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Consumer practices and prevalence of *Campylobacter*, *Salmonella* and norovirus in kitchens from six European countries

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ABSTRACT

About 40% of foodborne infections are acquired in the home. The aim of the present study was to track contamination of pathogens during domestic food preparation and link the contamination to preparation practices. Research participants from 87 households in six European countries were observed and interviewed during shopping and preparation of a chicken and vegetable meal. The presence of *Salmonella* spp., *Campylobacter* spp. and norovirus on raw chicken, kitchen surfaces, cloths and sponges was determined.

The prevalence of *Campylobacter* on raw chicken varied from 8.3% in Norway (NO) to 80% in France (FR) and Portugal (PT), with a mean prevalence of 57%. *Campylobacter* was found on half of the products that had been frozen and appeared to be less prevalent on chicken from supermarkets than other sources. *Salmonella* was found in 8.6% of raw chicken samples, exclusively from Hungary (HU).

A relationship between observed practices and spread of pathogens to kitchen surfaces was found only for the use of cutting boards for chicken and/or vegetables. After food preparation, *Campylobacter* and *Salmonella* were isolated from 23% (samples derived from HU, RO, UK) and 8.7% (HU), respectively of cutting boards. Research participants in France and Portugal were more likely to buy products that fitted their recipe, with less need for using cutting boards. Using the same board and knife for vegetables after using it for chicken and without washing with detergent was common in Portugal and Romania, but not in the other countries. Contamination with *Campylobacter* to other kitchen surfaces or washing utensils were found in five households (UK, RO, PT). Rinsing chicken in sinks was common in three countries (PT, HU, RO), and washing vegetables in the same sink was also usual. Prevalence of Norovirus was low, with detection in one out of 451 samples. The participants' awareness of the risk posed by pathogens from raw chicken differed among the six countries, with higher awareness in Norway and the UK than the other countries studied.

In conclusion, practices intended to avoid cross-contamination from chicken to kitchen surfaces and washing utensils are not established among consumers in all European countries. Nevertheless, cross-contamination events that disseminate infectious doses of pathogens seems to be rare, probably due to the relatively low levels of pathogens in food combined with food preferences. Food safety interventions must consider the national food culture, preferences, practices and the prevalence and levels of pathogens in food. Emphasis should be on

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providing and promoting chicken products with lower risk (prevalence of pathogens, ready-to-cook) and safe use of cutting boards.

1. Introduction

Campylobacter, *Salmonella* and norovirus cause the highest numbers of foodborne diseases in Europe (EFSA and ECDC, 2019) and the US (Scallan et al., 2011). The risk of acquiring norovirus infection from food is especially associated with eating raw or frozen produce and shellfish, but also by transfer of norovirus to any type of food from sick persons preparing food to others (Bosch et al., 2018). Generally, there is limited information available on the occurrence of norovirus in domestic kitchens and the importance of cross contamination for the transfer of norovirus to foods is not clear. There is a high prevalence of *Campylobacter* in raw poultry in many countries. *Salmonella* may also be found in raw poultry, but usually with a lower prevalence than *Campylobacter* (Goncalves-Tenorio et al., 2018). In the domestic environment, foodborne infections may not only occur from eating food prepared from contaminated raw materials, but consumers may also be infected during food preparation or from foods contaminated during preparation. Consumption of undercooked poultry and cross contamination events involving *Campylobacter* and *Salmonella* from raw poultry have been associated with risk of foodborne disease (Domingues et al., 2012a, 2012b; EFSA, 2018b). In a risk assessment on *Salmonella* and *Campylobacter*, it was concluded that cross-contamination is more important for food safety than undercooking meat, based on data that the bacteria are more common on the surfaces of meat than in the interior (Luber, 2009). Furthermore, a meta-analysis of case control studies identified poor hygiene as a factor associated with higher risk of sporadically acquired campylobacteriosis (Domingues et al., 2012a). Also, in restaurants and catering kitchens, cross-contamination events have been linked to outbreaks with *Campylobacter* and *Salmonella* (Humphrey et al., 2001; Mazick et al., 2006; Patel et al., 2010). As a consequence, avoiding cross-contamination from raw poultry by changing cutting boards and washing hands is often included in food safety messages (see e.g. ANSES, 2020; CDC, 2020; Matportalen, 2019; WHO, 2020).

In Europe, 40% of outbreaks of foodborne disease occur at home, and there is an increased focus on reducing the food safety risk at the consumer stage (EFSA and ECDC, 2019). In the UK, several studies performed about 20 years ago, investigated the spread of pathogens during preparation of chicken naturally contaminated with pathogens. The studies confirm that *Campylobacter* and *Salmonella* can be transferred to the kitchen environment, with the highest risk for sites in direct contact with raw chicken, such as cutting boards and hands, but also to other items like tap handles, sponges and cloths (Cogan et al., 1999; Cogan et al., 2002; Mattick et al., 2003; Redmond and Griffith, 2003). Also a study in Ireland confirmed the transfer of *Campylobacter* to surfaces after preparation of chicken naturally contaminated with *Campylobacter* (Gorman et al., 2002). In a couple of more recent studies, one from Austria and one from the UK, no transfer of pathogens from raw chicken meat to the kitchen environment or the final chicken salad was found (Hoelzl et al., 2013; Kennedy et al., 2011). The variation between studies may reflect both that contamination of chicken and consumer practices change over time and vary between and within countries based on differences in food culture, economy, facilities, knowledge, available food products and climate. It is difficult to extrapolate from old national studies, particularly because even small differences in peoples' preferences, practices and access to safe food could lead to totally different risks. More and updated information is needed on food handling practices and the link to the risk of cross-contamination with pathogens. In addition, more information is needed to perform comprehensive risk assessments, as they in general use many assumptions on both consumer practices across different countries and how they affect the levels of pathogens. To our knowledge there is limited information in scientific publications on details about why and how cross-contamination may occur and how it could be prevented, besides focus on cleaning of hands and surfaces.

In the present transdisciplinary study, a total of 87 research participants (consumers) in six different European countries were observed during shopping and preparation of a chicken dish and a green salad, and sampling and analyses of microbial pathogens from their kitchens were performed. The goal of the work was to increase the knowledge about the relationship between consumer practices, kitchen premises, and the risk of cross-contamination with pathogens.

2. Materials and methods

2.1. Kitchen visits

2.1.1. Methodology

The methodology was established to collect information both from a sociological and microbiological perspective. Prior to the visits, steps where consumer practices could reduce the likelihood of ingesting pathogens (either from food or during preparation) from chicken and vegetables and ready to eat (RTE) food were identified by integrating HACCP with practice theory (Skuland et al., 2020). Furthermore, an observational/interview guide and a shorter checklist/guideline for microbial sampling and analyses were developed, with focus on critical steps. The research participants (hereafter participants) were observed and interviewed during shopping and food preparation; video recording was used during food preparation. Field notes as well as transcriptions from the videos were used to analyse observations (Skuland et al., 2020).

Observational studies and microbial sampling of kitchens were performed in 2018 for a total of 87 households/families in six European countries: France, Hungary, Norway, Portugal, Romania and United Kingdom (15 households per country, except for 12 households for the UK) (Skuland et al., 2020). In total there were 29, 28 and 30 households, respectively from each of the three following consumer groups: pregnant women/family with child <1 year (< 5 year for Portugal), young single men, and elderly (>70 years). The consumer groups were selected based on being vulnerable to foodborne diseases (pregnant, elderly, children) or expected to be a behavioral risk group (young men, elderly) or cautious (pregnant, parents) (Medeiros et al., 2001). Households were from rural and urban areas, with different income levels and with different levels of education. All participants were informed about research objectives, methodology, anonymization and that they could withdraw from the research process at any time, both verbally and by written information prior to the visits. All participants signed an informed consent form. A recruitment agency, Norstat (Norway), was engaged to recruit all the research participants. The participants were given an incentive of 60–170 Euro (no incentive in Hungary) for participating in the study. Ethical approvals for the work were given by the Norwegian Centre for Research Data (Norway, 55256/3/AMS), The Ethical Panel at Keele university (UK, ERP1351), The National Data Protection Commission (Portugal, 13914/ 2017), The Ethical commission of University Dunarea de Jos (Romania, RCF1548/31.08.2017), NFCSO National Food Chain Safety Office (Hungary) and the Commission Nationale de l'Informatique et des Libertés (France, 152182 REC 0717 T001).

2.1.2. Observations

The participants were first observed during shopping, where a sociologist/anthropologist and sometimes also one or two microbiologist (s) followed, observed, and interviewed the participant during shopping

in a food store. In most cases, the scientists also joined the participant during the transport back to their home, including observing unpacking of goods from the store. In some cases, the shopping study was followed directly by an observational study of food preparation in the participant's home, in other cases the kitchen observational study was performed on another day. For Hungary, the shopping and kitchens studies were performed by four MSc. students in Food safety and quality engineering, who visited 3–4 kitchens each. Kitchen visits in other countries were in generally performed by a sociologist/anthropologist and a microbiologist together. In Portugal an additional microbiologist was present for all visits, in Romania an additional person performing video recording participated in six of the visits, while in Norway an additional sociologist/microbiologist participated in four visits for training purposes. Participants were asked to purchase food in their regular store (or garden/backyard/farm) and make a dish based on raw chicken and fresh vegetables by their own choice. The informants were video filmed, audio recorded, observed and interviewed through the preparation process. Their kitchen was subjected to microbial sampling before and after food preparation, and raw chicken used was also sampled. Prior to the visits to the 87 households described in the present study, a pilot study was conducted where 1–3 households in each country were visited, enabling training in the use of the interview-, observational- and sampling guides. The experiences from the pilot studies were discussed among the participating research teams, with a focus on improving the guidelines as well as to harmonize the work between the different countries.

2.1.3. Microbial sampling

A common plan for sampling and analyses to be used in all countries was established (Table 1). Relevant surfaces were sampled before and after food preparation according to the common sampling plan. Equipment and surfaces were sampled by two methods: Using a sampling cloth (pre-wet Sodibox cloth product no. 4030/4031, size 34 × 37 cm) for bacterial analyses, and a cotton swab (premoistened in PBS) for norovirus analyses. The areas sampled with sampling cloths varied between kitchens and sample sites, from the smallest areas of about 20 cm^2 for some tap handles and up to 9000 cm^2 for some sinks and countertops. For each sample, the surface area was estimated to enable calculation of detection limits. For sampling with swabs, the areas were 100 cm^2 or the whole surface if the area was <100 cm^2. When the cutting board was sampled before food preparation, the side not to be used for food was sampled to avoid any interference with the bacteria and not to transfer neutralization fluid from cloth to the participant's food. When sampled after cutting of the chicken, the side used for the cutting was sampled. If the participant used another surface to cut the chicken, e.g. a plate; that surface was sampled. In some cases, when cutting boards were not used for chicken, the cutting board used for vegetables was sampled. For the countertop, at least the part used by the participant to prepare the food was sampled. For the sink, the whole surface was swabbed. Relevant handles (doors, fridge, drawer, cabinet, etc.) were sampled as a pooled sample. The refrigerator was sampled in 39 of the kitchens, by swabbing the shelf where RTE foods were stored and the vegetable cabinet. Samples (approximately 25 g) of the raw chicken to be used in the food preparation were cut out with a sterile knife and transferred to a sterile plastic bag or box, directly after opening of the package. A kitchen cloth or a sponge was collected from most kitchens; the item most often used to clean kitchen surfaces, according to the research subject. In five kitchens (one in Hungary and four in Portugal) a kitchen towel was retrieved too. The towels were used to dry dishes or hands or to protect the counter-top while handling raw chicken.

All samples were placed in a cooling bag and transported to the laboratory. Within 1–5 h the samples were placed at 4–6 °C for 12–24 h before microbial analysis. The cotton swabs for norovirus detection were put in the freezer when arriving at the laboratory and stored at −20 °C until analysis.

2.1.4. Microbial analyses

2.1.4.1. Sampling cloths. The sampling cloths were added 25 ml buffered peptone water (BPW) and subjected to Stomacher treatment for 1 min. For analysis of *Campylobacter*, 1 ml of the macerate was added to 9 ml Bolton selective enrichment broth, and the further analysis performed according to ISO 10272-1:2006 (ISO, 2006). For *Campylobacter*, alternative methods for confirmation and species identification, were used in addition or in substitution of the ISO-test methods in some

Table 1
Overview of sample sites and number of analyses performed.

	Campylobacter	*Salmonella*	Norovirus
Before food preparation			
Raw poultry	77*	81	1**
Cutting board	28	38	12
Tap handle	82	80	15
Refrigerator	30	39	14
Sink inside	24	38	0
Handles, pooled sample	33	43	15
Countertop	31	43	16
After food preparation			
Cutting board after use	62	69	55
Tap handle	78	79	55
Sink inside***	49	62	73
Handles, pooled sample	82	82	58
Countertop	83	84	59
Cloth#	43	41	25
Sponge#	54	46	51
Towel	5	4	2
Total	**761**	**829**	**451**

*Some samples are not reported from Romania, due to problem with the analysis
**Voluntary samples according to sampling plan show in green
***Voluntary, but mandatory if poultry washed in sink
#If participants had both cloth and sponges, the item sampled was the one used in the kitchen during visit or most commonly used by the participants. In some households both cloths and sponges were sampled.

countries: 16S rDNA and *gltA* sequencing (Norway, Romania), multiplex PCR (Portugal), API Campy (BioMérieux) and Maldi-TOF (UK) (for details about methods, see Supplementary Table S1). 1 ml of the BPW macerate was frozen at −20 °C until analysis of norovirus. For *Salmonella*, the remaining BPW macerate volume (10–15 ml) was incubated for pre-enrichment, and the further analysis carried out according to ISO 6579-1:2017 (ISO, 2017a). In Hungary, *Salmonella* was identified to the serotype level by serological tests for somatic and flagellar antigens according to the Kauffmann-White-Le Minor scheme (based on the ISO/TR 6579–3:2014 standard (ISO, 2014)) with antisera from SIFIN and Bio-Rad.

2.1.4.2. Chicken samples collected from households. The chicken sample was divided in two parts, which were added 1:10 volume BPW or 1:10 volume Bolton selective enrichment broth, for analysis of *Salmonella* and *Campylobacter*, respectively. Both samples were treated with a stomacher and the further microbial analyses performed as described for sampling cloths. For the French and Portuguese samples, in addition to the qualitative analysis for *Campylobacter*, a quantitative analysis according to ISO 10272-2:2017 was performed (ISO, 2017b).

2.1.4.3. Cloth/sponges/towel collected from households. The cloth/sponge/towel was added 25 ml BPW and treated by Stomacher for 1 min. The analyses of pathogens were performed as described above. 1 ml of the macerate was frozen at −20 °C until analysis of norovirus.

2.1.4.4. Cotton swabs for virus analysis. The cotton swabs were frozen at −20 °C until further analysis. The norovirus analysis was performed according to ISO 15216-2 : 2019 (ISO, 2019), except for Hungarian samples where an older version of the standard was used (ISO, 2013). The differences between the two versions of the standard are relatively minor, and not likely to substantially influence the results. Norovirus analysis was not performed for samples from the UK. In Hungary, hepatitis A analysis was performed according to the same standard as used for norovirus analysis (ISO, 2013).

3. Results and discussion

Considering all sample types together, a total of 73 of 761 samples were positive for *Campylobacter,* 13 of 829 positive for *Salmonella* and one of 451 samples positive for norovirus. An overview of the results for *Campylobacter* is shown in Fig. 1. The raw data from the present work have been deposited in a data repository (Møretrø et al., 2021).

3.1. Prevalence of Campylobacter and Salmonella in raw chicken

3.1.1. The role of country origin

The highest prevalence of *Campylobacter* among all sample types was

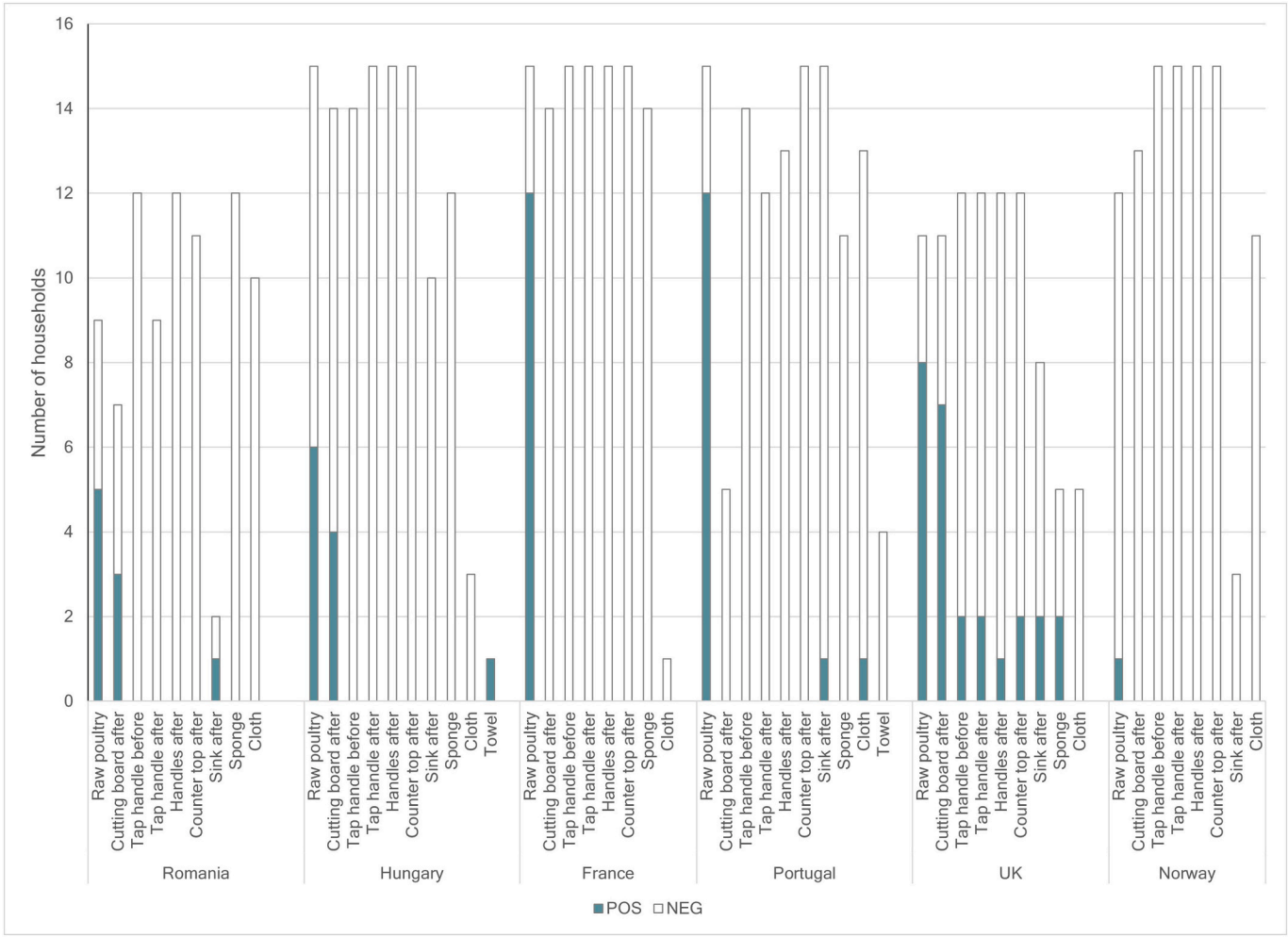

Fig. 1. *Campylobacter* positive samples in blue and negative in white from 87 kitchens, from sites sampled before and after food preparation. In addition to the samples shown, which included all *Campylobacter*-positive sample types, 145 samples that were all negative for *Campylobacter* were taken *before* food preparation from cutting board, countertop, handles, sink, or refrigerator. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

in raw chicken, with a mean prevalence of 57% (44 of 77 raw chickens were *Campylobacter* positive). In comparison, based on surveillance data, on average 38% of samples from fresh broiler meat from 22 European countries were *Campylobacter* positive in 2018 (EFSA and ECDC, 2019).

Differences between countries were found, with the highest prevalence of *Campylobacter* (80%) for France and Portugal (12 of 15 samples positive), while for Norway only one out of 12 samples (8.3%) were positive. Although the number of samples was too low in the present study to indicate reliable frequencies at national levels, the prevalence of *Campylobacter* was in general in the same range as in the national zoonotic reports from 2018 (France 80.0% for present study vs 75.3% of samples from broilers as reported by EUSR; Portugal 80.0% vs 57.9%, Hungary 40.0% vs 25%; Romania 55.5% vs 44% and the UK 66.6% vs 59.8% (EFSA, 2018b). For the official statistics, samples from processing plants are included as few or no samples were taken from retail in Hungary, Portugal and Romania. In accordance with the results obtained in the present study, the prevalence of *Campylobacter* among Norwegian chicken is known to be lower than in most European countries (Hog et al., 2016). No official sampling data of chicken meat was reported from Norway in 2018, but the prevalence in chicken flocks were reported to be in the range 3–7% (Norwegian Veterinary Institute, 2019).

The detection limit in the qualitative analysis of raw chicken varied between 10 and 25 CFU *Campylobacter* per gram depending on the size of the sample. In France, a quantitative analysis was performed, and two out of 15 samples were above the limit of quantification (>10 CFU/g), containing 60 and 180 CFU of *Campylobacter* per gram. Of the 12 positive Portuguese chicken samples, five had counts between 90 and 410 CFU/g, while the other positive samples contained <40 CFU/g (Cardoso et al., 2020). Levels of *Campylobacter* are usually low, but in the eight EU member states reporting quantitative data for 2018, 18% of raw broilers contained >3 log CFU *Campylobacter* per gram (EFSA and ECDC, 2019).

A total of 829 samples were analysed for *Salmonella*. *Salmonella* was only present in Hungarian samples and was found in seven of 15 raw chicken samples. In three chicken samples both *Campylobacter* and *Salmonella* were found. For comparison, available national surveillance data for raw broiler meat at the retail level in 2017 showed a *Salmonella* prevalence of 15.8% in Hungary, 3.8% in Romania and 0% (102 samples) in France (EFSA, 2018a).

3.1.2. The role of chicken product type

The selection of chicken product depended on the recipe/dish the participants had decided to prepare, the practicality (e.g. precut chicken), availability in the shop, preference (e.g. legs rather than breast) or diet (e.g. breast without fat). Overall, most informants (n = 46) prepared their meal from chicken breasts (one used turkey breast), followed by whole chicken (24) and chicken legs (16) when asked to make a dish based on raw chicken (Fig. 2). One consumer from Norway bought and used pre-cooked chicken. In France and Romania, the majority of the participants used whole chicken, while the majority used chicken breast in the UK, Hungary and Norway. A wide range of products were used by participants in Portugal (breasts and legs, whole chicken and whole chicken cut by the butcher at the shop). The overall *Campylobacter* prevalence of different types of chicken products were similar, with 70%, 67% and 48% for whole chicken, leg and breast, respectively (excluding Norway since only one sample tested positive). Previous studies report that products with skin have higher prevalence

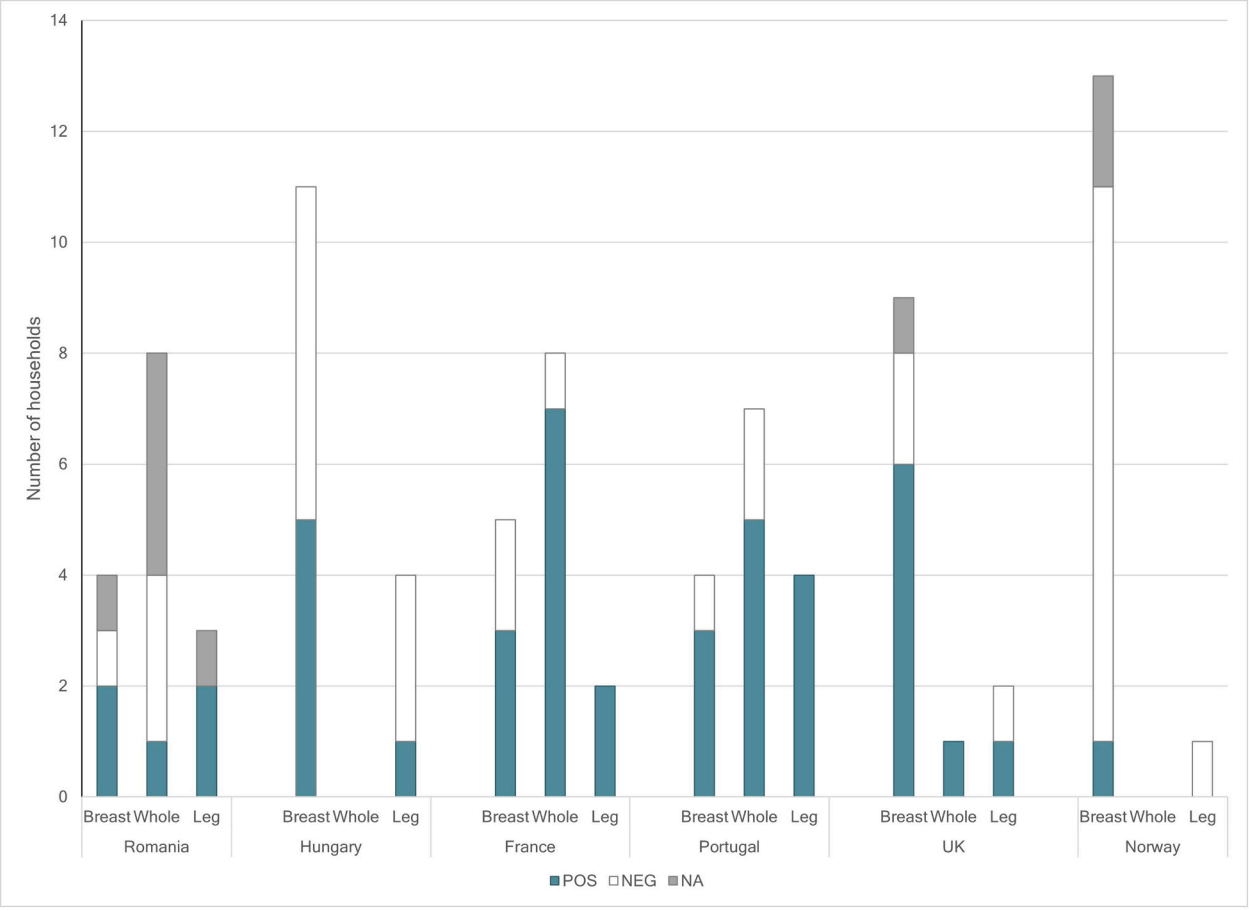

Fig. 2. Part of chicken meat used and results from *Campylobacter* analyses among 87 households from six European countries. POS; positive, NEG; negative, NA: not analysed. Five of the whole chicken in Portugal were precut in the shop.

of *Campylobacter* (Food Safety Authority of Ireland, 2016; Habib et al., 2019), but there was no difference ($p > 0.05$, Fisher's Exact Test) between products with and without skin in the present study. Among the seven *Salmonella*-positive samples of raw chicken in Hungary, five were from chicken breast and two from chicken legs.

3.1.3. The role of provenance

Regarding the provenance of chicken, 85% ($n = 73$) got raw chicken from supermarket, 9.3% from meat shop/butcher, 3.5% directly from farm and 2.3% (two participants) from their own backyard (Fig. 3). Freshness, which involved both safety and absence of spoilage, was mentioned as important for the choice of product by some participants, who were cautious about the use-by-date or froze the chicken to avoid 3–4 days storage in their fridge before consumption. However, many informants were not concerned about use-by-date dates and expressed trust in the supermarket. In Hungary and Portugal, several participants trusted more the date on pre-packed chicken in supermarket and considered it safer because it was protected from contamination, whereas others preferred buying pre-cut chicken at the butcher. Quality criteria such as brand, free range, specific label as well as local origin was mentioned by most French participants, as motivations when choosing chicken products, but never by Romanian participants. The type of farming was not important for Hungarian informants; however, some would have preferred organic chickens, but that were not currently available in the shops. Large differences in concerns about pathogens in chicken were found: While all participants from Norway and all but one from UK expressed concerns about pathogens, none of the participants from Romania and France did and only one third of the Portuguese participants mentioned pathogens in chicken. For comparison, about half of the participants in all countries (one third in Romania) were concerned about chemical hazards (antibiotics, hormones).

The *Campylobacter* prevalence (Norway excluded in analysis due to very low prevalence) was lower ($p < 0.05$, Fisher's Exact test) for chicken from supermarkets (52%) than from meat shop/butcher (100%) (meat shop used hereafter), but it should be noted that the latter group consists only of 8 households. It can still be mentioned that for the French households the chicken from meat shop and the backyard chicken had the highest levels of *Campylobacter*. The results are supported by studies in the UK where higher numbers of *Campylobacter* in chicken neck skin was found in products from small compared to large retailers. The FSA states that despite a reduction of *Campylobacter* in chickens in the UK the last years, there are still high contamination in chickens from smaller retailers, independents and butchers (Public Health England, 2019). Of the seven *Salmonella*-positive chicken from households from Hungary, six were from supermarkets and one from meat shop. Further research is needed to determine the role of the chicken production chain on the risk of *Salmonella* or *Campylobacter*.

3.1.4. The role of freezing

A freezing process is expected to reduce the numbers of *Campylobacter*, but nevertheless, viable *Campylobacter* was found in all four chickens that had been frozen in France and one frozen chicken each in the UK and Hungary. In total 13 (5 in Norway, 4 in France, 3 in the UK, 1 in Hungary) informants used chicken that had been stored frozen. One of the French informants who thawed chicken had levels above the limit of quantification with a *Campylobacter* concentration of 60 CFU/g. The products were bought fresh/chilled, or the chicken raised and slaughtered at home (one French household) and were frozen by the

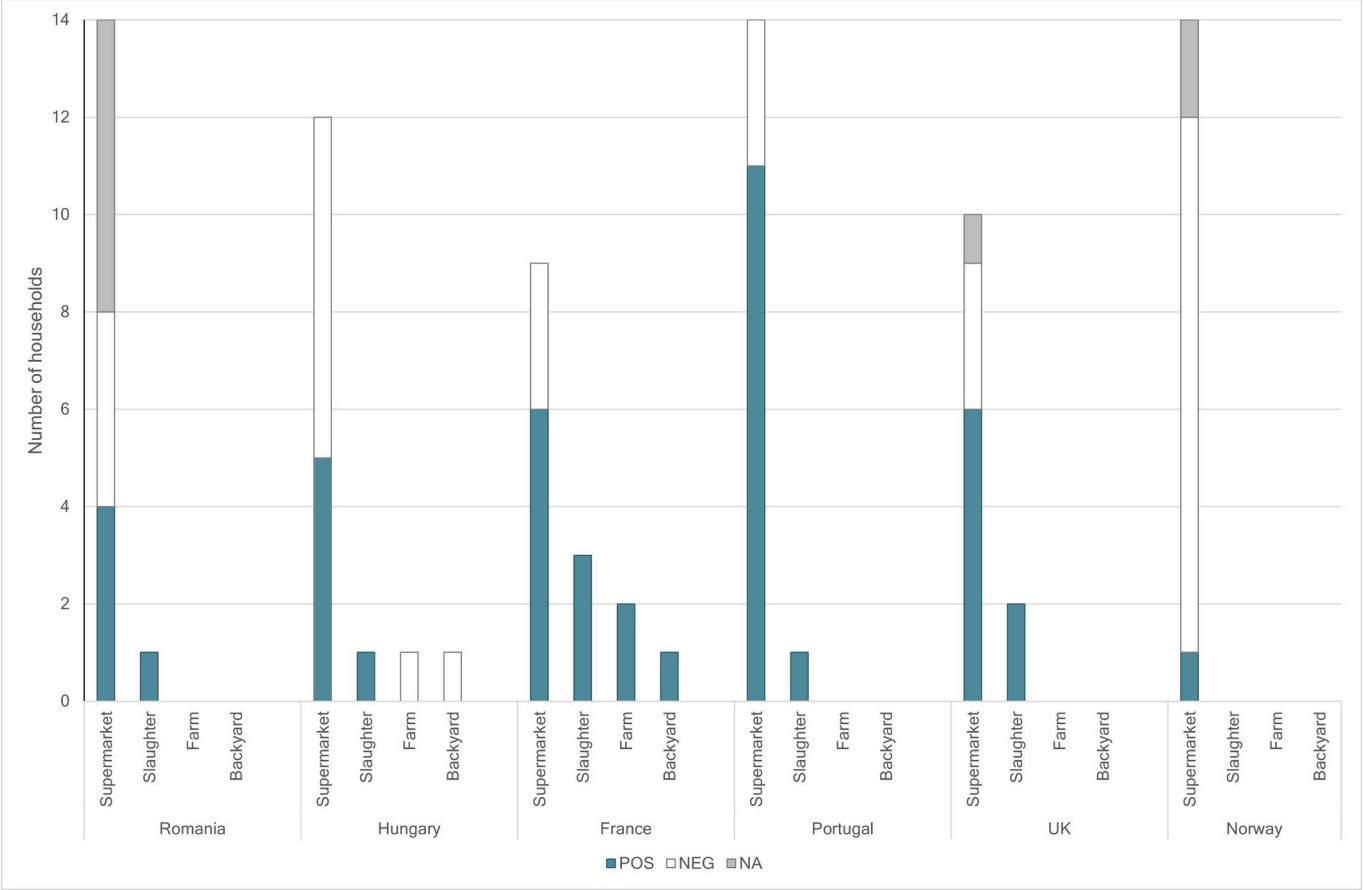

Fig. 3. Chicken provenance and prevalence of *Campylobacter* among 87 households in six European countries. POS; positive, NEG; negative, NA: not analysed. Meat shop = from meat shop/butcher; Farm = directly from farm; Backyard = own production.

participants. According to interviews with the participants, the freezing was motivated by the need for dividing large volumes and freezing them in portions, or to retain the food quality/safety because of the delay between purchase/slaughtering and cooking. Freezing for 3–7 days at −20 °C is reported to reduce the number of viable *Campylobacter* by 0.5–2 log, with a higher reduction on chicken skin than in ground chicken and chicken muscle. In general, increasing freezing time and lowering temperature will lead to higher reduction (Bhaduri and Cottrell, 2004; Harrison et al., 2013; Sukted et al., 2017). The participants freezing chicken used ordinary freezers, normally keeping a temperature as low as −20 °C, however the temperature was not monitored. Even if viable *Campylobacter* was detected in frozen chicken in the present study, freezing is still likely to have a risk reducing effect and the finding of viable *Campylobacter* in frozen chicken may indicate a high initial concentration in the chicken before freezing.

3.2. Contamination of the kitchen environment with Campylobacter and Salmonella

The high prevalence of *Campylobacter* on raw chicken, except from Norway, implies that *Campylobacter* is frequently introduced to kitchens, with a risk of transferring *Campylobacter* to the kitchen environment. The overall prevalence of *Campylobacter* in the kitchens are shown in Fig. 1, while the different contamination patterns observed are presented in Fig. 4. In the majority (65%) of kitchens where *Campylobacter* was found, it was found on raw chicken only. This shows that despite the frequent introduction of *Campylobacter* with raw chicken, in the majority of households *Campylobacter* is not spread to the kitchen environment in levels above the detection limit. It is likely that the degree of spread to kitchen surfaces during food preparation will both depend on the level of pathogens in the raw chicken and participant practices.

The products used and types of dishes prepared varied between countries, and the combination of chicken product and recipe affected the degree of handling of the raw chicken in the kitchens, which again can affect the risk of cross-contamination. In France eight participants cooked/baked whole chicken which led to reduced contact with hands and kitchen surfaces., while in Romania and Portugal the participants manipulated the whole chicken by cutting and removing the skin. Preparation of meals with chicken breasts also required handling, such as cutting from whole chicken (Romania), removing skin (Romania and Hungary), removing fat and sinews (Hungary) and cutting into smaller pieces (all countries).

3.2.1. Contamination of cutting boards

The most common contamination pattern besides detecting *Campylobacter* on raw chicken only, was the detection of *Campylobacter* on raw chicken *and* cutting boards (Figs. 1 and 4). None of the tested cutting boards were positive for *Campylobacter* or *Salmonella* before food preparation, but *Campylobacter* was found on 14 cutting boards and *Salmonella* on six cutting boards after food preparation. All the boards with *Salmonella* were from Hungarian households and among these, both *Campylobacter* and *Salmonella* were detected on three boards.

It should be noted that contamination of cutting boards was not just linked to chicken (Fig. 5). For example, in the UK, *Campylobacter* was found on three cutting boards that had been used for vegetables only and three used for chicken. The obvious explanation of the relatively frequent contamination of cutting boards (23% of boards tested across all countries) is that cutting boards are in direct contact with food during preparation. In many cases, fresh residues of chicken were visible on the cutting board sampled. Cutting boards are multifunctional, protecting other surfaces from sharp utensils but also having a hygienic function by reducing contamination to other surfaces (e.g. countertops) that may be more difficult to clean. The results show that contamination of countertops was rare, and only found in two UK households (Figs. 1 and 4).

Campylobacter was not detected on cutting boards in France or Portugal. The lack of spread could be explained both by the observed practices in these countries and low levels of pathogens on the chicken. In France, *Campylobacter* was found on 12 out of 15 raw chicken samples, but not in the kitchen environment at detectable numbers (Figs. 1 and 4). Many French participants prepared a meal with whole chicken and with limited handling and only five cut raw chicken on a cutting board. Among these, *Campylobacter* was detected on three chicken samples, but at low numbers (below 25 CFU/g). The two chickens with the highest numbers of *Campylobacter* were not cut and very rapidly handled in the kitchen. In Portugal, there was a similar situation with low *Campylobacter* concentrations (Cardoso et al., 2020) and only five participants used a cutting board for raw chicken. Here, the use of precut chicken led to limited handling and therefore also little spread to the kitchen environment.

The level of *Campylobacter* on a cutting board will depend both on the number of pathogens on the chicken and the transfer rate to the board. The transfer rates from chicken to surfaces may vary (Fravalo et al., 2009; Guyard-Nicodeme et al., 2013). In their review of the topic, Luber et al. (2006), reported transfer rates of *Campylobacter* from chicken to cutting board of 1.1%. Using this transfer rate and assuming that at an area of 100–300 cm^2 was in contact with the cutting board, the level of *Campylobacter* on the chicken must be at least in the range 8–45 CFU/cm^2 to be detected in our investigation, depending on the contact area and detection limit of the test (25–45 CFU per board). Only one third of the swab samples from cutting boards in contact with contaminated chicken (6 out of 18) were positive for *Campylobacter*, indicating levels below 45 CFU/cm^2 on the remaining chicken meat samples. However, transfer rates may vary, and we do not know the actual levels of *Campylobacter* in the chicken in the countries where only the qualitative analysis was performed.

Campylobacter was recovered from all types of cutting boards: wood, laminate, plastic and stone, and there were no statistical differences ($p > 0.05$) in *Campylobacter* prevalence between wood and other materials for cutting boards that had been in contact with raw chicken.

Transfer of *Campylobacter* from raw chicken to salad via cutting board and knives has been experimentally shown (Luber et al., 2006; Verhoeff-Bakkenes et al., 2008), and could be an important route of infection in cases with high contamination levels of the raw chicken, and/or if the *Campylobacter* strain is particularly virulent. So if these tools are not washed properly, either in a dish washing machine or with hot water with detergent after use, these pathogens may be transferred to other foods (Cogan et al., 1999; Cogan et al., 2002). Practices which may lead to pathogen transfer from raw chicken to vegetable salad were observed. Most participants prepared chicken before, or simultaneously with salad (80 of the 86 preparing salads) with no differences between countries. However, there were marked differences among the countries studied in the usage of common utensils for raw chicken and vegetables. In Portugal and Romania, most participants used the same knives and/or cutting boards for chicken and vegetables, some without washing in between and others only with a quick rinsing in running water. Only one participant in Hungary and two in Romania used separate knives for chicken and vegetables. This contrasted with the UK and Norway where only three (UK) and one (Norway) participants used the same knife/cutting board for chicken and vegetables without washing them with detergent or changing to other (machine washed) utensils. In France, the risk of cross contamination was reduced by other practices than washing in between cutting chicken and salad: Only five participants cut chicken and, among them, one prepared salad before chicken, two used fresh cut salad they ate without any preparation and one prepared lettuce without knives or cutting board. The last participant used a new cutting board for salad and cleaned the knife used for chicken with detergent. Potential cross-contamination was also observed in French households, where two participants used the same plate for thawed raw and cooked chicken, without washing, or even rinsing or wiping it, in between. This illustrates a risky practice independent of cutting the raw chicken. Luber et al. (2006), demonstrated the transfer of *Campylobacter* from raw chicken to cooked meat when the same plate was used for both.

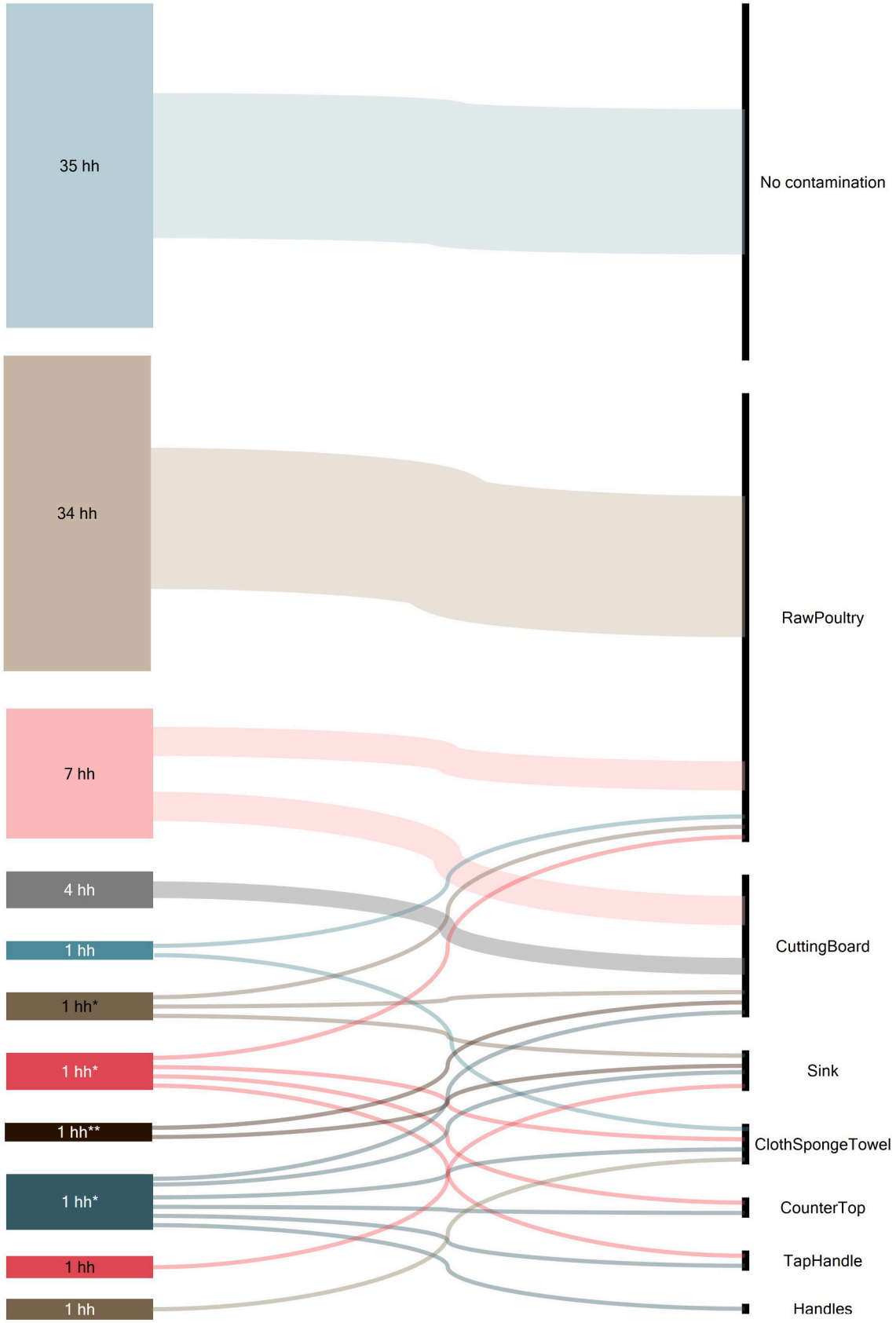

Fig. 4. Different observed contamination patterns of *Campylobacter* in 87 households (hh) in six European countries. Numbers indicate number of households with the specific contamination pattern. Multiple lines from a certain household group indicate multiple contamination sites of *Campylobacter*. Cleaning utensils cover cloth, sponge and towel. Three households from the UK and one from Romania with multiple environmental contamination sites are marked with one or two asterisks, respectively.

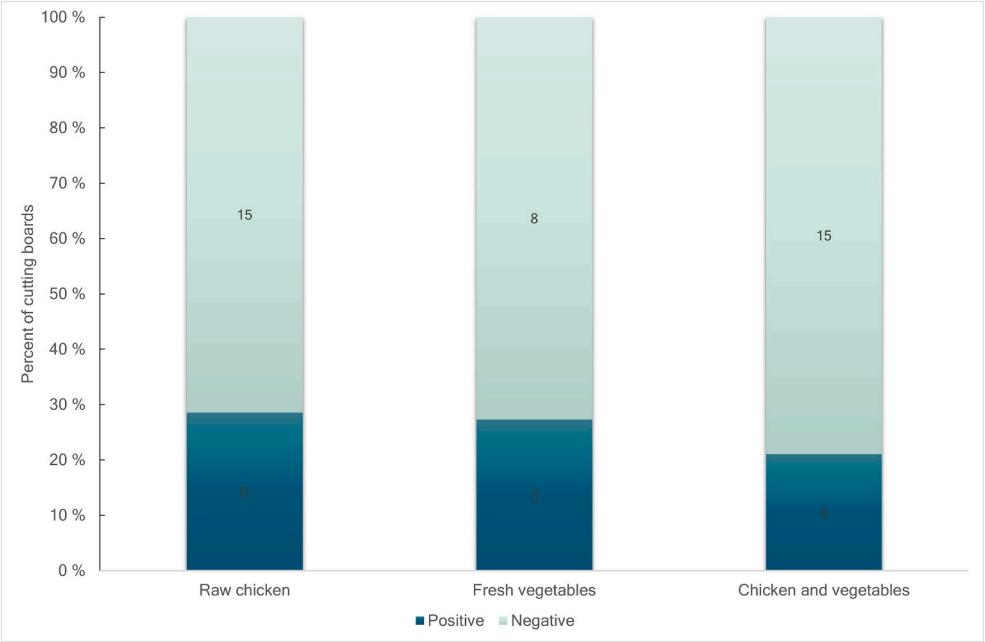

Fig. 5. Prevalence of *Campylobacter* on cutting boards after food preparation. The percentage and number of cutting boards with and without positive detection of *Campylobacter* after contact with raw chicken, fresh vegetables, or both raw chicken and fresh vegetables are shown.

3.2.2. Contamination of sinks

Campylobacter was detected in two sinks after food preparation in the UK, one in Portugal (Cardoso et al., 2020) and in a bowl used as a sink (regarded as a sink in the following text) in Romania. There were not any clear links between washing of chicken and recovering *Campylobacter* from the sink. Among 22 sink samples from households that washed chicken, two were positive (>45 CFU per sink) for *Campylobacter* and among the 15 samples taken from households not washing chicken, also two sinks (UK) were positive for the pathogen. In the latter case, the participants had used the sink to wash salad. *Campylobacter* was not detected in any of the eight sampled sinks in Hungary, where *Campylobacter*-positive chickens were washed. Regarding the prevalence of washing chickens in the present study, there was a clear difference between countries, as all (15) participants in Romania and 10 each in Hungary and Portugal washed the chicken, in contrast to no participants in Norway, France and the UK. Based on interviews with the participants from Romania, Hungary and Portugal, the motivation for washing chickens varied, being both a habit learned from their mothers and, as some explained, a hygienic measure (the product may have been touched by other people or they do not trust the hygiene in prior steps), a sensory necessity (remove the bloody/slimy layer), a health need (want to remove hormones) or a physical need (remove small bones). These motivations are in accordance with what was found in a US study (RTI International, 2019).

A laboratory study from Campden BRI concluded that rinsing of chicken should not be recommended, since bacterial numbers on the meat were not reduced and that droplets (measured using a dye) could be spread up to 70 cm during rinsing, representing a possibility of contamination of the environment (Everis and Betts, 2003). Spread of *Campylobacter* to the environment, such as the countertop after rinsing chicken was not found in the present study. In a study from US, it was suggested that the most important routes of infection were not splashes, but contamination of salad from the sink or hands, since many consumers washed salad in sinks that had been used for raw chicken (RTI International, 2019). It was observed that all informants in Romania, and 9 and 3 of the participants in Hungary and Portugal, respectively, washed salad/vegetables in the same sink (or bowl) as they washed the chicken. The sink (bowl)-positive sample in Romania was from a participant who washed the chicken in the same bowl as vegetables. After washing the chicken, the bowl was washed with standing cold water and detergent (bowl was sampled after this washing step) before adding water for washing vegetables. Overall, as for the cutting boards, it seemed like contamination with *Campylobacter* was not solely associated with fresh chicken but could also be derived from previous contact with raw chicken or other sources such as the vegetables. The prevalence of *Campylobacter* is generally lower in vegetables than in raw poultry meat (Mohammadpour et al., 2018), but as an example of a study with high prevalence, *Campylobacter* was found in 22% of ready to eat mixed salad vegetables in the UK (Phillips, 1998).

3.2.3. Contamination of cleaning utensils

Campylobacter was detected in two sponges (UK), a kitchen towel (Hungary) and in a cloth (Portugal). The sponges were sampled at the start of the visit and were not used during the visit. This means that *Campylobacter* had survived for an extended period (several hours/from last day) in the sponges. The towel was used during visit to wipe the dishes. It had been replaced at the day of sampling, so it was likely contaminated during the wiping procedure from the dishes or from contaminated hands. *Campylobacter* was not detected in the raw chicken used by this participant, but this does not exclude the possibility of the chicken as a source for the *Campylobacter*, since only a small piece of chicken was analysed and that *Campylobacter* may not be spread evenly over the whole chicken. The *Campylobacter* positive cloth from a Portuguese household was used on the cutting board to help cutting and trimming the chicken (which was *Campylobacter*-positive), and direct contact between the cloth and raw chicken was observed on several occasions. Also, there was extensive hand contact with the raw chicken, and the cloth was used to clean/dry hands after a short rinse in water.

Campylobacter has been found in used sponges, cloths and towels also in several previous investigations (Borrusso and Quinlan, 2017; Chaidez and Gerba, 2000; Enriquez et al., 1997; Mattick et al., 2003). As discussed in more detail in Section 3.2.5, our results suggested that washing utensils may act as vehicles for transmission of pathogens to clean surfaces, rather than tools for preventing cross-contamination.

3.2.4. Contamination of hand contact points

Handles and tap handles were sampled to investigate contamination of hand contact points before and during preparation of food. None of these sampling points tested positive for *Salmonella*. In two households, tap handles were contaminated with *Campylobacter* both before and after preparation of food and in one of these, handles were positive after food preparation. The practices in these households are discussed in Section 3.2.5. Continuing to cook without washing hands with soap and water was common and was observed in 54 of 87 households (Pierrine Didier and Tekla Izsó, unpublished results), but these practices did not seem to lead to detectable contamination of hand contact points.

3.2.5. Households with multiple Campylobacter positive sites

The UK households visited had the highest numbers of kitchen surfaces positive for *Campylobacter*. *Campylobacter* was found on seven cutting boards, and in three kitchens, *Campylobacter* was also found on other surfaces (Figs. 1 and 4).

Two UK kitchens stood out with detection of *Campylobacter*, not only on sponges, but also on tap handles before food preparation. This indicated that *Campylobacter* can survive on surfaces for hours in the kitchen environment. In both kitchens, *Campylobacter* were also found in several sampling points after preparation. Since these areas were only sampled after preparation of chicken and salad, it is difficult to tell if they were already contaminated before preparation of food, e.g. by using their contaminated sponge for cleaning. Few potential cross-contamination events were observed in these households: The elderly man (tertiary education, urban living area) did not express concerns about chicken being risky, but very little handling of chicken was observed during the visit. For example, he avoided to touch the chicken with his bare hands and did not use the cutting board. On the other hand, the kitchen appeared dirty and no hand washing was observed before or during food preparation, e.g. after touching the inside of lid of the chicken package. The same knife was used to lift chicken from their package and subsequently to cut spring onions on the chopping board. Due to the widespread surface contamination, it is tempting to speculate that chicken was not the main or only contamination source in this household, but that vegetables, earlier contamination, and/or the contaminated sponge contributed to contamination of the cutting board, countertop, sink, handles and tap handle. In the second UK household (young family, tertiary education, rural area, dog owner), the tap handle was *Campylobacter* positive both before and after food preparation, as well as countertop (but it is not known if they were already contaminated before food preparation). This participant was very concerned about food safety, conscious about washing hands and surfaces and used a natural antibacterial soap. Cross-contamination could have occurred from the *Campylobacter* positive chicken, as both hands were used to handle the chicken and the observed subsequent handwash was rather brief (approx. 2–3 s). Contamination could also originate from vegetables, which were cut in the hands or on the countertop. Although some potential cross-contamination events from chicken were observed in the households with multiple positive samples, the practices did not stand out as unique and could not fully explain why these households differed from others. One explanation could be that these households got food products with high levels of *Campylobacter*. Quantitative data are limited but it was reported that 15% of chickens from small retailers in the UK had *Campylobacter* levels >1000 CFU per gram of skin (Public Health England, 2019). Contamination could also have occurred from other sources than chicken, e.g. water, pets or vegetables. The prevalence of *Campylobacter* is much lower for vegetables than poultry (Mohammadpour et al., 2018), but contaminated vegetables can occasionally be introduced kitchens.

In addition to the UK kitchens, *Campylobacter* was also found in multiple sites (cutting board and a bowl used as substitute for sink) in a Romanian household. The household did not have indoor running water. After the bowl was used for washing the chicken, the bowl was washed (bowl tested positive for *Campylobacter* after washing), before being used to wash vegetables. The *Campylobacter*-positive cutting board was used both for raw chicken and vegetables. Before being used for cutting vegetables, it was rinsed in the water used for washing chicken.

3.3. Species identification of Campylobacter and Salmonella

In four countries, *Campylobacter* was identified to the species level. Overall, in the present study about similar prevalence of *C. jejuni* and *C. coli* were found. In Europe, *C. jejuni* has been reported to dominate (76.3% of *Campylobacter*) in broiler meats, followed by *C. coli* (23.5%) (EFSA and ECDC, 2019). In Hungary, the isolates (one colony per positive sample) were identified as seven *C. coli*, three *C. jejuni* and one *C. lari*. In one of the Hungarian kitchens, *C. coli* was found both in raw chicken and on the cutting board used for the same raw chicken. For Romanian samples positive for *Campylobacter*, about half were identified to the species level by sequencing, and about 50% of these were *C. jejuni* and 50% *C. coli*. The single isolate sequenced from Norwegian kitchens (raw chicken) was *C. jejuni*. In Portugal; 57% *C. coli* and 43% *C. jejuni* were found among *Campylobacter* from chicken and kitchen environment (Cardoso et al., 2020).

The Hungarian *Salmonella* isolates were serotyped as 11 isolates of *S.* Infantis and two isolates of *S.* Enteritidis. *S.* Infantis has been reported to be endemic among broilers in Hungary and is the most common *Salmonella* serovar in European poultry, and *S.* Enteritidis is also frequently associated with poultry (EFSA and ECDC, 2019; Nogrady et al., 2012). In four of the kitchens, *S.* Infantis was found both in raw chicken and on a cutting board after being in contact with the same raw chicken. The two *S.* Enteritidis isolates were from raw chicken and a cutting board used for the same raw chicken. In Hungary, three of the raw chickens contained both *C. coli* and *S.* Infantis, two of the cutting boards contained both *C. jejuni* and *S.* Infantis and one cutting board both *C. jejuni* and *S.* Enteritidis. The results indicate that *Salmonella* and *Campylobacter* were spread similarly in the Hungarian kitchens, as both were almost exclusively (one towel contained *Campylobacter*) detected on cutting boards beside raw chicken.

3.4. Prevalence of viruses

Only one of the 451 samples were positive for norovirus, a sponge from Romania. As norovirus was detected by PCR, it is not possible to state whether the virus was infective or not. The sponge was from a young family with four children, the participant claimed to change sponge every second day, and to clean sponges by soaking them in water with lemon. None of the 91 samples from Hungarian kitchens (cutting board, countertop, handles, sink, tap handles, sponges, cloths and towels sampled after food preparation) were positive for hepatitis A virus. Norovirus and hepatitis A virus are shed by infected humans, and the viruses can be found on surfaces/fomites, with increased prevalence during outbreaks (Barker et al., 2004; Boxman et al., 2011; Jones et al., 2007; Sundkvist et al., 2000). Norovirus can also be introduced to the kitchen environment through contaminated food, e.g. shellfish, leafy greens or soft red fruits (Bosch et al., 2018). The participant with the norovirus-positive sponge said she often prepares mussels at home, so that could be a potential source for the norovirus, as there had not been recent gastrointestinal problems in the household. The low observed prevalence of pathogenic viruses in the kitchens may indicate low infection prevalence of visited households and/or proper cleaning of hands and surfaces. In general, norovirus and hepatitis A virus may survive for weeks/months on surfaces (Boone and Gerba, 2007). Such surfaces may be a contamination risk, and proper handwashing and cleaning and disinfection can reduce the risk.

3.5. Overall discussion

Early studies from the UK suggested frequent cross contamination of kitchen surfaces during preparation of a chicken meal (Cogan et al.,

2002; Redmond and Griffith, 2004). However, more recent studies and the present study draw another picture. In an Austrian study in 2013, *Campylobacter* was not detected in the salad after preparation of chicken salad, although the pathogen was detected from 80% of the raw chicken samples and poor hand washing was observed (Hoelzl et al., 2013). The authors concluded that low levels of the pathogen on chicken combined with proper cleaning of the cutting board could explain lack of detectable cross contamination. In a UK study from 2011, with 60 participants, *Campylobacter* was not detected on any kitchen surfaces or in the chicken salad after preparation (Kennedy et al., 2011). Similarly, in the present study, the introduction of *Campylobacter* to kitchens through the chicken was relatively common in most countries, but spread to other surfaces than cutting boards was rare. Exclusively in Hungarian households also the introduction of *Salmonella* through raw chicken was common, but spread in the kitchen was limited. Widespread contamination of kitchen surfaces, similar to the early UK studies, was found only in two out of 86 households sampled, both in UK, but the link to chicken preparation practices in these kitchens was weak. Practices that could potentially spread pathogens from chicken to kitchen surfaces or leafy greens were quite common in most countries. Still, it was not possible to find a correlation between contamination of kitchen surfaces and consumer practices during chicken preparation, even after direct contact between surfaces and with chicken or chicken juices. One reason was that these surfaces in some cases were contaminated without contact with chicken, and the origin was more likely contaminated salad or a contaminated sponge. Also, low levels of *Campylobacter* in most raw chicken, low and highly variable transfer rates of *Campylobacter* from raw chicken to surfaces (Fravalo et al., 2009; Guyard-Nicodeme et al., 2013), rapid die-off of *Campylobacter* on dry surfaces (Møretrø et al., 2020) and a relative high detection limit in the present study due to sampling for several pathogens simultaneously could have contributed to a lack of correlation between practices and contamination patterns.

Therefore, looking at the present and most recent observation studies, it seems like acquiring a foodborne infection due to cross contamination issues from chicken is a very unlikely event. In the majority of households investigated, no cross-contamination from chicken to environments or salad was found. In situations where the levels of pathogens on raw materials are high the risk may still be significant. In a US study where consumers prepared a chicken and salad meal using heavily contaminated (10^7 to 10^{10} CFU of *E. coli*) chicken legs, the model microorganism was detected in 20% (not rinsing chicken) to 26% (rinsing chicken) of the final salads. Contamination of the salad was primarily associated with hand-facilitated cross-contamination (RTI International, 2019), which may be a more important transmission route than kitchen surfaces. Keeping levels of pathogens low (below 1000 CFU) would probably reduce risk from cross-contamination via kitchen surfaces to a level that can be regarded as insignificant. However, this is still not the situation in Europe. In the eight EU member states reporting quantitative data for 2018, 18% of raw broilers contained 1000 CFU *Campylobacter* per gram (EFSA and ECDC, 2019). Also, levels for *Salmonella* are usually low, but levels of 1000–10,000 CFU per chicken filet have been reported (Straver et al., 2007).

Consumer observation studies, such as the present study, are resource demanding, from establishing a transdisciplinary methodology, performing the visits and subsequent analysis of consumer and microbial results. The present study includes a similar number of households/participants as former studies but covered six countries and three different consumer groups. The number of households (87) in this study is limited and not a representative sample. Instead the study included a strategic sample of consumer groups where the number of participants was balanced against the aim to collect in-depth data to sufficiently investigate how consumer practices spread pathogens to kitchen surfaces (Wills et al., 2015). Also, one should be aware that the presence of observers may affect the consumer practices, although observations are considered as more reliable than self-reported practices (Contzen et al., 2015; Dharod et al., 2007; Skuland et al., 2020). Nevertheless, striking differences were found between countries that should not be overlooked.

Interestingly, high prevalence of *Campylobacter* or *Salmonella* in chicken products in a country was not at all associated with higher awareness of food safety issues nor more hygienic practices. As an example, in France (12/15 chicken contaminated) no participants expressed worries about pathogens, while in Norway (1/15 chicken contaminated) it was mentioned by all participants that chicken may contain pathogens. Participants from countries with large differences in the prevalence of *Campylobacter*, such as UK and Norway, were similarly concerned about pathogens and practices to prevent cross-contamination were also quite similar. In the other countries, awareness was low and practices that could lead to cross-contamination more common. Differences among countries in hygiene during preparation were evident, and some hygienic practices, such as using clean knives and cutting boards for salad, seemed to be more associated with the risk perception than the actual risk. The lack of common practices preventing cross-contamination in countries with high prevalence (and sporadically high levels) of pathogens is worrying. Unfortunately, changing such practices, especially those related to hygiene, through information campaigns are not always successful (RTI International, 2019) and alternative strategies should be considered.

To reduce risk without changing preparation practices, consumers could, at least in theory, select products with low prevalence and levels of pathogens. The prevalence of *Campylobacter* and *Salmonella* in poultry is low in some countries, e.g. Norway, leading to less risk of acquiring foodborne illness from poultry. In 2018 there were about 12% positive samples of *Salmonella* at the retail level for fresh broiler meat in the EU. There has been a decreasing trend in prevalence of *Salmonella* in broiler flocks in Europe, with a prevalence of about 3.5% in broiler flocks and most countries meet the criteria of <1% positive flocks for targeted serovars (EFSA and ECDC, 2019). For most European countries the prevalence of *Campylobacter* is high, although the recent EU microbial criteria on *Campylobacter* in broiler carcasses may lead to a decrease when fully implemented (European Commission, 2017). Although there are some differences in prevalence of pathogens between different poultry products and sources, there is limited information available for consumers on how to select safer products/variants of raw poultry. Based on the results in the present study, and on a large study in the UK, there were indications that the source of the chicken could play a role, with less *Campylobacter* found in chicken from supermarkets than from meat shops or backyards (present study), and more *Campylobacter* from small retailers (UK study) (Public Health England, 2019). However, more research is necessary to get validated information of the role of origin or product type on prevalence of *Campylobacter*. Freezing may reduce the number of viable *Campylobacter* (Bolton et al., 2014; Sandberg et al., 2005; Sukted et al., 2017), but it is not clear if this is recognized by consumers or if this knowledge influences their selection of product, as buying frozen products or freezing chicken by consumers themselves seem to be based on other motivations.

Although perceived risk seemed to be associated with safer practices (e.g. not using the same knife and cutting board for salad as chicken), it was not at all a prerequisite. Lower surface contamination in the kitchen was overall associated with chicken preparation without cutting, either because of the recipe (baking a whole chicken as in households in France) or because of the product purchased (precut chicken as in Portugal households). Since information sometimes have limited effect, the availability of such products which limits the necessity of handling (touching, cutting, marinating etc.) could permit consumers to find the one most adapted to their recipe and less handling of raw chicken may lower the risk. It is the manipulations that increase the risk, often being linked to ingrained habits (e.g. removing the skin from the chicken or washing chicken). These habits varied among countries and were rarely associated with a spoken intention to limit the health risk, although reducing risk may have been related to health and safety when these habits were established.

Although information campaigns to change behaviours that are habitual may have limited effect, consumers should get science-based information about risks and how to handle these risks. In the present study, more differences were found between countries than between consumer groups, indicating that practices are shared between generations. Some practices were common across countries. The vast majority (80 of 86) of participants prepared raw chicken before, or simultaneously with salad. Preparing salad before chicken will have a risk-reducing effect but would require a major change in food preparation practices among most consumers and is thus most likely difficult to change through information.

4. Conclusions

The prevalence of *Campylobacter* in raw chicken was high in most countries, still the spreading to the kitchen environment besides cutting boards was limited. Several practices that has been associated with cross-contamination were observed, but often in certain countries only. The observation of less risky practices by consumers in some countries, indicates that it may be possible to reduce cross-contamination, but that cultural and other type of barriers need to be overcome to obtain changes.

The prevalence of norovirus in the kitchens was very low. Technical limitations inherent to procedures employed for virus recovery from surfaces or kitchen cloths/sponges may contribute to the low prevalence reported.

4.1. Advice to food authorities

It seems like there is a link between risky behaviour and low awareness about pathogens on chicken, indicating that education or risk communication can potentially change behaviour in a direction that reduces risk. Many food authorities communicate that surfaces that has been in direct contact with chicken (e.g. cutting boards and hands) need to be properly washed before contact with salads, bread and other ready-to eat foods. This advice is strongly supported by the findings in this investigation. From a food safety standpoint, other practices observed could also be targeted to reduce risk. Consumers should also be informed that preparing the salad before the chicken, avoiding direct contact of ready-to-eat foods with the sink and, to selecting chicken product with lower levels of pathogens (e.g. frozen chicken or a product that requires limited handling such as pre-cut chicken) also reduce risk of serious foodborne illness. However, it should be considered that barriers such as product availability and food preparation habits and food preferences are limiting such risk reduction in practice.

4.2. Research

More investigations on the prevalence of *Campylobacter* and *Salmonella* in chicken from small retailers/slaughters is needed. Also, kinetics of inactivation of *Campylobacter* in different chicken products in domestic freezers should be studied. Studying cross contamination after preparation of chickens with high levels of *Campylobacter* will give better information about the risk in worst-case situations.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

ANSES, 2020. Kitchen hygiene tips, https://www.anses.fr/en/content/kitchen-hygiene-tips.

Barker, J., Vipond, I.B., Bloomfield, S.F., 2004. Effects of cleaning and disinfection in reducing the spread of Norovirus contamination via environmental surfaces. J. Hosp. Infect. 58, 42–49.

Bhaduri, S., Cottrell, B., 2004. Survival of cold-stressed *Campylobacter jejuni* on ground chicken and chicken skin during frozen storage. Appl. Env. Microbiol. 70, 7103–7109.

Bolton, D., Meredith, H., Walsh, D., McDowell, D., 2014. Poultry food safety control interventions in the domestic kitchen. J. Food Saf. 34, 34–41.

Boone, S.A., Gerba, C.P., 2007. Significance of fomites in the spread of respiratory and enteric viral disease. Appl. Env. Microbiol. 73, 1687–1696.

Borrusso, P.A., Quinlan, J.J., 2017. Prevalence of pathogens and indicator organisms in home kitchens and correlation with unsafe food handling practices and conditions. J. Food Prot. 80, 590–597.

Bosch, A., Gkogka, E., Le Guyader, F.S., Loisy-Hamon, F., Lee, A., van Lieshout, L., Marthi, B., Myrmel, M., Sansom, A., Schultz, A.C., Winkler, A., Zuber, S., Phister, T., 2018. Foodborne viruses: detection, risk assessment, and control options in food processing. Int. J. Food Microbiol. 285, 110–128.

Boxman, I.L.A., Verhoef, L., Dijkman, R., Hagele, G., Loeke, N., Koopmans, M., 2011. Year-round prevalence of norovirus in the environment of catering companies without a recently reported outbreak of gastroenteritis. Appl. Env. Microbiol. 77, 2968–2974.

Cardoso, M.J., Ferreira, V., Truninger, M., Maia, R., Teixeira, P., 2020. Cross-contamination events of *Campylobacter* spp. in domestic kitchens associated with consumer handling practices of raw poultry. Int. J. Food Microbiol. In press 108984.

CDC, 2020. Four steps to food safety: Clean, separate, cook, chill, https://www.cdc.gov/foodsafety/keep-food-safe.html.

Chaidez, C., Gerba, C.P., 2000. Bacteriological analysis of cellulose sponges and loofahs on domestic kitchens from a developing country. Dairy Food Env. San. 20, 834–837.

Cogan, T.A., Bloomfield, S.F., Humphrey, T.J., 1999. The effectiveness of hygiene procedures for prevention of cross-contamination from chicken carcases in the domestic kitchen. Lett. Appl. Microbiol. 29, 354–358.

Cogan, T.A., Slader, J., Bloomfield, S.F., Humphrey, T.J., 2002. Achieving hygiene in the domestic kitchen: the effectiveness of commonly used cleaning procedures. J. Appl. Microbiol. 92, 885–892.

Contzen, N., De Pasquale, S., Mosler, H.J., 2015. Over-reporting in handwashing self-reports: potential explanatory factors and alternative measurements. PLoS One 10.

Dharod, J.M., Perez-Escamilla, R., Paciello, S., Bermudez-Millan, A., Venkitanarayanan, K., Damio, G., 2007. Comparison between self-reported and observed food handling behaviors among Latinas. J. Food Prot. 70, 1927–1932.

Domingues, A.R., Pires, S.M., Halasa, T., Hald, T., 2012a. Source attribution of human campylobacteriosis using a meta-analysis of case-control studies of sporadic infections. Epidemiol. Infect. 140, 970–981.

Domingues, A.R., Pires, S.M., Halasa, T., Hald, T., 2012b. Source attribution of human salmonellosis using a meta-analysis of case-control studies of sporadic infections. Epidemiol. Infect. 140, 959–969.

EFSA, 2018a. Biological Hazards Report. EFSA. https://www.efsa.europa.eu/en/biological-hazards-data/reports.

EFSA, 2018b. The European Union summary report on trends and sources of zoonoses, zoonotic agents and food-borne outbreaks in 2017. EFSA J. 16, 5500.

EFSA, ECDC, 2019. The European Union one health 2018 zoonoses report. EFSA J. 17, e05926.

Enriquez, C.E., Enriques-Gordillo, R., Kennedy, D.I., Gerba, C.P., 1997. Bacteriological survey of used cellulose sponges and cotton dishcloths from domestic kitchens. Dairy Food Env. San. 17, 20–24.

European Commission, 2017. Commission Regulation (EU) 2017/1495 of 23 August 2017 amending Regulation (EC) No 2073/2005 as regards *Campylobacter* in broiler carcases (Text with EEA relevance.), in: European Union (Ed.). https://eur-lex.europa.eu/eli/reg/2017/1495/oj.

Everis, L., Betts, G., 2003. Microbial risk factors associated with the domestic handling of meat: sequential transfer of bacterial contamination. R&D Report No. 170. Cambden BRI, Chipping Cambden, UK.

Food Safety Authority of Ireland, 2016. Survey to determine the prevalence of *Campylobacter* and *Salmonella* on raw chicken at retail sale in Ireland in 2011 (11NS2) Monitoring and surveillance series 2016, pp. 1–21.

Fravalo, P., Laisney, M.J., Gillard, M.O., Salvat, G., Chemaly, M., 2009. *Campylobacter* transfer from naturally contaminated chicken thighs to cutting boards is inversely related to initial load. J. Food Prot. 72, 1836–1840.
Goncalves-Tenorio, A., Silva, B.N., Rodrigues, V., Cadavez, V., Gonzales-Barron, U., 2018. Prevalence of pathogens in poultry meat: a meta-analysis of European published surveys. Foods 7.
Gorman, R., Bloomfield, S., Adley, C.C., 2002. A study of cross-contamination of food-borne pathogens in the domestic kitchen in the Republic of Ireland. Int. J. Food Microbiol. 76, 143–150.
Guyard-Nicodeme, M., Tresse, O., Houard, E., Jugiau, F., Courtillon, C., El Manaa, K., Laisney, M.J., Chemaly, M., 2013. Characterization of *Campylobacter* spp. transferred from naturally contaminated chicken legs to cooked chicken slices via a cutting board. Int. J. Food Microbiol. 164, 7–14.
Habib, I., Coles, J., Fallows, M., Goodchild, S., 2019. A baseline quantitative survey of *Campylobacter* spp. on retail chicken portions and carcasses in metropolitan Perth, Western Australia. Foodborne Pathog. Dis. 16, 180–186.
Harrison, D., Corry, J.E.L., Tchorzewska, M.A., Morris, V.K., Hutchison, M.L., 2013. Freezing as an intervention to reduce the numbers of campylobacters isolated from chicken livers. Lett. Appl. Microbiol. 57, 206–213.
Hoelzl, C., Mayerhofer, U., Steininger, M., Bruller, W., Hofstadter, D., Aldrian, U., 2013. Observational trial of safe food handling behavior during food preparation using the example of *Campylobacter* spp. J. Food Prot. 76, 482–489.
Hog, B.B., Sommer, H.M., Larsen, L.S., Sorensena, A.I.V., David, B., Hofshagen, M., Rosenquist, H., 2016. Farm specific risk factors for *Campylobacter* colonisation in Danish and Norwegian broilers. Prev. Vet. Med. 130, 137–145.
Humphrey, T.J., Martin, K.W., Slader, J., Durham, K., 2001. *Campylobacter* spp. in the kitchen: spread and persistence. J. Appl. Microbiol. 90, 115s-120s.
ISO, 2006. ISO 10272-1:2006 Microbiology of Food and Animal Feeding Stuffs — Horizontal Method for Detection and Enumeration of Campylobacter spp. — Part 1: Detection Method. ISO.
ISO, 2013. ISO 15216-2:2013. Microbiology of Food and Animal Feed — Horizontal Method for Determination of Hepatitis A Virus and Norovirus in Food Using Real-time RT-PCR — Part 2: Method for Qualitative Detection.
ISO, 2014. ISO/TR 6579–3:2014. Microbiology of the Food Chain — Horizontal Method for the Detection, Enumeration and Serotyping of Salmonella — Part 3: Guidelines for Serotyping of Salmonella spp.
ISO, 2017a. ISO 6579-1:2017. Microbiology of the Food Chain — Horizontal Method for the Detection, Enumeration and Serotyping of Salmonella — Part 1: Detection of Salmonella spp. ISO.
ISO, 2017b. ISO 10272-2:2017. Microbiology of the Food Chain — Horizontal Method for Detection and Enumeration of Campylobacter spp. — Part 2: Colony-count Technique. ISO.
ISO, 2019. ISO 15216-2:2019. Microbiology of the Food Chain — Horizontal Method for Determination of Hepatitis A Virus and Norovirus Using Real-time RT-PCR — Part 2: Method for Detection.
Jones, E.L., Kramer, A., Gaither, M., Gerba, C.P., 2007. Role of fomite contamination during an outbreak of norovirus on houseboats. Int. J. Environ. Health Res. 17, 123–131.
Kennedy, J., Nolan, A., Gibney, S., O'Brien, S., McMahon, M.A.S., McKenzie, K., Healy, B., McDowell, D., Fanning, S., Wall, P.G., 2011. Deteminants of cross-contamination during home food preparation. Br. Food J. 113, 280–297.
Luber, P., 2009. Cross-contamination versus undercooking of poultry meat or eggs - which risks need to be managed first? Int. J. Food Microbiol. 134, 21–28.
Luber, P., Brynestad, S., Topsch, D., Scherer, K., Bartelt, E., 2006. Quantification of *Campylobacter* species cross-contamination during handling of contaminated fresh chicken parts in kitchens. Appl. Env. Microbiol. 72, 66–70.
Matportalen, 2019. Kjøkkenhygiene, https://www.matportalen.no/matsmitte_og_hygiene/tema/kjokkenhygiene/.
Mattick, K., Durham, K., Hendrix, M., Slader, J., Griffith, C., Sen, M., Humphrey, T., 2003. The microbiological quality of washing-up water and the environment in domestic and commercial kitchens. J. Appl. Microbiol. 94, 842–848.
Mazick, A., Ethelberg, S., Nielsen, E.M., Mølbak, K., Lisby, M., 2006. An outbreak of *Campylobacter jejuni* associated with consumption of chicken, Copenhagen, 2005. Euro Surveill. 11, 137–139.
Medeiros, L.C., Hillers, V.N., Kendall, P.A., Mason, A., 2001. Food safety education: what should we be teaching to consumers? J. Nutr. Educ. 33, 108–113.
Mohammadpour, H., Berizi, E., Hosseinzadeh, S., Majlesi, M., Zare, M., 2018. The prevalence of *Campylobacter* spp. in vegetables, fruits, and fresh produce: a systematic review and meta-analysis. Gut Pathog. 10.
Møretrø, T., Martens, L., Teixeira, P., Ferreira, V.B., Maia, R., Maugesten, T., Langsrud, S., 2020. Is visual motivation for cleaning surfaces in the kitchen consistent with a hygienically clean environment? Food Control 111, 107077.
Møretrø, T., Nguyen-The, C., Didier, P., Maître, I., Izsó, T., Kasza, G., Skuland, S., Cardoso, M., Ferreira, V., Teixeira, P., Borda, D., Dumitrascu, L., Neagu, C., Nicolau, A., Anfruns-Estrada, E., Foden, M., Voysey, P., Langsrud, S. 2021. Microbiological and observational data from 87 European kitchens, Mendeley Data, v1, https://doi.org/10.17632/gxg5b7j6bg.1.
Nogrady, N., Kiraly, M., Davies, R., Nagy, B., 2012. Multidrug resistant clones of *Salmonella* Infantis of broiler origin in Europe. Int. J. Food Microbiol. 157, 108–112.
Norwegian Veterinary Institute, 2019. The Norwegian Zoonoses Report 2018. https://www.vetinst.no/rapporter-og-publikasjoner/rapporter/2019/the-norwegian-zoonoses-report-2018.
Patel, M.K., Chen, S., Pringle, J., Russo, E., Vinaras, J., Weiss, J., Anderson, S., Sunenshine, R., Komatsu, K., Schumacher, M., Flood, D., Theobald, L., Bopp, C., Wannemuehler, K., White, P., Angulo, F.J., Behravesh, C.B., 2010. A prolonged outbreak of *Salmonella* Montevideo infections associated with multiple locations of a restaurant chain in Phoenix, Arizona, 2008. J. Food Prot. 73, 1858–1863.
Phillips, C.A., 1998. The isolation of *Campylobacter* spp. from modified atmosphere packaged foods. Int. J. Environ. Health Res. 8, 215–221.
Public Health England, 2019. A microbiological survey of *Campylobacter* contamination in fresh whole UK-produced chilled chickens at retail sale. https://www.food.gov.uk/research/foodborne-diseases/a-microbiological-survey-of-campylobacter-contamination-in-fresh-whole-uk-produced-chilled-chickens-at-retail-sale-y234.
Redmond, E.C., Griffith, C.J., 2003. Consumer food handling in the home: a review of food safety studies. J. Food Prot. 66, 130–161.
Redmond, E.C., Griffith, C.J., 2004. Microbiological and observational analysis of cross contamination risks during domestic food preparation. Br. Food J. 106, 581–597.
RTI International, 2019. Food safety consumer research project: meal preparation experiment related to poultry washing, https://www.fsis.usda.gov/wps/wcm/connect/9bb3a252-e12e-40e5-b76b-cb46a2322c3f/FSCRP_Year+2_Final_Aug2019.pdf?MOD=AJPERES.
Sandberg, M., Hofshagen, M., Ostensvik, O., Skjerve, E., Innocent, G., 2005. Survival of *Campylobacter* on frozen broiler carcasses as a function of time. J. Food Prot. 68, 1600–1605.
Scallan, E., Hoekstra, R.M., Angulo, F.J., Tauxe, R.V., Widdowson, M.A., Roy, S.L., Jones, J.L., Griffin, P.M., 2011. Foodborne illness acquired in the United States-major pathogens. Emerg. Infect. Dis. 17, 7–15.
Skuland, S.E., Borda, D., Didier, P., Dumitraşcu, L., Ferreira, V., Foden, M., Langsrud, S., Maître, I., Martens, L., Møretrø, T., Nguyen-The, C., Nicolau, A. I., Nunes, C., Rosenberg, T. G., Teigen, H. M., Teixeira, P., Truninger, M., 2020. European Food Safety: Mapping Critical Food Practices and Cultural Differences in France, Norway, Portugal, Romania and the UK, in: Skuland, S.E. (Ed.). SIFO report, Oslo. https://fagarkivet.oslomet.no/handle/20.500.12199/3112.
Straver, J.M., Janssen, A.F.W., Linnemann, A.R., van Boekel, M.A.J.S., Beumer, R.R., Zwietering, M.H., 2007. Number of *Salmonella* on chicken breast filet at retail level and its implications for public health risk. J. Food Prot. 70, 2045–2055.
Sukted, N., Tuitemwong, P., Erickson, L.E., Luangtongkum, T., Chokesajjawatee, N., Tuitemwong, K., 2017. Reducing risk of campylobacteriosis from poultry: a mini review. Int. J. Food Process. Technol. 4, 41–52.
Sundkvist, T., Hamilton, G., Hourihan, B., Hart, I., 2000. Outbreak of hepatitis a spread by contaminated drinking glasses in a public house. Comm. Dis. Publ. Health 3, 60–62.
Verhoeff-Bakkenes, L., Beumer, R.R., de Jonge, R., van Leusden, F.M., de Jong, A.E.I., 2008. Quantification of *Campylobacter jejuni* cross-contamination via hands, cutlery, and cutting board during preparation of a chicken fruit salad. J. Food Prot. 71, 1018–1022.
WHO, 2020. Five keys to safer food. https://www.who.int/foodsafety/publications/consumer/en/5keys_en.pdf?ua=1.
Wills, W.J., Meah, A., Dickinson, A.M., Short, F., 2015. I don't think I ever had food poisoning. A practice-based approach to understanding foodborne disease that originates in the home. Appetite 85, 118–125.