., &
784 Hammer, K. A. (2009). Antimicrobial activity of commercial *Olea europaea* (olive) leaf
785 extract. *International Journal of Antimicrobial Agents*, **33**, 461-463.

786 Svetoch, E. A., Eruslanov, B. V., Pereygin, V. V., Mitsevich, E. V., Mitsevich, I. P.,
787 Borzenkov, V. N., Levchuk, V. P., Svetoch, O. E., Kovalev, Y. N., Stepanshin, Y. G.,
788 Siragusa, G. R., Seal, B. S., & Stern, N. J. (2008). Diverse antimicrobial killing by
789 *Enterococcus faecium* E 50-52 bacteriocin. *Journal of Agricultural and Food Chemistry*,
790 **56**, 1942-1948.

791 Teixeira, A., Baenas, N., Dominguez-Perles, R., Barros, A., Rosa, E., Moreno, D. A., &
792 Garcia-Viguera, C. (2014). Natural bioactive compounds from winery by-products as
793 health promoters: a review. *International Journal of Molecular Sciences*, **15**, 15638-
794 15678.

795 Thanissery, R., Kathariou, S., & Smith, D. P. (2014). Rosemary oil, clove oil, and a mix
796 of thyme-orange essential oils inhibit *Salmonella* and *Campylobacter* *in vitro*. *The*
797 *Journal of Applied Poultry Research*, **23**, 221-227.

798 Theoret, J. R., Cooper, K. K., Zekarias, B., Roland, K. L., Law, B. F., Curtiss, R., &
799 Joens, L. A. (2012). The *Campylobacter jejuni* Dps homologue is important for *in vitro*
800 biofilm formation and cecal colonization of poultry and may serve as a protective antigen
801 for vaccination. *Clinical Vaccine Immunology*, **19**, 1426-1431.

802 Torrecilla, J. S. (2010). Phenolic compounds in olive oil mill wastewater. In Preedy, V.
803 R., & Watson, R. R. (Eds.) *Olives and olive oil in health and disease prevention*. pp. 357-
804 365. Elsevier Inc., San Diego.

805 Torres-Alvarez, C., Núñez González, A., Rodríguez, J., Castillo, S., LeosRivas, C., &
806 Báez-González, J. G. (2017) Chemical composition, antimicrobial, and antioxidant
807 activities of orange essential oil and its concentrated oils. *CyTA - Journal of Food*, **15**,
808 129-135.

809 Trošt, K., Klančnik, A., Mozetič Vodopivec, B., Sternad Lemut, M., Jug Novšak, K.,
810 Raspor, P., & Smole Možina, S. (2016). Polyphenol, antioxidant and antimicrobial
811 potential of six different white and red wine grape processing leftovers. *Journal of the*
812 *Science of Food and Agriculture*, **96**, 4809-4820.

813 Umaraw, P., Prajapati, A., Verma, A. K., Pathak, V., & Singh, V. P. (2017). Control of
814 *Campylobacter* in poultry industry from farm to poultry processing unit: A review.
815 *Critical Reviews in Food Science and Nutrition*, **57**, 659-665.

816 USDA: United States Department of Agriculture/Foreign Agricultural Service. (2017).
817 Citrus: World Markets and Trade. <http://www.fas.usda.gov>

818 Valtierra-Rodríguez, D., Heredia, N. L., García, S., & Sánchez, E. (2010). Reduction of
819 *Campylobacter jejuni* and *Campylobacter coli* in poultry skin by fruit extracts. *Journal*
820 *of Food Protection*, **73**, 477-482.

821 Van Gerwe, T., Bouma, A., Klinkenberg, D., Wagenaar, J. A., Jacobs-Reitsma, W. F., &
822 Stegeman, A. (2010). Medium chain fatty acid feed supplementation reduces the
823 probability of *Campylobacter jejuni* colonization in broilers. *Veterinary Microbiology*,
824 **143**, 314-318.

825 Vandeplas, S., Marcq, C., Dauphin, R. D., Beckers, Y., Thonart, P., & Thewis, A. (2008).
826 Contamination of poultry flocks by the human pathogen *Campylobacter* spp. and
827 strategies to reduce its prevalence at the farm level. *Biotechnologie Agronomie Societe et*
828 *Environnement*, **12**, 317-334.

829 Wagenaar, J. A., French, N. P., & Havelaar, A. H. (2013). Preventing *Campylobacter* at
830 the Source: Why Is It So Difficult? *Clinical Infectious Diseases*, **57**, 1600-1606.

831 Wang, H., Qian, J., & Ding, F. (2018). Emerging chitosan-based films for food packaging
832 applications. *Journal of Agricultural Food Chemistry*, **66**, 395-413.

833 Wideman, N., Bailey, M., Bilgili, S. F., Thippareddi, H., Wang, L., Bratcher, C., Sanchez-
834 Plata, M., & Singh, M. (2016). Evaluating best practices for *Campylobacter* and
835 *Salmonella* reduction in poultry processing plants. *Poultry Science*, **95**, 306-315.

836 Whyte, P., Collins, J. D., McGill, K., Monahan, C., & O'Mahony, H. (2001). The effect
837 of transportation stress on excretion rates of campylobacters in market-age broilers.
838 *Poultry Science*, **80**, 817-820.

839 Wyszynska, A., Raczko, A., Lis, M., & Jagusztyn-Krynicka, E. K. (2004). Oral
840 immunization of chickens with avirulent *Salmonella* vaccine strain carrying *C. jejuni*
841 72Dz/92 cjaA gene elicits specific humoral immune response associated with protection
842 against challenge with wild-type *Campylobacter*. *Vaccine*, **22**, 1379-1389.

843 Younes, I., & Rinaudo, M. (2015). Chitin and chitosan preparation from marine sources.
844 structure, properties and applications. *Marine Drugs*, **13**, 1133-1174.

845 Young, K. T., Davis, L. M., & Dirita, V. J. (2007). *Campylobacter jejuni*: molecular
846 biology and pathogenesis. *Nature Reviews Microbiology*, **5**, 665-679.

847 Yu, J. M., & Ahmedna, M. (2013). Functional components of grape pomace: their
848 composition, biological properties and potential applications. *International Journal of*
849 *Food Science and Technology*, **48**, 221-237.

850 Zakarienė, G., Šernienė, L., & Malakauskas, M. (2015). Effects of lactic acid, linalool
851 and cinnamaldehyde against *Campylobacter jejuni in vitro* and on broiler breast fillets.
852 *Veterinarija ir Zootechnika*, **72**, 45-52.

853 Zhang, Q., & Plummer, P. J. (2008). Mechanisms of antibiotic resistance in
854 *Campylobacter* In Nachamkin, I., Szymanski, C. M., & Blaser, M. J. (Eds.)
855 *Campylobacter*. 3rd ed., pp. 263-276. Washington DC: ASM Press.

856 Zhengxin, M., Garrido-Maestu, A., & Jeong, K. C. (2017). Application, mode of action,
857 and in vivo activity of chitosan and its micro- and nanoparticles as antimicrobial agents:
858 a review. *Carbohydrate Polymers*, **176**, 257-265.

859 Zhu, L., Zhang, Y., & Lu, J. (2012). Phenolic contents and compositions in skins of red
860 wine grape cultivars among various genetic backgrounds and originations. *International*
861 *Journal of Molecular Sciences*, **13**, 3492-3510.

Figure 1. Scanning electron microscope image shows the characteristic spiral, or corkscrew, shape of *Campylobacter jejuni* cells. Source: Agricultural Research Service (ARS) is the U.S. Department of Agriculture's Chief Scientific Research Agency.

Figure 2. Number of the confirmed human cases of 13 zoonoses in the EU, 2016. In 2016, campylobacteriosis was the most commonly reported zoonoses, as it had been since 2005, representing almost 70% of all the reported cases. Source: EFSA, 2017.

Figure 3. The sources and outcomes of *Campylobacter jejuni* infection. Several environmental reservoirs can lead to human infection by *C. jejuni*. It colonizes the chicken gastrointestinal tract, and is passed between chicks through the faecal-oral route. *C. jejuni* can enter the water supply, and possibly form biofilms. *C. jejuni* can infect humans directly through the drinking water or through the consumption of contaminated animal products. In humans, *C. jejuni* can invade the intestinal epithelial layer, resulting in inflammation and diarrhoea. Source: Young et al., 2007.

Figure 4. Hypothetical model for *C. jejuni* mechanisms of human infection. The bacteria can interact with, invade into, transmigrate across, and survive within polarized intestinal epithelial cells, as indicated. Source: Backert & Hofreuter, 2013.

Figure 5. Antimicrobial resistance in *Campylobacter* from humans (2010-2015). The data indicates a high level of antibiotic resistance for *Campylobacter*, with temporal trends indicating a rise in resistance to specific antibiotics. Of particular interest is the rise in resistance to antibiotics, such as nalidixic acid, ciprofloxacin and tetracyclines. Source: The European Union summary reports on antimicrobial resistance in zoonotic and indicator bacteria from humans, animals and food 2010-2015 (EFSA and ECDC, www.efsa.europa.eu).

(a) From 2013 is reported as a mixture of amoxicillin and clavulanic acid (co-amoxiclav).
(b) From 2012 is not reported.

Figure 6. Effect of pectic oligosaccharides (POS) concentration in the invasion of undifferentiated Caco-2 cells by *C. jejuni*. The results represent the mean values of invasive bacteria compared to control (IRC) and the standard error of the means for three different experiments. Asterisk represents significant differences respect to control with $p \leq 0.05$. Source: Ganan et al., 2010.

Figure 7. Qualitative antibacterial activity of grape seed collected fractions against *C. jejuni* and their phenolic composition (mg/L). Source: Silvan et al., 2013.

Control	F1	F2	F3	F4

Compound	F1	F2	F3	F4
<u>Flavonols</u>				
Quercetin-3-glucoside	<i>n.d.</i>	<i>n.d.</i>	78.0 ± 4.0	<i>n.d.</i>
Myricetin-3-glucoside	<i>n.d.</i>	<i>n.d.</i>	9.1 ± 0.1	<i>n.d.</i>
Kaempferol-3-glucoside	<i>n.d.</i>	<i>n.d.</i>	6.0 ± 0.2	<i>n.d.</i>
<u>Phenolic acids</u>				
Gallic acid	0.8 ± 0.1	10.6 ± 1.0	<i>n.d.</i>	<i>n.d.</i>
Protocatechuic acid	4.6 ± 0.1	13.0 ± 2.0	<i>n.d.</i>	1.0 ± 0.0
Caftaric acid	45.3 ± 0.3	<i>n.d.</i>	<i>n.d.</i>	<i>n.d.</i>
Homogentisic acid	1.7 ± 0.2	<i>n.d.</i>	<i>n.d.</i>	<i>n.d.</i>
Homovanillic acid	0.21 ± 0.0	<i>n.d.</i>	<i>n.d.</i>	<i>n.d.</i>
Chlorogenic acid	6.1 ± 0.1	4.0 ± 0.1	<i>n.d.</i>	<i>n.d.</i>
<u>Catechins</u>				
B1	7.1 ± 0.1	74.0 ± 3.0	<i>n.d.</i>	<i>n.d.</i>
Ec-Ec-Cat	<i>n.d.</i>	88.0 ± 6.0	<i>n.d.</i>	<i>n.d.</i>
Catechin	<i>n.d.</i>	81.0 ± 16.0	<i>n.d.</i>	<i>n.d.</i>
B2	<i>n.d.</i>	108.0 ± 8.0	<i>n.d.</i>	<i>n.d.</i>
Epicatechin	<i>n.d.</i>	95.0 ± 10.0	<i>n.d.</i>	<i>n.d.</i>
Epicatechin gallate	3.4 ± 0.1	<i>n.d.</i>	<i>n.d.</i>	<i>n.d.</i>
<u>Anthocyanins</u>				
Delphinidin-3-glucoside	<i>n.d.</i>	<i>n.d.</i>	<i>n.d.</i>	<i>n.d.</i>
Peonidin-3-glucoside	<i>n.d.</i>	<i>n.d.</i>	<i>n.d.</i>	<i>n.d.</i>
Malvidin-3-glucoside	<i>n.d.</i>	<i>n.d.</i>	<i>n.d.</i>	<i>n.d.</i>
Malvidin-3-acetate	<i>n.d.</i>	<i>n.d.</i>	<i>n.d.</i>	<i>n.d.</i>
TPC ^a	118.4 ± 5.0	795.0 ± 13.3	405.5 ± 6.1	73.5 ± 5.0

n.d. = non detected.

^a Total phenolic content (mg GAE/L).

Table 1. Main features of the genus *Campylobacter*. Source: Oyarzabal & Carrillo, 2016.

Feature	Values/Comments
Capnophilic	Some species require 35% CO ₂ to grow
Catalase activity	Positive
Chemoorganotrophs	Do not ferment or oxidize carbohydrates
Energy	Obtained from amino acids or intermediates of the tricarboxylic acid cycle
High temperature for growth	42°C in case of thermotolerant species: <i>C. jejuni</i> , <i>C. coli</i> , <i>C. hyointestinalis</i> , <i>C. lari</i> , and <i>C. upsaliensis</i>
Microaerobic atmosphere	O ₂ concentration between 3% and 15%. Concentrations of 5% are commonly used for isolation
Minimal growth temperature	30°C
Motility	Corkscrew-like darting motility observed with phase contrast or darkfield microscopy. High motility in fresh cultures
Shape	Spiral, S-shaped, or gull-winged-shaped when two cells form short chains. Cells in old cultures can form spherical or coccoid bodies
Special requirements to grow	Some species require hydrogen or formate with fumarate (electron donors) to grow in microaerobic conditions. If not, anaerobiosis becomes an optimal growth condition for these species

Table 2. Control intervention strategies for prevention *Campylobacter* infection in poultry industry. Source: this work.

Intervention	Strategy	Reference
Preharvest	Biosecurity measures	Newell et al., 2011; Riedley et al., 2011
	Bacteriocins application	Messaoudi et al., 2012; Svetoch et al., 2008
	Vaccination	Nothaft et al., 2016; Meunier et al., 2016
	Subunit vaccines	Buckley et al., 2010; Theoret et al., 2012
	Killed whole cell vaccines	Wyszyńska et al., 2004
	Competitive exclusion	Laisney et al., 2004
	Phage therapy	Carvalho et al., 2010; El-Shibiny et al., 2009
	Fatty acids and essential oils	Brenes et al., 2010; Van Gerwe et al., 2010
Postharvest	Hauling and transportation	Hastings et al., 2010; Whyte et al., 2001
	Scheduled slaughter	FSAI, 2011; Umaraw et al., 2017
	Logistic slaughter	Evers, 2004; Potturi-Venkata et al., 2007
Processing	Scalding	Lehner et al., 2014
	Counter-current scald tanks	FSAI, 2011
	Water flow rates	Osiriphun et al., 2011
	Multi-stage scalds tanks	Hinton et al., 2004
	Defeathering	Guerin et al., 2010
	Evisceration	Gruntar et al., 2015
	Prevention spillage intestinal content	Rosenquist et al., 2006
	Chilling	Boysen & Rosenquist, 2009
	Sanitation	Wideman et al., 2016
	House practices	Umaraw et al., 2017

Table 3. Different food processing industries and their wastes. Source: Rao, 2010.

Food processing industry	Waste materials generated
Cereal processing	Husks, hull, rice, bran
Fruits and vegetable processing	Skin, peels, pulp, seeds, stem, fiber
Animal products	Skin, bones, blood, feathers, intestines
Marine products processing	Viscera, heads, backbones, shells
Dairy products processing	Whey, lactose

Table 4. Antibacterial activity of lactic acid treatments against *Campylobacter*. Source: this work.

<i>Campylobacter</i> strain	Reduction	Concentration	Treated sample	Application	Exposure time	Reference
<i>C. jejuni</i> DSM 4688	1.51 log CFU/g	15%	Carcass	Immersion	30 s	Ellerbroek et al., 2007
<i>C. jejuni</i> DSM 4688	0.70 log CFU/g	15%	Carcass	Spraying	30 s	Ellerbroek et al., 2007
<i>C. jejuni</i> DSM 4688	0.31 log CFU/g	10%	Carcass	Immersion	30 s	Ellerbroek et al., 2007
<i>C. jejuni</i> DSM 4688	0.78 log CFU/g	10%	Carcass	Spraying	30 s	Ellerbroek et al., 2007
<i>C. jejuni</i> NCTC 11168	~4 log CFU/mL	0.5%	Chicken juice	Incubation	24 h	Birk et al., 2010
<i>C. jejuni</i> NCTC 11168	~6 log CFU/mL	0.5%	BHI Broth	Incubation	24 h	Birk et al., 2010
<i>C. jejuni</i> C356 ribotype	6.7-6.9 log CFU	5.7%	Broiler feed	Incubation	20 min	Heres et al., 2004
<i>C. jejuni</i> farm-isolated	nd	5.7%	Housed broiler chickens	Acidified feed	20 days	Heres et al., 2004
<i>C. jejuni</i> NCTC 11168	1.69 log CFU/mL	2.5%	Chicken skin	Immersion	1 min	Riedel et al., 2009
<i>C. jejuni</i> NCTC 11168	3.87 log CFU/mL	2.5%	Chicken skin	Immersion + storage 24 h at 5°C	1 min	Riedel et al., 2009
<i>C. jejuni</i> NCTC 11168	~0.7 log CFU/mL	2.5%	Chicken meat	Immersion	1 min	Riedel et al., 2009
<i>C. jejuni</i> NCTC 11168	~2 log CFU/mL	2.5%	Chicken meat	Immersion + storage 24 h at 5°C	1 min	Riedel et al., 2009
<i>C. jejuni</i> ATCC 33291	1.06 log MPN/cm ²	3%	Chicken leg meat	Immersion	10 min	Coşansu et al., 2010
<i>C. jejuni</i> ATCC 33291	0.36 log MPN/cm ²	1%	Chicken leg meat	Immersion	10 min	Coşansu et al., 2010
<i>C. jejuni</i> ATCC 33291	1.98 log MPN/cm ²	3%	Chicken breast meat	Immersion	10 min	Coşansu et al., 2010
<i>C. jejuni</i> ATCC 33291	1.27 log MPN/cm ²	1%	Chicken breast meat	Immersion	10 min	Coşansu et al., 2010
<i>C. jejuni</i> and <i>C. coli</i> combined	1.26 log CFU/ cm ²	5%	Chicken skin	Immersion	15 s	Meredith et al., 2013
<i>C. jejuni</i> and <i>C. coli</i> combined	0.77 log CFU/ cm ²	1%	Chicken skin	Immersion	15 s	Meredith et al., 2013
<i>C. jejuni</i> and <i>C. coli</i> combined	5.17 log CFU/ cm ²	5%	Chicken skin	Immersion + storage 15 days at 4°C	15 s	Meredith et al., 2013
<i>C. jejuni</i> and <i>C. coli</i> combined	4.25 log CFU/ cm ²	1%	Chicken skin	Immersion + storage 15 days at 4°C	15 s	Meredith et al., 2013
<i>C. jejuni</i> and <i>C. coli</i> combined	0.75 log CFU/ cm ²	5%	Chicken skin	Spraying	15 s	Meredith et al., 2013
<i>C. jejuni</i> and <i>C. coli</i> combined	2.98 log CFU/ cm ²	5%	Chicken skin	Spraying + storage 15 days at 4°C	15 s	Meredith et al., 2013
<i>C. jejuni</i> and <i>C. coli</i> combined	100% inhibition	0.05%	Bacterial inoculum	Incubation	48 h	Navarro et al., 2015
<i>C. jejuni</i> combined strains	3.43-3.03 log CFU/mL	3%	Bacterial inoculum	Incubation	24 h	Rajkovic et al., 2009
<i>C. jejuni</i>	1.81-1.85 log CFU/g	10%	Chicken leg artificially inoculated	Immersion	2 min	Rajkovic et al., 2010
<i>C. jejuni</i>	1.85-2.98 log CFU/g	10%	Chicken leg naturally contaminated	Immersion	1.5 min	Rajkovic et al., 2010
<i>C. jejuni</i>	2.05 log CFU/g	0.125%	Culture medium	Incubation	2 min	Zakariéné et al., 2015
<i>C. jejuni</i>	4.25 log CFU/g	0.25%	Culture medium	Incubation	2 min	Zakariéné et al., 2015
<i>C. jejuni</i>	5.67 log CFU/g	0.5%	Culture medium	Incubation	2 min	Zakariéné et al., 2015
<i>C. jejuni</i>	5.94 log CFU/g	2%	Culture medium	Incubation	2 min	Zakariéné et al., 2015
<i>C. jejuni</i>	1.22 log CFU/g	5%	Broiler breast fillets	Immersion	2 min	Zakariéné et al., 2015
<i>C. jejuni</i>	0.9 log CFU/g	3%	Broiler breast fillets	Immersion	2 min	Zakariéné et al., 2015