Contamination des poulets de chair par *Campylobacter*

Avis de l'Anses
Collective Expert Appraisal Report

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**Saisine n° 2016-SA-0183**
Saisine liée n°2001-SA-0313

Le directeur général

Maisons-Alfort, le 12 octobre 2018

AVIS
de l'Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail

relatif à l'état des connaissances sur la contamination des poulets de chair par *Campylobacter* et à l'évaluation de l'impact des interventions à différents stades de la chaîne alimentaire en France

L'Anses met en œuvre une expertise scientifique indépendante et pluraliste.
L'Anses contribue principalement à assurer la sécurité sanitaire dans les domaines de l'environnement, du travail et de l'alimentation et à évaluer les risques sanitaires qu'ils peuvent comporter.
Elle contribue également à assurer d'une part la protection de la santé et du bien-être des animaux et de la santé des végétaux et d'autre part à l'évaluation des propriétés nutritionnelles des aliments.

Elle fournit aux autorités compétentes toutes les informations sur ces risques ainsi que l'expertise et l'appui scientifique technique nécessaires à l'élaboration des dispositions législatives et réglementaires et à la mise en œuvre des mesures de gestion du risque (article L.1313-1 du code de la santé publique).

Ses avis sont publiés sur son site internet.

L'Anses a été saisie le 11 août 2016 par la Direction générale de l'alimentation (DGAL) d'une demande d'avis relatif à l'actualisation des connaissances sur la contamination par *Campylobacter* des volailles de chair afin d'établir une analyse coûts/bénéfices des mesures de maîtrise aux différentes étapes de la chaîne alimentaire au niveau national.

1. CONTEXTE ET OBJET DE LA SAISINE

En France et en Europe, *Campylobacter* est la cause la plus fréquente de zoonoses alimentaires d'origine bactérienne avec une augmentation constante du nombre de cas au cours des quinze dernières années. Les plans de surveillance français montrent un niveau élevé de contamination par *Campylobacter* des volailles et des produits avicoles. En Europe, 50 à 80% des campylobactérioses humaines sont attribuées au réservoir « volailles » dans son ensemble selon l'Autorité européenne de sécurité des aliments (EFSA, 2011). À ce jour, la France n'a pas mis en place de plan national de maîtrise pour *Campylobacter* alors que plusieurs autres États membres de l'UE l'ont réalisé depuis plusieurs années, par exemple le Danemark (Rosenquist *et al.* 2009) et la Suède (Hansson *et al.* 2007).

Dans ce contexte, l'Anses a été sollicitée par la DGAL pour évaluer le risque de campylobactériose humaine et modéliser l'impact d'éventuelles mesures de maîtrise dans la filière volailles de chair.

La demande de la DGAL portait sur les points suivants :

1 / une **revue des connaissances et collecte des données** sur :

- les nouvelles études menées depuis le dernier avis de l'EFSA en 2011 sur la contamination des poulets de chair par *Campylobacter*, les différentes mesures de maîtrise du risque et leur l'efficacité. Cette synthèse visera en particulier les résultats obtenus au niveau

Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail,
14 rue Pierre et Marie Curie, 94701 Maisons-Alfort Cedex
Téléphone : + 33 (0)1 49 77 13 50 - Télécopie : + 33 (0)1 49 77 26 26 - www.anses.fr

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national ; elle pourra être également élargie aux autres filières de production de volailles de chair, si pertinent ;

- l'impact des pratiques des consommateurs sur le risque de campylobactériose ;

- la disponibilité et les contraintes des méthodes analytiques relatives à *Campylobacter*.

2 / Une **évaluation de l'impact des mesures de maîtrise sur le risque** de campylobactériose attribuable à la viande de volailles. Cette évaluation s'appuiera notamment sur le modèle d'analyse de risque quantitative développé par l'EFSA en 2011.

3 / Une **analyse coûts/bénéfices** pour différents scénarios de maîtrise le long de la chaîne alimentaire (de l'élevage au consommateur), adaptée à la filière française de volailles de chair, en s'appuyant notamment sur le modèle publié en 2012 par les entreprises ICF GHK et ADAS pour le compte de la Commission européenne.

Les experts ont travaillé sur les questions ci-dessus, avec les exceptions suivantes :

• La disponibilité et les contraintes des méthodes analytiques pour la détection et le dénombrement de *Campylobacter* n'ont pas été pris en compte car elles n'ont pas d'influence sur l'effet des interventions lorsqu'il est exprimé en risque relatif (méthode retenue par le groupe de travail).

• Concernant l'analyse coûts/bénéfices de la réduction des risques, elle n'a pas été réalisée par le groupe de travail car elle nécessite des compétences spécifiques et des données difficilement disponibles. Le groupe de travail a donc décidé de se concentrer sur les questions de sécurité des aliments.

La présente expertise porte sur les poulets de chair et non sur les autres types de production avicole. Pour l'ensemble de ce document, le terme *Campylobacter* est utilisé pour désigner l'ensemble des deux espèces *C. jejuni* et *C. coli*.

2. ORGANISATION DE L'EXPERTISE

L'expertise a été réalisée dans le respect de la norme NF X 50-110 « Qualité en expertise – Prescriptions générales de compétence pour une expertise (Mai 2003) ».

L'expertise relève du domaine de compétences du Comité d'experts spécialisé « Evaluation des risques biologiques dans les aliments » (CES BIORISK). L'Anses a confié l'expertise au groupe de travail « *Campylobacter* », mis en place après un appel public à candidatures.

L'Anses analyse les liens d'intérêts déclarés par les experts avant leur nomination et tout au long des travaux, afin d'éviter les risques de conflits d'intérêts au regard des points traités dans le cadre de l'expertise.

Les déclarations d'intérêts des experts sont publiées sur le site internet de l'Anses (www.anses.fr).

Le groupe de travail « *Campylobacter* » s'est réuni treize fois, de mars 2017 à juin 2018. Ses travaux ont été régulièrement soumis au CES BIORISK, tant sur les aspects méthodologiques que scientifiques lors des réunions de janvier 2017, et janvier, mai, juin et juillet 2018. Le rapport du groupe de travail (rédigé en anglais) a tenu compte des commentaires et des ajouts proposés par les membres du CES BIORISK et les relecteurs. En conséquence, le rapport final est le fruit d'un travail d'expertise interactif et collectif réalisé par des experts aux compétences complémentaires. Le rapport final a été présenté et adopté lors de la réunion CES BIORISK du 11 juillet 2018.

Le point de départ de l'expertise était le rapport de l'EFSA (2011). Une revue approfondie des articles scientifiques publiés depuis 2011 a été réalisée sur les bases de données Scopus et PubMed avec les termes de recherche « *Campylobacter* AND poultry AND control ». La recherche a été conduite le 26 avril 2017.

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Trois cent trente-deux références ont été retenues et regroupées par les experts selon les thèmes suivants :

- production primaire : 192 articles ;

- transport et abattage : 68 articles ;

- emballage et pratiques de consommation et de préparation domestique : 42 articles ;

- évaluation quantitative des risques microbiens : 33 articles.

Au moins deux experts ont été désignés pour examiner une même liste de références correspondant aux quatre thèmes ci-dessus. Un modèle de grille de lecture a été fourni aux experts. Dans la première fenêtre, l'expert devait indiquer son nom, la référence de l'article et son type (article, littérature grise, livre, rapport), le pays d'origine, les espèces de volailles. Il renseignait dans la deuxième fenêtre le stade de la chaîne alimentaire, l'intervention et à quel endroit son effet était mesuré, le type et la taille des échantillons, comment l'effet de l'intervention était mesuré (risque relatif, odds ratio, nombre de réductions décimales et écart-type), et il devait indiquer quelle confiance il accordait à l'effet de l'intervention. Dans la troisième fenêtre, l'expert signalait si les auteurs étaient en conflit d'intérêts, si l'intervention était applicable en France, et le(s) biais qu'il avait identifié(s). Seules les références avec un biais faible ou vraisemblablement faible et utilisant une méthode appropriée ont été sélectionnées. En outre, les experts du groupe de travail pouvaient ajouter des articles et des rapports non identifiés par la recherche initiale.

Des fédérations professionnelles du secteur de la volaille ont été auditionnées par le groupe de travail, en juin et en septembre 2017.

Les données de consommation utilisées pour estimer l'exposition alimentaire proviennent de l'étude INCA3 (Anses, 2017), la troisième enquête nationale sur la consommation réalisée entre février 2014 et septembre 2015 en France métropolitaine, auprès de 2 698 enfants et adolescents de 17 ans et moins, et de 3 157 adultes de 18 à 79 ans représentatifs de la France métropolitaine (hors Corse).

3. ANALYSE ET CONCLUSIONS DU CES BIORISK

3.1. *Campylobacter* et campylobactériose

Campylobacter est une bactérie non sporulée, présente dans l'intestin des oiseaux domestiques et sauvages. Les oiseaux sauvages (corneilles, canards, cailles, étourneaux p.ex.) et domestiques(volailles) sont considérés comme les principaux réservoirs de *Campylobacter jejuni* et, dans une moindre mesure, de *C. coli*. Cette bactérie est abondante également dans le tube digestif du bétail domestique (bovins, caprins, porcins, ovins) (Jonaidi-Jafari *et al.* 2016, Manyi-Loh *et al.* 2016, Weis *et al.* 2016, EFSA et ECDC 2017, Johnson *et al.* 2017) et des carnivores domestiques (Pintar *et al.* 2015). Chez les poulets de chair, il a été observé que la contamination par *Campylobacter* est plus fréquente en été. *Campylobacter* peut également être isolé des sols et des sources. L'eau des rivières, des étangs, des lacs et des piscines publiques peut constituer un réservoir secondaire. *Campylobacter* n'affecte pas la santé des volailles et ne peut pas se développer sur les carcasses dans leurs conditions habituelles de conservation (ANSES 2011).

Campylobacter provoque, chez l'Homme, la campylobactériose, première cause d'entérite bactérienne d'origine alimentaire dans les pays industrialisés (EFSA et ECDC 2017). La viande de volailles est considérée comme la source la plus importante de campylobactériose, mais il est également reconnu que la viande des ruminants joue un rôle important. L'incidence de la campylobactériose en France dans la population générale pour la période 2008-2013 a été estimée à 492 705 cas par an (Van Cauteren *et al.* 2018). Les principaux symptômes de la campylobactériose sont des troubles gastro-intestinaux légers à sévères qui sont généralement

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spontanément résolutifs et ne durent que quelques jours, mais la réinfection est possible. Malgré le nombre élevé de cas, leur létalité déclarée est faible (0,03%). Toutefois, l'infection peut entraîner de graves séquelles, telles qu'un syndrome de Guillain-Barré ou une maladie inflammatoire chronique de l'intestin (Man 2011). Le nombre d'années de vie perdues, ajusté pour les incapacités et infirmités (DALY), associé à *Campylobacter* a été estimé à 41 ans pour 1000 malades (données des Pays-Bas en 2009, Havelaar *et al.* (2012)).

Le règlement (CE) n°2073/2005 modifié comporte un critère d'hygiène des procédés pour *Campylobacter* applicable dans les abattoirs de poulets de chair. À compter du 1er janvier 2018, sur 50 échantillons composites de peau de cou, le nombre maximal d'échantillons dépassant 1000 UFC/g ne doit pas dépasser 20. Ce nombre sera de 15 en 2020 et de 10 en 2025. En cas de non-conformité, l'exploitant doit améliorer l'hygiène de l'abattage et réexaminer les mesures de maîtrise des procédés, l'origine des animaux et les mesures de biosécurité mises en place dans les exploitations d'origine.

3.2. Contamination des poulets de chair de la ferme à l'assiette en France

Le rapport du groupe de travail rappelle les étapes par lesquelles les poulets passent de la production fermière à la viande destinée à la consommation, et indique quelles sont les sources de contamination et les points sensibles tout au long de la chaîne. Il souligne les particularités nationales de ces productions allant de jeunes poulets (moins de 39 jours) élevés en claustration jusqu'à des poulets plus âgés (plus de 81 jours) ayant accès à un parcours extérieur. Ce dernier type de production, regroupé en particulier sous le signe de qualité « Label Rouge », constituait en 2011, 15 % de la production ; en 2013, plus de la moitié (57,3 %) des poulets entiers (carcasses) consommés par les ménages français à domicile sont des produits sous « Label Rouge » (référence : « La filière volaille de chair », rapport IGF-CGAAER, mars 2014).

Les données mises à disposition permettent d'évaluer la contamination des poulets de chair en France de la manière suivante :

À l'étape de la production primaire, selon l'enquête de référence européenne réalisée en 2008, *Campylobacter* a été isolé dans 77% des échantillons de contenus cæcaux avec en moyenne 10^8 UFC/g (70% chez les poulets de chair élevés en claustration et 100% chez les poulets de chair élevés en plein air). Les études françaises publiées en 2010, 2011 et 2014 confirment ces ordres de grandeur (Hue *et al.* 2010, Hue *et al.* 2011, Allain *et al.* 2014). Mahler *et al.* (2011) ont rapporté que, en 2009, 87% des lots de poulets de chair testés avaient des *Campylobacter* dans leur cæcum après le transport à l'abattoir ; la charge moyenne était de 10^8 UFC/g.

En ce qui concerne la prévalence au sein du troupeau contaminé, celle-ci atteint, dans la majorité des cas, 100% des oiseaux dans les deux semaines suivant l'infection naturelle par *Campylobacter* (Huneau-Salaun *et al.* 2018).

À l'abattoir, selon l'enquête de référence européenne réalisée en 2008, 87,5% des carcasses étaient contaminées avec en moyenne $10^{2,39 \pm 0,08}$ UFC/g, et 15 % des échantillons présentaient une numération de *Campylobacter* supérieure à 10^3 UFC/g (Hue *et al.* 2010, 2011). Une corrélation positive entre la concentration moyenne de *Campylobacter* dans le cæcum et sur les carcasses a été observée, mais une prévalence plus élevée a été observée sur les carcasses, ce qui indique que des transferts de *Campylobacter* se produisent durant le processus d'abattage.

Une étude récente menée en France a évalué la concentration moyenne de *Campylobacter* sur les carcasses (après refroidissement par air ventilé). Le niveau moyen de contamination des échantillons composites de peau de cou a été évalué à $10^{2,6}$ UFC/g de juin à décembre, alors que ce niveau était significativement plus faible de janvier à mai (10 UFC/g) (Duqué *et al.* 2018).

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Un plan de surveillance de la production de poulets de chair sous le signe de qualité « Label Rouge » de 2009 à 2014 a montré que seulement 2 à 5% des carcasses (sur la peau des cuisses) présentaient une concentration supérieure à 10^3 UFC/g (Salvat *et al.* 2017).

Au stade de la distribution, le plan de surveillance mené d'avril à décembre 2009 a permis de détecter *Campylobacter* dans 76% des prélèvements (DGAL 2010). Selon Guyard-Nicodeme *et al.* (2013), les produits conditionnés sous air présentent une contamination plus élevée que celle de ceux conditionnés sous atmosphère modifiée. Dans cette étude, la prévalence et le dénombrement de *Campylobacter* étaient respectivement de 90% et de $10^{1,9}$ UFC/g sur les carcasses, de 85% et de $10^{1,72}$ UFC/g sur les cuisses et de 53% et $10^{0,82}$ UFC/g sur les filets. Selon Rivoal *et al.* (2011), les produits avec peau sont significativement plus contaminés que ceux sans peau.

3.3. Points clefs de la contamination par *Campylobacter*

3.3.1. À la ferme

L'épidémiologie de la contamination par *Campylobacter* dans les troupeaux de poulets de chair a été largement étudiée depuis 1990. Il est généralement admis que la transmission horizontale est responsable de la colonisation des troupeaux de poulets de chair (Evans et Sayers 2000, Hansson *et al.* 2010, Hermans *et al.* 2011, Newell *et al.*, 2011) et plusieurs études ont identifié des facteurs de risque (Lyngstad *et al.* 2008) : la contamination de l'environnement pendant la période d'élevage (Gibbens *et al.* 2001), le mauvais entretien du bâtiment, le nettoyage et la désinfection inadéquats, le stockage de fumier à la ferme, la présence d'autres animaux (Cardinale *et al.* 2004). L'âge du troupeau, la taille de l'exploitation, la taille du troupeau, la qualité de l'eau et la saison sont également des facteurs importants (Evans et Sayers 2000, Refrégier-Petton *et al.* 2001). De plus, le détassage (dépeuplement partiel) est considéré comme un facteur de risque majeur de colonisation du troupeau (Hermans *et al.* 2011, Torralbo *et al.* 2014).

Les sources identifiées de *Campylobacter* dans l'environnement des poulets de chair comprennent le bétail à proximité (Ogden *et al.* 2009, Zweifel *et al.* 2008), le personnel (Ridley *et al.* 2011), les insectes (Hald *et al.* 2008), les animaux domestiques (Whiley *et al.* 2013), les rongeurs (Meerburg *et al.* 2006), l'équipement (Agunos *et al.* 2014, Battersby *et al.* 2016) et l'environnement extérieur du poulailler (Ogden *et al.* 2009). De plus, lorsque les points sensibles comme le revêtement de sol, les vêtements, le sas, la porte, les abreuvoirs, les murs, les colonnes, les barrières et les déjections ne sont pas nettoyés et désinfectés correctement, des transferts de *Campylobacter* d'un lot de volailles au suivant apparaissent inévitables (Battersby *et al.* 2016).

L'âge est un facteur de risque pour la colonisation par *Campylobacter* des troupeaux de poulets de chair (Evans et Sayers 2000, Hartnett *et al.* 2001, Bouwknegt *et al.* 2004). Les oiseaux sont habituellement exempts de *Campylobacter* pendant les 2-3 premières semaines, mais une fois infectés, ces bactéries se développent rapidement dans le cæcum, puis dans les fèces et se répandent rapidement dans tout le bâtiment. Dans les troupeaux plus âgés (8-9 semaines), la proportion d'oiseaux positifs peut diminuer (Brena 2013).

3.3.2. Avant et pendant l'abattage

Le réservoir principal de *Campylobacter* étant le tube digestif, la contamination de la carcasse est essentiellement superficielle et peut provenir de l'animal vivant (pendant l'élevage, lors de l'enlèvement, le transport, l'attente et l'accrochage) ou peut être acquise *post-mortem*. La contamination par *Campylobacter* dans la profondeur des muscles, provenant de bactériémies digestives et/ou d'accident d'éviscération, est considérée comme un événement très rare, voire improbable. Par conséquent, la dissémination du contenu digestif est à l'origine de la grande majorité des contaminations et donc, jusqu'au retrait du tube digestif, toutes les étapes du processus conduisant à une dissémination fécale sont considérées comme des étapes sensibles pour le transfert de *Campylobacter* à la surface de la peau ou des muscles.

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- Avant l'abattage

Des durées de jeûne supérieures à 12 heures peuvent entraîner une détérioration de l'état et de l'intégrité des viscères et augmenter la fluidité du contenu gastro-intestinal, et ainsi augmenter le risque de contamination fécale des carcasses. Le rapport de l'EFSA (2011) montre les résultats de diverses études réalisées les années précédentes, confirmant qu'avec l'augmentation du temps de jeûne avant l'abattage, la concentration en *Campylobacter* augmente exponentiellement dans le cæcum (Willis *et al.* 1996, Byrd *et al.* 1998, EFSA 2011). Ainsi, l'excrétion fécale peut se produire pendant le transport et le séjour dans une caisse de transport. À titre d'exemple, l'hormone norépinéphrine sécrétée par les oiseaux stressés pendant le transport pourrait stimuler la colonisation et la multiplication de *Campylobacter* dans l'intestin, puis augmenter par la suite la possibilité de contamination de la carcasse (Cogan *et al.* 2007). Les caisses et les cages de transport présentent de nombreuses anfractuosités permettant l'accumulation de souillures. L'usure après une utilisation répétée des caisses et des cages de transport endommage les surfaces et crée des sites permettant l'accumulation de saleté et la formation de biofilm. Les caisses et les cages de transport sont donc très difficiles à nettoyer et à désinfecter. Elles sont une source de contamination et de transferts de *Campylobacter* de la surface des oiseaux transportés pour l'abattage et pouvant précédemment être indemnes de *Campylobacter*. Cependant, dans une étude réalisée sur 30 troupeaux suivis de la ferme à l'abattage, aucune différence significative n'a été trouvée entre les dénombrements de *Campylobacter* dans le cæcum à la fin de l'élevage, durant le transport et l'attente, et à l'abattage (Chemaly *et al.* 2010).

- Pendant le processus d'abattage

La première étape sensible est l'opération d'échaudage[1] : au cours de cette étape, de nombreuses carcasses provenant de différents lots sont immergées successivement dans la même eau. Si l'échaudage n'est pas fait dans un but hygiénique, cette opération semble néanmoins être efficace pour réduire le niveau de contamination par *Campylobacter* (Pacholewicz *et al.* 2015), car la température de l'eau est suffisamment élevée pour inactiver *Campylobacter*.

Pendant la plumaison, une augmentation de la contamination de la carcasse par *Campylobacter* est fréquemment observée, provoquée par les doigts des plumeuses qui transfèrent, de poulet en poulet, les *Campylobacter* provenant des souillures par les fientes. En outre, des aérosols contenant *Campylobacter* sont formés lors de la plumaison (Haas *et al.* 2005, Johnsen *et al.* 2007) et peuvent causer une contamination importante des carcasses (EFSA 2011).

L'éviscération peut également être une source de contamination des carcasses et de transfert de *Campylobacter* (Corry et Atabay 2001), lors d'accident du processus entraînant une déchirure des intestins et, par conséquent, une propagation des matières fécales vers la surface de la carcasse. Le transfert de *Campylobacter* peut résulter de l'impossibilité de nettoyer et de désinfecter les ustensiles et les équipements entre chaque animal. L'étape d'éviscération est identifiée comme étant à l'origine d'une augmentation notable de la prévalence de carcasses contaminées (Seliwiorstow *et al.* 2016).

Le refroidissement par air ventilé semble être une étape importante pour réduire le niveau de contamination, même si la prévalence de carcasses contaminées reste inchangée (Rivoal *et al.* 2015, Rivoal *et al.* 2018).

- Pendant la découpe

Lorsque la découpe est effectuée mécaniquement, il y a davantage de possibilités de transfert de *Campylobacter* entre les carcasses et les pièces de découpe par l'intermédiaire des équipements.

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[1] Echaudage : trempage des carcasses dans un bain d'eau chaude pour « faciliter » la plumaison ultérieure par dilatation des follicules plumeux.

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La peau de certaines parties, en particulier les blancs (poitrine), est retirée, ce qui réduit habituellement le nombre de *Campylobacter* à la surface de la pièce.

3.3.3. Transfert de *Campylobacter* chez les consommateurs

Plusieurs études françaises ont investigué les pratiques courantes dans les cuisines domestiques. Elles ont montré que la viande de poulet peut contaminer d'autres aliments et différentes surfaces de la cuisine (par exemple les ustensiles) pendant la préparation des repas. Il a été montré que *Campylobacter* provenant de cuisses de poulet naturellement contaminées (achetées dans des points de vente au détail) était transféré sur la planche à découper dans 80% des cas après 10 minutes de contact (Fravalo *et al.* 2009). Une autre étude a examiné le transfert de *Campylobacter* présent dans des produits crus naturellement contaminés (achetés dans des points de vente au détail) à un produit cuit après un contact avec une planche à découper (Guyard-Nicodème *et al.* 2013). Cette étude a montré que le transfert de *Campylobacter* s'est produit dans près de 30% des cas et que les principales espèces impliquées dans la campylobactériose humaine, *C. jejuni* et *C. coli*, pouvaient passer de la viande de volailles crue à un produit prêt à être consommé par l'intermédiaire de la planche à découper. Tous les isolats testés ont pu adhérer et envahir les cellules eucaryotes, révélant des propriétés de virulence potentielle conservées pour ces isolats pouvant être en contact avec le consommateur (Guyard-Nicodème *et al.* 2013).

3.4. Efficacité des interventions sélectionnées par le groupe de travail

Pour pouvoir sélectionner des interventions, une revue bibliographique approfondie a été menée pour mettre à jour les connaissances figurant dans le rapport de l'EFSA (2011). Les experts n'ont pas retenu les interventions inapplicables en France (notamment en raison de la réglementation) et celles pour lesquelles les résultats n'étaient pas présentés sous forme quantitative, ou l'étaient sous forme d'odds ratios. Dans ce qui suit, les interventions retenues comme étant potentiellement applicables sont listées avec leur effet, exprimé en termes :

- soit de pourcentage de réduction de la prévalence inter-troupeaux ;
- soit du nombre de divisions par dix (ou réductions décimales, abrégé en RD) de la charge bactérienne en *Campylobacter*.

3.4.1. Interventions à la production primaire

- Moustiquaires : la prévalence a diminué de 40% à 10% au Danemark lors d'un essai sur le terrain (troupeaux en claustration uniquement).
- Vaccination : 1 à 4 réductions décimales (RD) dans le cæcum.
- Utilisation de phages : 1,3 à 2,8 RD dans le cæcum.
- Substances chimiques et biologiques ajoutées à l'eau d'abreuvement : 0,7 à 3 RD dans le cæcum.
- Arrêt de la pratique du détassage : une diminution de 13% de la prévalence de *Campylobacter* à la ferme est attendue. Le détassage est utilisé uniquement pour certaines productions de poulets de chair élevés en claustration.
- L'âge d'abattage : l'abattage des troupeaux de poulets de chair avant l'âge de 35 jours réduirait la prévalence de *Campylobacter* de 14% en moyenne. Cette mesure pourrait s'appliquer uniquement aux poulets de chair à croissance rapide élevés en claustration.

Pour mémoire, plusieurs études épidémiologiques ont suggéré qu'une amélioration du respect des recommandations relatives à la biosécurité réduirait la prévalence de *Campylobacter* dans les troupeaux de poulets de chair. Cependant, aucune donnée n'est disponible pour évaluer l'état

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actuel d'application des mesures de biosécurité en France. Dans ces conditions, l'évaluation de l'impact potentiel de cette intervention n'est pas possible.

3.4.2. Interventions pendant le transport et avant l'abattage

L'optimisation de l'heure de début du jeûne peut avoir un impact marginal sur la contamination de la surface après échaudage, plumaison et éviscération (diminution de moins de 5%).

Pour mémoire, une autre intervention pour laquelle aucune donnée quantitative n'est disponible est l'amélioration du nettoyage des caisses et des cages avant le transport.

3.4.3. Interventions à l'abattoir

- Échaudage : 0,1 à 0,2 RD de la concentration de *Campylobacter* sur la carcasse avant la réfrigération.
- Echaudage à la vapeur en caisson : 0,2 à 0,4 RD sur la carcasse.
- Prévention des accidents d'éviscération, fuites de contenu intestinal : 0,9 RD sur la carcasse.
- Immersion dans l'eau chaude après éviscération : 0,3 à 0,5 RD sur la carcasse.
- Refroidissement par air ventilé : jusqu'à 1,5 RD sur la carcasse.

Pour mémoire, il est difficile de faire des recommandations générales pour l'amélioration des équipements d'abattoir, car les mesures d'hygiène pour l'abattage semblent variables et spécifiques de chaque usine.

3.4.4. Interventions après l'abattoir

- Congélation : 1 à 3,2 RD.
- Technologies utilisant la lumière visible pulsée (405 nm) : jusqu'à 2,1 RD.
- Ionisation : > 8 RD.

Concernant les interventions chez le consommateur, le modèle retenu par les experts tient compte du lavage des mains et du nettoyage des ustensiles de cuisine, en supposant que les recommandations de bonnes pratiques d'hygiène seraient suivies à 100%.

3.5. Modélisation et résultats

3.5.1. Modèle utilisé

Le groupe de travail a fait une revue bibliographique des différents modèles d'évaluation quantitative du risque lié aux *Campylobacter*, en filière volailles. Sur la base de cette revue, la stratégie retenue par le groupe de travail est la suivante :

- A la ferme, l'effet de différentes interventions testées au stade de l'élevage a été directement exprimé en termes de réduction de la prévalence inter-troupeaux ou de réductions décimales des concentrations en *Campylobacter* dans les cæca avant l'abattage. Sur la base de la bibliographie, le groupe de travail a retenu l'hypothèse que tous les poulets d'un troupeau infecté sont porteurs de *Campylobacter* (100% de prévalence intra-troupeau).

- A l'abattoir, le groupe de travail a choisi d'utiliser le modèle CARMA, développé aux Pays-Bas à l'Institut national pour la santé publique et l'environnement (RIVM) (Nauta *et al.* 2005, 2009). Il s'agit d'un modèle mécaniste mesurant la dynamique des transferts et de survie des *Campylobacter* pendant les différentes phases de l'abattage. Le modèle a été développé aux Pays-Bas, mais le groupe de travail a fait l'hypothèse que le processus d'abattage des poulets de chair est similaire en France.

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- <u>Chez le consommateur</u>, le groupe de travail a choisi d'utiliser le modèle développé en France à l'Anses par Poisson *et al.* (2015). C'est un modèle mécaniste qui suit la dynamique des transferts de *Campylobacter* par contact direct ou indirect avec le poulet cru. Ce modèle s'appuie sur celui développé par Pouillot *et al.* (2012), utilise des données françaises issues d'une enquête récente conduite en 2012-2013 portant sur les pratiques des consommateurs lors de la préparation de repas contenant du poulet et impliquant 659 consommateurs français représentatifs.

3.5.2. Scénarios testés

Le groupe de travail a choisi de tester des scénarios ne modifiant qu'une étape de la chaîne puis des scénarios combinant plusieurs interventions à différentes étapes de la chaîne.

Il est convenu d'introduire dans le modèle des niveaux de réduction de la prévalence de *Campylobacter* ou de leur nombre, sans indiquer de façon précise les mesures de maîtrise qui permettraient d'atteindre ces niveaux. Il n'y a donc pas de lien univoque entre ces niveaux de réduction et l'efficacité des mesures disponibles, telles qu'elles sont listées dans la section 3.4.

- Scénarios testés à la ferme :

  Les scénarios A1a et A1b testent l'effet d'une diminution de la prévalence inter-troupeaux de poulet.

  Les scénarios A2 à A5 testent l'effet d'une diminution de la concentration de *Campylobacter* dans les cæca.

  Le scénario A6 combine une diminution de prévalence inter-troupeaux et une diminution de la concentration en *Campylobacter* dans les cæca.

- Scénarios testés à l'abattoir :

  Les scénarios B1 à B4 testent l'effet d'une diminution de concentration en surface des carcasses (diminution exprimée en nombre de réductions décimales) ou d'une diminution de la probabilité de contamination fécale suite à la plumaison ou à un accident d'éviscération. Ces scénarios s'appliquent à différentes étapes du procédé d'abattage : à l'échaudage, pendant la plumaison, pendant l'éviscération, pendant le refroidissement par air ventilé.

  Le scénario B5 combine une diminution de 10% du risque de contamination fécale au cours de la plumaison, une diminution de 10% du risque de contamination par accident d'éviscération et une réduction décimale de la concentration en *Campylobacter* en surface pendant le refroidissement par air ventilé.

- Scénarios testés chez le consommateur :

  Le scénario C1a teste l'hypothèse que 100% des consommateurs se lavent efficacement les mains après avoir manipulé le blanc de poulet.

  Le scénario C1b teste l'hypothèse d'un parfait nettoyage des ustensiles de cuisine, et donc aucun transfert de *Campylobacter* dans la cuisine.

  Le scénario C2 combine les scénarios C1a et C1b.

- Enfin, deux scénarios combinant des interventions à chacune des étapes ont été testés : le scénario D1 combine les scénarios à faible impact sur le risque et le scénario D2 combine ceux à fort impact.

Le tableau 1 montre des exemples d'options d'intervention susceptibles de permettre l'atteinte de l'effet attendu (à condition que la reproductibilité, après des expérimentations de terrain, soit vérifiée en France) pour les scénarios testés.

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Tableau 1 : Scénarios pour lesquels une intervention potentielle est identifiée, avec une quantification de l'effet justifiée par les études expérimentales, permettant d'atteindre des objectifs de réduction du risque (RD : réduction décimale)

Étape du modèle	Scénario	Paramètre (variable ou opération)	Effet de l'intervention	Intervention potentielle
Production primaire	A1a	Prévalence	- 10% (70-10 = 60% de prévalence inter-troupeaux)	Troupeau en claustration seulement : • Moustiquaires **ou** • Arrêt du détassage **ou** • Âge à l'abattage
	A1b	Prévalence	- 30% (70-30 = 40% de prévalence inter-troupeaux)	Troupeau en claustration seulement : • Moustiquaires
	A2	Concentration	- 0,5 RD	• Vaccination **ou** • Utilisation de phages **ou** • Ajout de substances biologiques ou chimiques dans l'aliment ou l'eau de boisson
	A3	Concentration	- 1 RD	
	A4	Concentration	- 1,5 RD	
	A5	Concentration	- 2,5 RD	
Abattoir	B4	Refroidissement par air ventilé	- 1 RD de la concentration	Amélioration des paramètres de refroidissement par air ventilé (température, durée, vitesse de l'air)

En fonction de l'effet attendu, le gestionnaire du risque pourra choisir les interventions à mettre en place, en s'appuyant sur la revue des interventions et de leurs effets, présentée dans la section 6 du rapport.

3.5.3. Résultats

Le modèle a d'abord été utilisé pour estimer le nombre annuel de cas provoqués par *Campylobacter* par an en France, soit 272 930 (nommé « référence » dans les tableaux suivants). Cette référence est à comparer aux 492 705 cas annuels (IC95 = 272 669 à 1 078 543) estimés sur des considérations épidémiologiques (Van Cauteren *et al.* 2018). La similitude des ordres de grandeur des deux nombres tend à montrer que les valeurs des variables dans la présente modélisation ne sont pas irréalistes. Pourtant, le résultat de référence est évidemment surestimé, et il ne concerne que la consommation de blancs de poulet produits en France, alors que l'estimation par l'étude épidémiologique concerne tout type d'aliments d'origine domestique ou non.

En tout état de cause, la valeur absolue de la référence n'a pas d'effet sur les résultats qui sont présentés ci-dessous. En effet, comme l'objectif du présent travail est de comparer l'effet de diverses interventions sur le risque pour la santé du consommateur, c'est la réduction du risque qui a été estimée, calculée comme suit :

$$reduction\ du\ risque\ (\%) = 100 * (1 - \frac{nombre\ de\ cas\ après\ intervention(s)}{nombre\ de\ cas\ avant\ intervention(s)})$$

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Bien que l'estimation de la réduction du risque ait été faite en prenant en compte uniquement les repas pendant lesquels sont consommés des blancs de poulet et des aliments consommés crus[2], le pourcentage de réduction de risque sera identique quelle que soit la partie du poulet consommée (avec ou sans peau, issu d'un élevage en claustration ou en plein air). Les résultats de réduction des risques présentés ci-dessous fournissent donc une estimation globale de l'effet des interventions testées dans cet exercice de modélisation.

- Effet des interventions à la ferme

Stade de la chaîne	Scénario	Variable	Réduction	Nb cas	Réduction du risque (%)	
Référence				272930		
Production primaire	A1a	Prévalence	- 10% (70-10 = 60% prévalence inter-troupeaux)	233940		14
	A1b	Prévalence	- 30% (70-30 = 40% prévalence inter-troupeaux)	155960		43
	A2	Concentration	- 0,5 RD	148560		46
	A3	Concentration	- 1 RD	77800		71
	A4	Concentration	- 1,5 RD	41760		85
	A5	Concentration	- 2,5 RD	18780		93
	A6	Prévalence	- 10%	128570		53
		Concentration	-0,5 RD			

- Effet des interventions à l'abattoir

Stade de la chaîne	Scénario	Opération(s)	Réduction	Nb cas	Réduction du risque (%)	
Référence				272930		
Abattoir	B1	Echaudage	- 1 RD	264560		3
	B2	Plumaison	- 10% de probabilité de contamination fécale	261470		4
	B3	Eviscération	- 10% de probabilité d'accident d'éviscération	264520		3
	B4	Refroidissement par air ventilé	- 1 RD	66570		76
	B5	Plumaison	- 10% de probabilité de contamination fécale	60030		78
		Eviscération	- 10% de probabilité d'accident d'éviscération			
		Refroidissement par air ventilé	- 1 RD			

- Effet des interventions chez le consommateur[3]

Stade de la chaîne	Scénario	Opération(s)	Respect des bonnes pratiques	Nb cas	Réduction du risque (%)	
Référence				272930		
Consommateur	C1a	Lavage des mains	100%	270260		1
	C1b	Nettoyage des ustensiles	100%	40080		85
	C2	C1a + C1b		35670		87

- Effet des interventions combinées

	Scénario	Combinaison d'interventions		Nb cas	Réduction du risque (%)	
Référence				272930		
	D1	Interventions à effets faibles	A1 + B2 + C1a	224110		18
	D2	Interventions à effets élevés	A4 + B4 + C2	2800		99

<u>En fonction de l'objectif de réduction de risque attendu, le gestionnaire du risque pourra choisir les interventions à mettre en place, en utilisant les résultats présentés ci-dessus ainsi que, comme il a été indiqué précédemment, la revue des interventions et de leurs effets présentée dans la section 6 du rapport du groupe de travail.</u>

Il convient de noter que les effets estimés des interventions, tels que rapportés dans la littérature et résumés dans la section 6 du rapport, sont le plus souvent associés à une variabilité et à des incertitudes fortes. Les résultats publiés sont en général obtenus à partir d'un petit nombre d'essais expérimentaux, qui ne sont donc pas représentatifs de tous les poulets, fermes, abattoirs et cuisines en France. En outre, il est difficile de savoir dans quelle mesure les situations expérimentales rapportées sont comparables à celle des autres élevages français.

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[2] Susceptibles d'avoir été contaminés par transfert de *Campylobacter* entre le poulet, par les mains et/ou les ustensiles de cuisine.
[3] Le nettoyage des ustensiles correspond au nettoyage à la main ou au lave-vaisselle.

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Enfin, les pratiques françaises ne sont pas connues avec précision et, la plupart du temps, il est difficile d'évaluer, si une intervention est déjà en place, dans quelle mesure elle est respectée, et quel serait son effet réel si elle était appliquée de façon systématique.

Par exemple, le gestionnaire du risque pourrait décider d'intervenir au stade de l'élevage, en testant la vaccination. Selon la littérature scientifique, la vaccination permet expérimentalement de 1 à 4 réductions décimales de la concentration de *Campylobacter* dans les cæca : l'incertitude est donc grande. A l'appui d'une décision que prendrait le gestionnaire du risque, une expérimentation de longue durée à grande échelle serait utile pour mesurer la réduction réelle de la contamination des animaux et des carcasses par *Campylobacter*. D'une façon générale, la mise en œuvre d'une nouvelle intervention gagnerait à être précédée d'une enquête sur son acceptabilité par les professionnels concernés et plus largement par tous les acteurs de la filière et par les consommateurs, et d'une analyse coûts/bénéfices (incluant la prise en compte du DALY). Enfin, il ne faudrait pas omettre de tenir compte des produits importés et de la proportion de ces produits dans la consommation nationale. Ces derniers points ne faisaient pas partie du mandat du groupe de travail.

3.5.4. Prise en compte de l'incertitude et limites de l'étude

- Incertitude liée aux données disponibles

Pour décrire la situation en France, le groupe de travail a utilisé les données des plans de surveillance de l'EFSA conduits en 2008 et 2009. Depuis 2009, des enquêtes de prévalence ont été conduites, mais pas à l'échelle nationale.

La collecte des données utilisées par le groupe de travail a reposé en partie sur des articles sélectionnés après consultation des bases de données Scopus et Pubmed, ainsi que sur des données des experts du groupe de travail. Il y a donc une incertitude liée à la non exhaustivité des données collectées. Notamment, toutes les données non publiées (biais de publication) telles que les données de la littérature dite « grise » n'ont pas été incluses dans les travaux du groupe de travail.

Par ailleurs, les données publiées sont le plus souvent issues d'essais réalisés dans des systèmes de production différents des modèles français, et il est difficile de savoir dans quelle mesure les résultats rapportés s'appliqueraient à la situation française.

Enfin, comme cela a été indiqué précédemment, les pratiques françaises ne sont pas connues avec précision et, la plupart du temps, il est difficile d'évaluer si une intervention est déjà en place, dans quelle mesure elle est appliquée, et quel serait son effet réel si elle était appliquée de façon systématique.

- Incertitude liée à la méthode d'évaluation

Le groupe de travail a fait le choix de modéliser le risque relatif de campylobactériose pour le consommateur en fonction de différents scénarios d'intervention le long de la chaîne.

Pour la modélisation, les principales sources d'incertitudes identifiées sont liées au choix du modèle retenu par le groupe de travail. En effet, pour la partie abattoir, les experts ont fait le choix de retenir un modèle développé aux Pays-Bas et ont émis l'hypothèse que le fonctionnement d'un abattoir en France est similaire à celui d'un abattoir aux Pays-Bas.

Afin de réduire l'incertitude, les experts ont recommandé l'acquisition de connaissances à différents niveaux de la chaîne alimentaire (voir paragraphe 3.6.4. Recommandations).

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3.6. Conclusions et recommandations du CES BIORISK

3.6.1. Mise à jour des connaissances disponibles relatives aux mesures de maîtrise de *Campylobacter* dans la filière poulet de chair, depuis le rapport de l'EFSA (2011)

En ce qui concerne les nouvelles connaissances disponibles sur la contamination par *Campylobacter* des poulets de chair et de leurs produits, il faut tout d'abord souligner qu'aucune nouvelle enquête d'envergure nationale n'a été réalisée sur la situation de *Campylobacter* (prévalence, niveau de contamination) dans la filière volailles en France depuis les études européennes de référence de 2008 et 2009.

En ce qui concerne les mesures de maîtrise, si de nombreux articles rapportent les résultats d'essais de diverses interventions à plusieurs stades de la chaîne alimentaire, réalisés en France, dans l'UE et dans le monde depuis 2010, les études fournissent peu de données quantitatives utilisables dans l'évaluation quantitative de risque. En outre, les résultats d'essais contrôlés dans des fermes ou à l'abattoir manquent pour évaluer l'efficacité et l'applicabilité de ces interventions dans des conditions de terrain. Jusqu'à présent, aucune mesure de maîtrise ne s'est révélée efficace et applicable par le secteur professionnel.

De nouvelles données sur le comportement des consommateurs en cuisine ont été obtenues en France. Le transfert de *Campylobacter* entre les produits de volailles et les aliments consommés crus est identifié comme une source majeure de campylobactériose humaine. Les comportements des consommateurs en cuisine jouent un rôle important sur le risque de campylobactériose, en particulier ceux relatifs aux pratiques de nettoyage des ustensiles.

Sur la base de l'examen du rapport de l'EFSA (2011) et de la littérature récente, les experts ont recensé les interventions à la ferme, à l'abattoir ou dans la cuisine du consommateur, qu'ils jugeaient applicables en France, et ils ont associé à chacune de ces interventions une valeur numérique de leur effet potentiel attendu sur la prévalence ou sur le nombre de réductions décimales de la concentration en *Campylobacter* sur les carcasses.

3.6.2. Modélisation de la filière avicole française de l'élevage au consommateur

Le modèle CARMA développé aux Pays-Bas à l'Institut national pour la santé publique et l'environnement (RIVM) pour l'étape abattoir, complété par deux modules (refroidissement par air ventilé et consommateur), a permis de tester l'effet de plusieurs scénarios sur le risque de campylobactériose humaine par comparaison à une référence reflétant la situation actuelle. Les résultats de ces scénarios sont présentés sous la forme d'une réduction du risque relatif de campylobactériose.

• À la ferme, selon ses hypothèses et avec les scénarios testés, le modèle a montré que les interventions les plus efficaces sont celles qui réduisent le niveau de contamination des carcasses (UFC/g), plutôt que celles qui réduisent la prévalence des carcasses contaminées. Par conséquent, dès que, par exemple, la vaccination sera disponible, elle pourrait s'avérer très efficace pour protéger la santé publique. Si, par exemple, la vaccination atteignait 1,5 réduction décimale du niveau de contamination des carcasses par *Campylobacter*, la réduction du risque relatif pour le consommateur serait de 85%.

• À l'abattoir, une réduction décimale supplémentaire de la contamination des carcasses au cours de l'échaudage ou en réduisant les contaminations fécales au cours des étapes de plumaison ou d'éviscération n'entraînerait qu'une réduction du risque relatif de 3% à 4% dans l'état actuel de fonctionnement de la chaîne d'abattage, en raison des multiples transferts de *Campylobacter* qui s'y produisent après ces étapes. En revanche, le processus de refroidissement par air ventilé semble être très efficace et, à titre d'exemple, le modèle montre qu'une réduction décimale supplémentaire de contamination des carcasses au cours de cette étape réduirait le risque de 76%.

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• Chez le consommateur, le lavage des mains seul a un effet limité sur l'incidence de campylobactériose (réduction de 1% du risque relatif car cette recommandation est déjà largement appliquée) en raison de l'importance des transferts de *Campylobacter* par les ustensiles de cuisine. Mais, le nettoyage de ces derniers pour prévenir les transferts est efficace. Si, par exemple, les recommandations sur le nettoyage des ustensiles étaient effectivement appliquées par tous les consommateurs, la réduction du risque relatif serait de 85%. L'application parfaite de bonnes pratiques d'hygiène dans la cuisine à domicile serait très efficace. Cependant, selon un précédent rapport (ANSES 2015), il peut être difficile de changer le comportement du consommateur.

• Les experts ont également testé deux scénarios combinant des mesures de maîtrise à la ferme, à l'abattoir et dans la cuisine du consommateur. Il faut noter que l'effet de la combinaison des interventions n'est pas strictement additif. Le scénario combinant des interventions ayant chacune un faible effet sur le risque aboutirait à une réduction du risque relatif de 18% tandis que celui combinant des interventions induisant chacune un effet élevé aboutirait à une réduction du risque de 99%.

3.6.3. Considération finale

Les résultats présentés ci-dessus montrent qu'il existe manifestement une marge d'amélioration pour la protection de la santé publique vis-à-vis du risque lié à *Campylobacter*. Mais les résultats disponibles montrent également qu'une réduction majeure du risque relatif nécessiterait l'application d'interventions qui sont encore au stade de l'expérimentation et du développement (comme la vaccination), l'amélioration de la conception hygiénique des équipements d'abattage, ainsi qu'un meilleur respect des bonnes pratiques d'hygiène, tout au long de la chaîne alimentaire, consommateurs inclus.

3.6.4. Recommandations de l'expertise collective

Les recommandations ne sont pas hiérarchisées.

R1 – Un plan national de maîtrise de *Campylobacter* en filière volailles impliquant tous les acteurs de la chaîne alimentaire (comme celui existant pour *Salmonella*) devrait être mis en place. Comme le montrent les résultats du modèle, pour obtenir une forte diminution du risque relatif, il conviendrait de combiner des interventions appliquées à chacune des trois étapes du modèle : élevage, abattoir et consommateur.

R2 - Une meilleure connaissance des sources de campylobactériose humaine est nécessaire (étude d'attribution). En effet, cette maladie n'est pas uniquement liée à la consommation de poulets de chair élevés en France. Les produits de volailles importées et d'autres aliments peuvent également être la cause de la maladie. Les résultats présentés plus haut doivent donc être compris comme ne représentant qu'une partie des cas de campylobactériose humaine.

R3 – La mise en place d'interventions à la ferme et pendant le transport devrait être encouragée. Des expériences de terrain devraient être menées pour tester l'effet (ainsi que sa variabilité), l'applicabilité et le coût de ces interventions. Elles devraient estimer les effets des interventions sur les niveaux de prévalence et de contamination, ainsi que leur impact sur la survie de *Campylobacter.* Ces expériences de terrain devraient prendre en compte la spécificité des systèmes de production des poulets de chair français.

R4 - À l'abattoir, les bonnes pratiques d'hygiène devraient être améliorées, en particulier pour éviter la contamination des carcasses par les matières fécales et les transferts de *Campylobacter* qui s'ensuivent. Leur mise en œuvre devrait faire l'objet d'un suivi régulier.

R5 - Les paramètres de refroidissement par air ventilé (température, hygrométrie, vitesse du flux d'air) pour assurer une diminution rapide et efficace de la température de la carcasse devraient

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être maîtrisés car le processus de refroidissement est un point clef pour réduire la contamination de surface par *Campylobacter*.

R6 - L'hygiène domestique devrait être largement encouragée, et une formation à l'hygiène domestique dès l'école pourrait être envisagée.

R7 – Une nouvelle enquête sur la situation de *Campylobacter* (prévalence, niveau de contamination) dans les filières volailles en France devrait être conduite et suivie d'une surveillance régulière.

R8 – Des essais de terrain devraient être conduits à chaque étape de la chaîne alimentaire pour tester les interventions les plus prometteuses, y compris celles relevant de nouvelles technologies, afin d'estimer leur effet sur la prévalence et le niveau de contamination des *Campylobacter*. Ces essais devraient également permettre d'évaluer la variabilité des effets des interventions. La survie des *Campylobacter* lors du refroidissement des carcasses devrait aussi être explorée.

R9 – Les experts recommandent également la mise en place d'un système de centralisation des autocontrôles des industriels de façon à être informée de l'application du nouveau critère d'hygiène des procédés, dans le but d'évaluer l'impact des interventions et de recueillir des données utiles à l'évaluation quantitative des risques.

4. CONCLUSIONS ET RECOMMANDATIONS DE L'AGENCE

L'Anses souligne que *Campylobacter* constitue la première cause de maladie alimentaire d'origine bactérienne en France, avec 400 000 à 800 000 cas humains annuels de campylobactériose.

Dans ce contexte, l'Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail endosse les conclusions et recommandations du Comité d'experts spécialisé BIORISK.

L'Anses rappelle l'importance de mettre en place les diverses mesures évoquées dans le présent avis, à tous les maillons de la chaîne depuis la production jusqu'à la consommation, avec une attention particulière au niveau des consommateurs et des préparations alimentaires domestiques. A cet égard, la stratégie d'élaboration de messages préventifs vers les consommateurs pourra être éclairée par le rapport antérieur de l'Anses *sur l'information des consommateurs en matière de prévention des risques biologiques liés aux aliments* (ANSES 2015).

Depuis janvier 2018, un nouveau critère d'hygiène portant sur *Campylobacter* est appliqué dans les abattoirs. Les données d'autocontrôles générées par cette nouvelle réglementation permettraient d'affiner les modèles d'évaluation quantitative du risque et de mieux orienter la stratégie globale de lutte. Le partage de ces données dans cette perspective gagnerait à faire l'objet d'une réflexion dans le cadre de la plateforme de surveillance sanitaire de la chaîne alimentaire.

Celle-ci permettrait également de mieux documenter les sources de *Campylobacter* en tant qu'agent infectieux d'origine alimentaire.

Avis de l'Anses
Saisine n° 2016-SA-0183
Saisine liée n°2001-SA-0313

Dr Roger Genet

State of knowledge relating to the contamination of broilers with *Campylobacter* and assessment of the impact of interventions at different stages of the food chain in France

Collective Expert Appraisal Report

Expert Committee on Assessment of the biological risks in food (CES BIORISK)

Working group « *Campylobacter* »

June 2018

Key words

Campylobacter, poultry, broilers, interventions, control measures, quantitative microbial risk assessment

Presentation of participants

PREAMBLE: EXPERT MEMBERS OF EXPERT COMMITTEES, WORKING GROUPS OR APPOINTED RAPPORTEURS ARE ALL APPOINTED IN A PERSONAL CAPACITY, *INTUITU PERSONAE,* AND DO NOT REPRESENT THEIR PARENT ORGANISATION.

WORKING GROUP

Chair

Olivier CERF – Emeritus Professor, Alfort Veterinary School. Food safety risk evaluation, bacteriology, surveillance, analytical methods, modelling, QMRA.

Members

Declan BOLTON – Principal Research Officer, Food Safety Department, Teagasc Food Research Centre, Agriculture and Food Development Authority, Ireland. Microbioloy, epidemiology, poultry primary production.

Marianne CHEMALY – Head of Hygiene and Quality of Poultry and Pig Products Unit, ANSES, Ploufragan-Plouzané Laboratory. Microbiology and food safety, hygiene.

Pierre COLIN – Honorary Professor, University of Western Britanny. Food microbiology and hygiene, meat products and poultry

Lieven DE ZUTTER – Honorary Professor, Ghent University, Faculty of Veterinary Medicine, Department of Veterinary Public Health and Food Safety. Food microbiology, veterinary public health, food hygiene, epidemiology of foodborne pathogens in the food chain.

Mr Michel FEDERIGHI – ONIRIS, Nantes. Health risk assessment, hygiene and microbiology of foods (meat and meat products), food bacteriology (*Campylobacter*), decontamination processes (antimicrobial substances, high pressure, pulsed light, radiation).

Philippe FRAVALO – University of Montreal, Canada, Faculty of Veterinary Medicine. Health risk assessment, hygiene and microbiology of foods (poultry and pig products); food bacteriology (*Salmonella*, *Listeria monocytogenes*, *Campylobacter*), microbial ecology, molecular biology and genetic engineering.

Milen GEORGIEV – Food Standards Agency, UK. Veterinary adviser, Team leader in Meat Hygiene Policy. Food bacteriology, epidemiology, primary production.

Muriel GUYARD-NICODEME – Scientific officer, Hygiene and Quality of Poultry and Pig Products Unit, ANSES, Ploufragan-Plouzané Laboratory. Microbiology and food safety, host-pathogen relationship.

Nabila HADDAD – Associate professor in food safety and microbiology, Secalim UMR1014, INRA, Oniris, Nantes. Food microbiology and hygiene.

Adeline HUNEAU-SALAÜN – Scientific officer, Avian and Rabbit Epidemiology and Welfare Unit, ANSES, Ploufragan-Plouzané Laboratory. Epidemiology, biosecurity, French poultry sector.

Maarten NAUTA – Senior Scientist, National Food Institute, Technical University of Denmark. Quantitative microbiological risk assessment.

REVIEWERS

Michel GAUTIER – AGROCAMPUS OUEST. Microbial ecology, molecular biology and genetic engineering, food hygiene.

Laurent GUILLIER – ANSES Laboratory for Food Safety, Maisons-Alfort. Modelling, QRA, predictive microbiology, hygiene and microbiology of foods.

EXPERT PANEL

The work covered in this report was monitored and adopted by the following Expert Committee (CES): CES on Assessment of the biological risks in foods (CES BIORISK)

Chairwoman

Isabelle VILLENA – Reims University Hospital. Parasitology, health risk assessment, infectious diseases.

Members

Jean-Christophe AUGUSTIN – Maisons-Alfort Veterinary School. Health risk assessment, modelling, predictive microbiology, analytical methods.

Anne BRISABOIS – ANSES Laboratory for Food Safety, Maisons-Alfort. Microbiology of foods, microbial ecology, analytical methods.

Frédéric CARLIN – INRA. Microbiology of foods, fruit and vegetable industry, decontamination technology.

Olivier CERF – Emeritus Professor, Alfort Veterinary School. Food safety risk evaluation, bacteriology, surveillance, analytical methods, modelling, QMRA.

Pierre COLIN – University of Western Brittany. Health risk assessment, hygiene and microbiology of foods (meat and meat products - poultry), food bacteriology (*Salmonella*, *Campylobacter*, *Listeria monocytogenes*).

Philippe DANTIGNY – ENSBANA. Mycology, decontamination processes, microbial ecology and hygiene of foods, modelling, predictive microbiology.

Florence DUBOIS-BRISSONNET – AGROPARITECH. Stress coping mechanism, biofilms, hygiene of surfaces and processes.

Michel FEDERIGHI – ONIRIS, Nantes. Health risk assessment, hygiene and microbiology of foods (meat and meat products), food bacteriology (*Campylobacter*), decontamination processes (antimicrobial substances, high pressure, pulsed light, radiation).

Benoit FOLIGNE – Lille School of Pharmacy. Intestinal microbiota, food/microbiota ecosystem interaction.

Florence FORGET-RICHARD – INRA. Mycotoxins, filamentous fungi, biochemistry, cereal industries.

Philippe FRAVALO – University of Montreal - Faculty of Veterinary Medicine. Health risk assessment, hygiene and microbiology of foods (poultry and pig products), food bacteriology (*Salmonella*, *Listeria monocytogenes*, *Campylobacter*), microbial ecology, molecular biology and genetic engineering.

Pascal GARRY – IFREMER. Hygiene of foods (delicatessen meat products in particular), shellfish, modelling, predictive microbiology, food technologies.

Michel GAUTIER – AGROCAMPUS OUEST. Microbial ecology, molecular biology and genetic engineering, food hygiene.

Laurent GUILLIER – ANSES Laboratory for Food Safety, Maisons-Alfort. Modelling, QRA, predictive microbiology, hygiene and microbiology of foods.

Nathalie JOURDAN-DA-SILVA – Santé publique France. Epidemiology of enteric diseases and zoonoses.

Alexandre LECLERCQ – Institut Pasteur. Standardisation, *Listeria monocytogenes*, hygiene and microbiology of foods.

Simon LE HELLO – Institut Pasteur. Epidemiology, *E. coli, Shigella* and *Salmonella,* clinical infectious diseases, microbial ecology, analytical and statistical methods.

Eric OSWALD – Toulouse University Hospital - Paul Sabatier University. Clinical infectious diseases, microbial ecology, epidemiology, molecular biology and genetic engineering, food bacteriology of *E. coli.*

Nicole PAVIO – ANSES Laboratory for Food Safety, Maisons-Alfort. Virology.

Sabine SCHORR-GALINDO – Montpellier 2 University. Mycology, microbial ecology, food technologies, biotechnologies, hazard analysis, HACCP.

Muriel THOMAS – INRA. Intestinal microbiota, human nutrition, probiotics, health.

ANSES PARTICIPATION

The scientific coordination of the work was conducted by the Unit on food risk assessment (UERALIM) under the supervision of Moez SANAA (head of Unit) and Nathalie ARNICH (deputy head of unit).

Scientific Coordination

Marie-Bénédicte PEYRAT – Risk assessment department, Unit on food risk assessment.

Scientific Contribution

Virginie DESVIGNES – Risk assessment department, Unit on food risk assessment.

Sonia POISSON – Risk assessment department, Unit on methodology and studies.

Administrative Secretariat

Angélique Laurent – Risk assessment department.

HEARING OF PERSONALITIES

Primary production:

Yannick CARRE representing the CIDEF-CIPC-CICAR (CIDEF: Interprofessional Committee of the French Turkey, CIPC: Interprofessional Committee of the Broiler, CICAR: Interprofessional Committee of the Duck to Roast).

Juliette PROTINO and Grégoire MIDY (veterinarian of Terrena Group – Farmers of Ancenis), representing the SYNALAF (National Union of Poultry Labels of France).

Slaughterhouses and cutting plants

Julie MAYOT and Paul LOPEZ representing the FIA (Federation of Poultry Industries).

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Collective Expertise: Summary of the Discussion and Conclusions

Campylobacteriosis is a gastro-intestinal disease caused by the ingestion of food contaminated by bacteria belonging to the genus *Campylobacter*. These bacteria are frequent inhabitants of the digestive tract of poultry, and broiler is considered the main source of campylobacteriosis. *Campylobacter* do not affect poultry health. The European Food Safety Authority (EFSA) published in 2011 an opinion on *Campylobacter* in broiler meat production that exhaustively reviewed the scientific literature, modelled the effect of a variety of interventions at different stages of the food chain aimed at reducing the risk of campylobacteriosis. ANSES was requested by the French General Directorate for Food (DGAL) to update the knowledge on *Campylobacter* contamination of broilers and to assess the impact of interventions at different stages of the food chain in France.

A group of experts from five European Member States was set up by ANSES for this purpose. The experts had been chosen for their competence in microbiology, technology and quantitative risk assessment.

The experts gathered the scientific literature published since 2011, and organized hearings of representatives of the French poultry sector. They reviewed carefully the recent publications and the newly acquired knowledge. They listed the interventions that could be applied in France, in the current state of the European legislation. Then they proposed those that could be reasonably applied, with indication of their plausible effects.

To calculate a "baseline estimate" of the number of campylobacteriosis cases in France, the mathematical CARMA model was used. It was complemented with two modules: one for the chilling and storage step, and one for the consumer stage. The latter used data acquired by ANSES to describe hygienic practices typical of the behaviour in French households.

The model was run with data relevant to the manufacture of fresh fillets from broilers reared in-door.

Then, the model was used to evaluate the effect of single or combined interventions at each stage of the food chain that is at the farm, the slaughter or the consumer level. Finally, the effect of combinations of interventions at the three stages was evaluated.

To compare the number of cases after intervention(s) to the baseline estimate, a percentage of relative risk reduction was calculated as follows:

$$risk\ reduction\ (\%) = 100 \times \left(1 - \frac{number\ of\ cases\ after\ intervention(s)}{number\ of\ cases\ before\ intervention(s)}\right)$$

Importantly, with the modelling approach used here, whether broilers are reared in- or out-door (for most interventions), the part of carcass submitted to the interventions, the level of detection of analytical methods and the absolute value of the number of cases before interventions (whether underestimated or overestimated as it was in the present case) have no influence on the relative risk reduction.

The Working Group conclusions are as follows:

Almost no new data have been generated about the situation of *Campylobacter* in broiler products in France since the European baseline study in 2008.

However, various interventions at different stages of the food chain have been tested in France, in the EU and in the world since 2010. Up to now, no single intervention has been proven to be effective and applicable enough to be adopted by the broiler production sector. Controlled trials on farms or in slaughterhouses are lacking and it is not possible to quantitatively evaluate the efficacy and the applicability of these interventions in commercial conditions.

The CARMA model, completed in this work, with a chilling module and a consumer phase, enabled to estimate the effect of a number of scenarios:

- At the farm, the model, according to its specific hypotheses, showed that the most effective interventions are those that reduce the contamination level on carcasses (CFU/g), rather than reducing the prevalence of contaminated carcasses. Therefore, as soon as, for example, vaccination will be available, it might prove quite effective at protecting public health. If, for instance, vaccination would achieve 1.5 decimal reductions of carcass contamination level, the relative risk reduction would be 85%.

- At the slaughter plant, achieving one more decimal reduction of carcass contamination by scalding or by reducing faeces leakage at the plucking or evisceration steps would result only in a relative

risk reduction of 3% or 4% in the present state of the slaughter chain technology. By contrast, the chilling process seems to be very effective and, as an example, the model shows that one DR of carcass contamination would reduce the risk by 76%.

In the home kitchen, hand washing alone has a limited effect on campylobacteriosis incidence (1% reduction of relative risk). However, the cleaning of utensils to prevent cross contamination is effective. If, for example, recommendations on utensil cleaning were effectively applied by all consumers, the relative risk reduction would be 85%. Perfect application of good hygienic practice in the home kitchen would be highly effective. However, according to a previous ANSES report on consumer information (2015) it may be difficult to change consumer behaviour. The experts tested also two scenarios including operations at the farm, at the slaughterhouse and at home. The effect of a combination of interventons is not strictly cumulative. The scenario with the weakest interventions would achieve a relative risk reduction of 16% while the scenario with the strongest interventions would achieve a risk reduction of 99%.

The results demonstrated that there is room for improvement of public health protection. However, a major relative risk reduction would need the application of interventions that are presently at the stage of experimentation and development (such as vaccination), improvement of hygienic design of slaughter machinery, as well as better compliance to good hygienic practices all along the food chain including by the consumers. Perfect application of good hygienic practices in the home kitchen would be highly effective. However it is difficult to change consumer behaviour.

Field trials should be done to measure the actual reduction effect of the interventions on faecal content, animal contamination and carcass contamination. The results of these trials, a survey on the acceptability by the farmers, an estimation of the future farmer compliance to guidelines, etc. would have to be combined with those from a cost/benefit analysis (including the benefit of DALY reduction) in actual conditions.

A further consideration to be accounted for would be the influence on the final result of the imported products contamination level and the proportion of these products in the national consumption.

Abbreviations

ANSES: French Agency for Food, Environmental and Occupational Health and Safety

AST: ANSES Scientific and Technical Statement

CES: Expert Panel

CFU: Colony Forming Unit

CPM: Consumer Phase Model

DGAL: General Directorate for Food, French Ministry of Agriculture

DR: Decimal Reduction (also called log reduction)

EC: European Commission

ECDC: European Centre for Disease Prevention and Control

EFSA: European Food Safety Authority

EU: European Union

GBS: Guillain-Barré Syndrome

GGHP: Guide to Good Hygiene Practice and Application of the HACCP Principles

HACCP: Hazard Analysis Critical Control Point

INAO: National Institute of Origin and Quality

INCA: Individual and National Food Consumption Survey

INSEE: National Institute of Statistics and Economic Studies

MPRM: Modular Process Risk Modelling

OMP: Outer Membrane Proteins

PHC: Process Hygiene Criterion

QMRA: Quantitative Microbiological Risk Assessment

RTE: Ready to Eat

SD: Standard Deviation

TEC: Tonnes of Carcass Equivalents

ToR: Terms of Reference

VBNC: Viable But Non-Culturable

WG: Working Group

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Glossary

For the purpose of the present document, the following definitions apply:

Biosecurity: Set of preventative measures implemented to reduce the risk of transmission of infectious disease from reservoirs of the infectious agent to the target host (EFSA 2011).

Thinning: Partial flock depopulation, prior to complete depopulation.
NOTE: Thinning is done according to the need for light or heavy birds. It reduces the stocking density and allows more space for the remaining birds and reduces the natural temperatures in housing.

1. Context, objectives and realisation of the expertise

1.1 Context

Campylobacter spp. is the most common cause of food zoonosis in France and in Europe with a steady increase in the number of cases over the past fifteen years (Van Cauteren *et al.* 2015, EFSA 2017). Monitoring plans show a high level of *Campylobacter* contamination in poultry and poultry products in France. Fifty to eighty percent of human campylobacteriosis in Europe is attributed to chicken reservoir as a whole according to EFSA (2011). To date, France does not have a national control plan for *Campylobacter* while several other EU Member States (e.g. Denmark (Rosenquist *et al.* 2009), Sweden (Hansson *et al.* 2007)) have implemented control measures several years ago.

In this context, ANSES was requested by the French General Directorate for Food (DGAL) to assess the risk of human campylobacteriosis and evaluate the impact of possible control measures in the poultry meat sector.

1.2 Terms of reference as provided by the DGAL (letter in Annex 1)

The request of the DGAL was to update knowledge about *Campylobacter* in broilers and chicken products, strategies for controlling the risk posed by the contamination and their efficacy. The review had to focus on the French situation more specifically with emphasis on the impact of consumers' practices on the risk of campylobacteriosis and on availability of analytic methods and their constraints.

The Working Group, in agreement with DGAL received the following remit:

1 / Survey of control measures of *Campylobacter* in the poultry production, and of their improvement since the report of EFSA (2011).

The effectiveness of control measures should be documented at the following steps:

- Placing on the market of live birds (breeder end product),
- Placing on the market of carcasses (abattoir end product),
- Purchasing at the retail level,
- Consumption.

Consideration should be given to the performance of available analytical methods for the detection and enumeration of *Campylobacter*.

2 / Modelling of the French poultry food chain from rearing to consumption with the view of:

- Assessing the risk of consumer disease,
- Selecting/optimizing the control measures with respect to their effectiveness *per se* and considering their cost effectiveness/efficiency.

3 / Cost-benefits analysis of risk reduction.

1.3 Terms of reference as retained in the present report

The ToRs were all considered by the experts, with the following exceptions:

- The performance of available analytical methods for the detection and enumeration of *Campylobacter* was not accounted for because it has no influence on the effect of interventions when the latter is expressed in relative terms.

- Concerning the cost-benefits analysis of the risk reduction, it was not deemed a priority for the Working Group because it requires specific competences and data not easily available. Moreover, the Working Group decided to focus on food safety issues.

The present report will focus on broilers and not on other avian sectors.

1.4 Modalities of treatment

After a public call of experts, the Working Group « *Campylobacter* » has been established by ANSES to instruct the referral, under the supervision of the Expert Panel on the evaluation of Biological Risks in Foods (so called BIORISK Committee).

The Working Group had met on thirteen occasions from March 2017 to June 2018. The work of the WG was submitted on a regular basis to the BIORISK Committee, with regard to methodological as well as scientific aspects. The work was presented at the meeting of January 2017, January, May and June 2018. The WG report accounted for the comments and additions suggested by the BIORISK Committee members and the reviewers. As a consequence, the final report is the product of an interactive and collective work of expertise done by experts with complementary competences. The work was presented and adopted at the CES BIORISK meeting of the 11th July 2018.

The French Standard NF X 50-110 (May 2003) "Quality in Expertise - General Competence Requirements for Expertise" was applied.

1.5 Data collection

1.5.1 Extensive bibliographical research

The starting point of the expertise was the EFSA (2011) report.

An extensive bibliographical research of scientific articles published since 2011 was conducted on the databases Scopus and PubMed with the search terms "*Campylobacter* AND poultry AND control". The request was made on the 26th of April 2017.

332 references were retained and grouped according to the following topics:

- primary production: 192 articles,

- transport and slaughter: 68 articles,

- packaging and consumer and kitchen practices: 42 articles,

- quantitative microbial risk assessment: 33 articles.

Two or three experts were designated to review the same list of references corresponding to the above four topics. A reading grid template (Annex 2) was provided to the experts. In the first window, the expert had to fill in their name, the reference of the article and its type (article, grey literature, book, report), the country of origin, the poultry species. The expert indicated in the second window the stage in the food chain, the intervention and where its effect was measured, the type and size of the samples, how the effect of the intervention was measured (relative risk, odds ratio, number of decimal reductions and standard deviation), and the expert had to provide an opinion on the confidence with respect to the intervention effect. In the third window, the expert indicated if the authors had any conflict of interest, if the intervention is applicable in France, and the bias identified. Only references with low and likely low bias and with relevant method were selected and experts of the working group could add articles and reports along the work of the working group (see annex 3: Literature update of interventions).

1.5.2 Hearings of representatives of the poultry sector

In addition to the review of the literature, two auditions of representatives of the French poultry sector took place (see above the section "Hearing of Personalities").

1.5.3 Consumption data: survey INCA 3

The information on the dietary exposition was drawn from the third national consumption survey (ANSES 2017) (https://www.anses.fr/en/content/inca-studies).

The INCA3 study has been used to provide the data. The INCA3 survey was conducted between February 2014 and September 2015, in metropolitan France, among 5855 individuals (2698 children and adolescents from birth to 17 years old, and 3157 adults from 18 to 79 years old). The INCA3 survey population is representative of all individuals living in an ordinary household in metropolitan France (excluding Corsica). To ensure the national representativeness of the results, the data have been adjusted according to a method defined in consultation with INSEE.

1.6 Prevention of the risks of conflict of interests

ANSES analyses interests declared by experts prior to their appointment and throughout their work in order to avoid potential conflicts of interest with regard to the matters dealt with as part of the scientific assessment. The experts' declarations of interests are made public via the Ministry in charge of public health website (https://dpi.sante.gouv.fr)

No interests or conflicts of interest were identified during the appraisal.

2. *Campylobacter* and public health

2.1 Campylobacter

Bacteria belonging to the genus *Campylobacter* are Gram-negative, spiral, rod-shaped, or curved, approximately 0.2 to 0.8 µm wide and 0.5 to 5 µm long. These non-spore-forming bacteria are chemoorganotrophs which obtain their energy from amino acids or tricarboxylic acid cycle intermediates (Vandamme *et al.* 2005). Most *Campylobacter* species grow under microaerobic conditions and have a respiratory type of metabolism. Yet, some species require hydrogen or formate as an electron donor for microaerobic growth, such as *C. concisus or C. curvus.* In addition, certain species prefer anaerobic conditions for growth (Man 2011). The optimal growth of this microaerophilic and capnophilic pathogen requires 5% of oxygen, 10% of carbon dioxide and 85% of nitrogen. In addition, its optimal temperature of growth is variable according to the species, but for the thermotolerant species, which are mainly involved in campylobacteriosis cases, the optimal temperature of growth is 42°C and minimal growth temperature is 30°C (Butzler 2004). Therefore, in field conditions, *Campylobacter* cannot grow on the carcasses.

The genus *Campylobacter* is comprised of several species isolated from human and animal cases, however, to date, those most commonly isolated from foodborne disease are the thermophilic species (EFSA and ECDC 2017). Indeed, according to EFSA and ECDC (2017), human cases of campylobacteriosis are mainly due to *C. jejuni* in 83.6% of cases, followed by *C. coli* (8.5%), *C. lari*, *C. fetus* and *C. upsaliensis*. In France, *C. jejuni* (84%) and *C. coli* (13%) were the main species isolated from human cases in 2016 according to the National Reference Centre for *Campylobacter* and Helicobacter http://invs.santepubliquefrance.fr/content/download/138051/497180/version/1/file/Bilan_*Campylobacter*_2016.pdf)

This microorganism is widespread in the gut of domestic and wild birds (Johnson *et al.* 2017, Jonaidi-Jafari *et al.* 2016, Weis *et al.* 2016), but can also commonly colonizes domestic livestock, including cattle, goats, pigs, sheep (EFSA and ECDC 2017, Manyi-Loh *et al.* 2016) and in domestic carnivores (Pintar *et al.* 2015). In broilers, it has been observed that *Campylobacter* is more prevalent during summer (EFSA 2011). *Campylobacter* can be isolated from various environmental reservoirs, such as environmental water sources (EFSA and ECDC 2017) and soils. Although *Campylobacter* concentrations in this hydro-telluric environment is relatively low, the water of the rivers, ponds, lakes and public swimming pools, can be a secondary reservoir of these bacteria (ANSES 2011).

2.2 Campylobacteriosis

In industrialized countries, *Campylobacter* is recognized as the highest cause of bacterial foodborne enteritis and the associated illness is called campylobacteriosis. Patients affected by campylobacteriosis may experience mild to severe symptoms, with common clinical symptoms including watery, sometimes bloody diarrhoea, abdominal pain, fever, headache and nausea. Infections are usually self-limiting and last only a few days, however the reinfection is possible too. Despite the high number of human campylobacteriosis cases, their severity in terms of reported case fatality is low (0.03%) (EFSA and ECDC 2017).

Moreover, *C. jejuni* infection can lead to autoimmune conditions known as Guillain-Barré syndrome (GBS) and can been associated with a range of gastrointestinal conditions, including inflammatory bowel diseases, Barrett's oesophagus (Man 2011). Post-infection complications, such as reactive arthritis and neurological disorders, can also occur. Nowadays, *C. jejuni* has become the most commonly recognized antecedent cause of Guillain–Barré Syndrome, a polio-like form of paralysis that can result in respiratory failure and severe neurological dysfunction and even death (EFSA and ECDC 2017). According to Havelaar *et al.* (2012), the DALY associated with campylobacteriosis is 41 years for 1000 inhabitants in the Netherlands in 2009.

2.3 Epidemiology

In the European Union, human campylobacteriosis is the most commonly notified bacterial food-borne disease with around 246 000 confirmed cases reported in 2016, resulting in an EU notification rate of 66.3 cases per 100,000 population (EFSA and ECDC 2017). Broiler meat is considered the most important source of human campylobacteriosis (EFSA and ECDC 2017).

While *Campylobacter* sp. from the broiler reservoir is well recognized as an important source of human infection there is increasing evidence that bovine reservoir also plays an important role (Thépault *et al.* 2017). A variation in assignments of French clinical cases over the years indicated the importance of a yearly based surveillance (Thepault, Quesne, *et al.* 2018). The contamination of bovine meat appeared to be low to absent (DGAL 2012), therefore the environmental transmission (indirect transmission from cattle to humans via the environment) should be investigated as a possible source of transmission to humans. Indeed, several other studies pointed out the cattle reservoir as to be highly contaminated (Cha *et al.* 2017, De Haan *et al.* 2010, Hakkinen *et al.* 2007, Thepault, Poezevara, *et al.* 2018). In addition to be the main food-borne causative agent in sporadic cases in the EU, this pathogen is also responsible of strong-evidence outbreaks.

Differently from 2014 when broiler meat was the most common food vehicle implicated in strong-evidence outbreaks caused by *Campylobacter*, in 2015 the most frequently reported food vehicle was raw milk (14 outbreaks), followed by broiler meat and products thereof (6 outbreaks) (EFSA and ECDC 2017).

Recently the incidence of campylobacteriosis in France in the general population for the period 2008-2013 was estimated based on data related to the probabilities of a case visiting a doctor, having a stool requested, having a positive laboratory test and having the case reported to the national reference centre (Van Cauteren *et al.* 2018). The reported cases within this period were 4608 annually and the estimated incidence was 492,705 cases. The multiplication factor between reported cases and estimated cases was 115. Also, the number of hospitalisations due to a *Campylobacter* infection was considered. Annually 3088 cases were reported. Taking the diagnostic sensitivity of the stool culture into account the number increases to 5182 cases/year. Comparison of results for human salmonellosis indicated that the under-estimation ratio of *Campylobacter* infections is much higher than for *Salmonella* infections, *viz.* 20.

In France, a national case-control study was conducted from September 2002 to June 2004 to identify risk factors for acquiring sporadic *Campylobacter* infection. Results showed that "Ate undercooked beef", "ate at restaurant" and "poor utensils hygiene in the kitchen" were the main independent risk factors for infection (Gallay *et al.* 2008).

2.4 *Campylobacter* in EU Food Regulation

The prevention of food-borne zoonoses in general relies on EU Regulations N° 852/2004, 853/2004 and 854/2004 for food from animal origin. Before 2018, no specific regulation existed for the mitigation of the risk caused by *Campylobacter* in poultry meat. No coordinated action plan was carried out by the food business operators.

A public health risk reduction > 50% or > 90% could be achieved if all batches would comply with microbiological criteria with a critical limit of 1000 or 500 CFU/gram of neck and breast skin, respectively.

The European Commission adopted the Regulation 2017/1495 amending Regulation (EC) No 2073/2005. The text established a processing hygiene criterion (PHC) for *Campylobacter* applicable in broiler slaughterhouses. Coming into force on the 1st of January 2018, this Regulation introduced a microbiological PHC for *Campylobacter* on broiler carcasses after chilling (table 1). Over time, the maximum number of samples exceeding 1000 CFU/g of 50 neck skin samples will be reduced from 20 in 2018 to 10 in 2025.

Table 1 - Microbiological criterion in Regulation 2073/2005 (consolidated)

Food category	Micro-organism	Sampling plan ([1])		Limits ([2])		Analytical reference method ([3])	Stage where the criterion applies	Action in case of unsatisfactory results
		n	**c**	**m**	**M**			
2.1.9 Carcases of broilers	Campylobacter spp.	50 ([5])	c = 20 From 1.1.2020 c = 15; From 1.1.2025 c = 10	1000 CFU/g		EN ISO 10272-2	Carcases after chilling	Improvements in slaughter hygiene, review of process controls, of animal's origin and of the biosecurity measures in the farms of origin

([5]) The 50 samples shall be derived from 10 consecutive sampling sessions in accordance with the sampling rules and frequencies laid down in this Regulation.

The European Commission discussed intervention options to assist processors in achieving these targets. To date, EFSA considered the use of trisodium phosphate, acidified sodium chlorite, chlorine dioxide or peroxyacid solutions to decontaminate the carcasses. All these chemicals are considered to be "safe" for use and effective in achieving the *Campylobacter* reductions required (EFSA 2011), but no authorisation has been granted so far at European level.

3. Organisation of the French poultry sector

3.1 The broiler sector

3.1.1 Poultry production

In the European Union, France is the second largest producer of poultry meat, after Poland, with a global production reaching 1 872 000 tonnes of carcass equivalents (TEC) in 2015 (13% of the EU production). EU chicken meat represents two-thirds of the French poultry meat production and is the single poultry species showing an increase of the production over the last 5 years. Poultry meat is the second meat consumed (26.3 kg per habitant in 2014) in France after pork meat; broiler is the most popular poultry meat and about 90% of the French households purchase this meat. In 2015, about one quarter of broilers were sold as whole carcasses whereas cutting parts and elaborated products account respectively for 44% and for 31% of the purchases (Figures 1 and 2) (FranceAgriMer 2016).

The consumption of chicken meat (all products combined) has been stable for several years (figure 3).
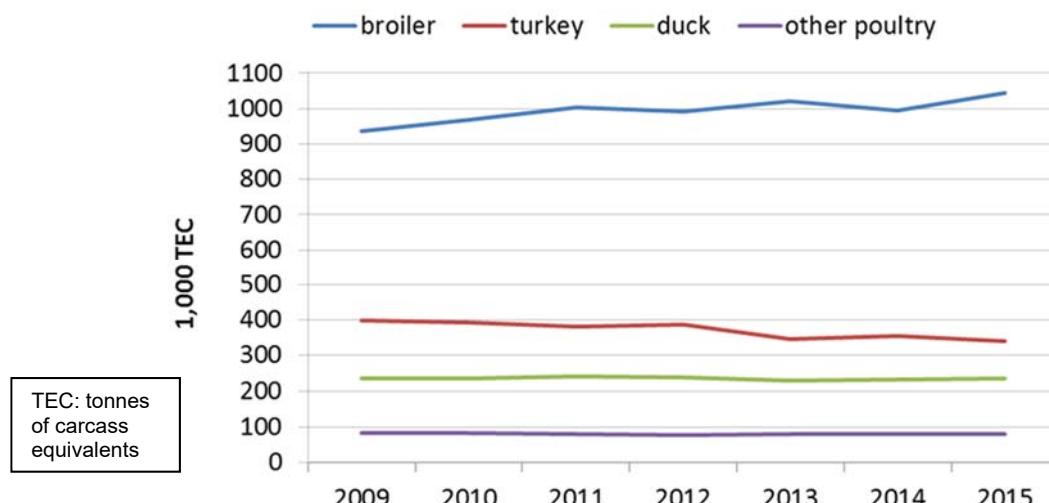
**Figure 1 : Production of poultry meat in France from 2009 to 2015 (FranceAgriMer 2016)**
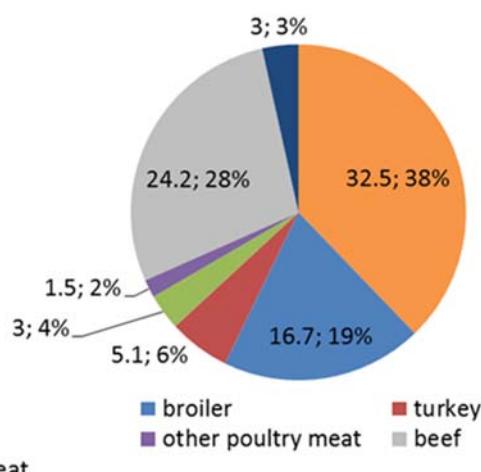
Figure 2: Consumption of meat (kg per habitant) in France in 2014 (FranceAgriMer 2016)
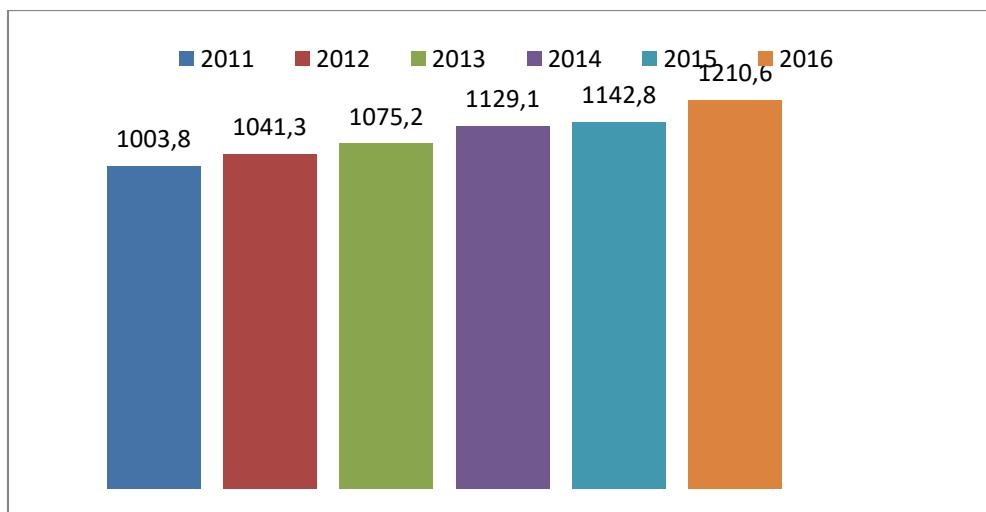
Figure 3: Consumption of broiler meat in France from 2011 to 2016 (in millions of tons carcass equivalent)

The major household purchasing trends in mainland France concerning broiler show a significant increase (+ 2.4%, 2016 vs 2015) of cuts (including + 3.6% for skinless fillets) to the detriment of whole broiler (-7.7% over the same period). In 2015, household purchases were distributed as follows:

- Whole broiler 30% (of which two thirds of "Label Rouge"),

- Broilers cuts 44%,

- "Elaborates" of broiler 26%.

All products combined, purchases are still predominantly in supermarkets (78%).

3.1.2 Main production systems in France

French poultry production is very diverse. There are five main production systems for broilers (Table 2) with differences in housing conditions, genetics used and rearing practices.

1. The "**small standard**" production is a specific production, mainly for exporting to third countries. The slaughter age is low (less than 39 days), allowing a high density housing of birds (22-30/m²); these products are mainly sold as frozen.

2. The "**standard**" production is the typical "French production" for broiler. About 10 to 15% of the flocks are thinned to meet abattoirs' demand for small and heavy broilers. This product is mainly a 'ready to cook', that means eviscerated and chilled. These products could be cooked in different ways (e.g. roasted, barbecues, stew).

3. The "**heavy standard**" production is a new type, allowing to rear, in the same house, broilers for two different markets: the youngest (females) are designed to the traditional "Standard" market, the oldest (male) for cutting and further processing. This production is the consequence of the market fragmentation including the increasing need of cut up (e.g. legs, wings, fillets) and further processed products (e.g. nuggets, "cordon bleu"). Thinning of part of broilers occurs during the rearing period, after 39-41 days.

4. The "**certified**" production responds to specific requirements that are controlled by independent certification organisms. The main features of the production are the use of medium growing strains, an extended rearing period (>56 days of age) and a lower rearing density but broilers are kept inside the poultry house (no open-air range). About 75% of the flocks are thinned for the production of "cockerel" *i.e.* small broilers (28 days of age, 400 to 700 g) sold as whole carcasses.

5. The "**free range**" and the "**organic**" productions, mainly characterized by slow growing strains of broilers and the access to an open-air range. Organic production system meets the requirements set for organic production at European and national levels. For the free-range production system, a large

part of the production fulfils the specific requirements of the "Label Rouge" standard or of the "Protected Geographical Indication" standard (INAO, http://www.inao.gouv.fr/eng/).

Table 2: Characteristics of main production systems for broilers in France

	Indoor				Outdoor	
	Standard			Certified	Free-range	Organic
	small	standard	heavy			
% production in 2015*	74.9%			8.0%	15.9%	1.2%
Approx. number of farms	3,600				5,000	600
Genetic strain	Fast growing			Medium growing	Slow growing	
Stocking density, m^2	22-30	20-25	17-18	16-18	11	10
Down-time	No specific requirement				14 d	8 weeks for open-air run
Slaughter age (days)	< 39	39-42	♀ 39-41 ♂ 49-51	>56	>81	>81
Sex segregation	No	No	Yes	No	No	No
Outdoor access	No	No	No	No	Yes	Yes
Thinning	No	Not frequent	Yes	Yes	No**	No**
Max. houses/farm	No specific requirement				3	3
Max. birds/house	No specific requirement				4.500	4.000

* Based on slaughtered volume in abattoirs (Agreste 2016)
** Except for Christmas products as capons.

3.2 Transport from farms to slaughterhouses

At the farm level, feed must be withdrawn from the flock in order to reduce defaecation during transportation, to reduce faecal leakage during defeathering and to facilitate evisceration in the slaughter plant by improving the clearance of the gastrointestinal tract and consequently reducing the risk of contamination of the carcasses. The Council Directive 2007/43/EC limits feed withdrawal to a maximum of 12 hours before the expected slaughter time (EFSA 2011). This operation consists of suspension of the availability of feed and water before transport to the slaughterhouse and during transportation.

The transport of broilers to slaughterhouses is done in crates or cages. The duration depends of the distance between the farm and the slaughterhouse and cannot last longer than 12 hours according to the Regulation 1/2005, otherwise, broilers must be watered and fed.

3.3 Broiler slaughtering process

Organisation of the slaughtering and cutting processes:

A slaughterhouse is an establishment for the preparation of meat, the processing of by-products (edible or not) where these products are subject to a health inspection and to the assessment of their quality. The approved establishments specialized or not, public or private, will thus allow the progressive transformation of a live animal coming from the poultry sector, in carcass, in meat and co-products. The combination of these steps represents the "first transformation."

The production of poultry and rabbits' carcasses has remained very stable in France since 2008 (Figure 4, (ITAVI 2018)).
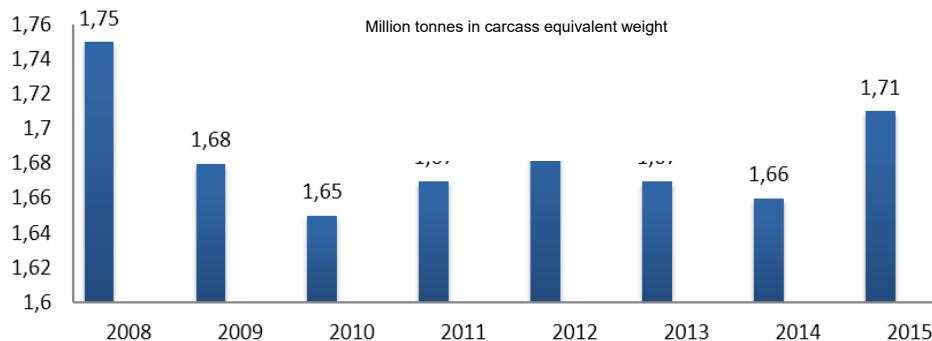
Figure 4: Annual production from French abattoirs of poultry and rabbits (in million Tonnes in carcass equivalent weight) (ITAVI 2018)

The list of EC approved slaughterhouses for poultry, rabbits (and related animals) (https://fichiers publics.agriculture.gouv.fr/dgal/ListesOfficielles/SSA1_VIAN_COL_LAGO._pdf, consulted on 2018-04-16) shows, excluding the overseas departments and territories, in 2016, a total of 684 approved establishments distributed according to their specialisation as described in Table 3.

Table 3: Mainland France slaughterhouses distribution by activity in January 2016 (A: avian; L: rabbit or related; R: ratites [ostrich and emus])

Type of slaughterhouses	A	L	R	Mixed*	Total
Number	516	17	12	139	684

* A-L or A-R or A-L-R

If one excludes the twenty-nine specialized slaughterhouses of rabbits and ratites, this data obviously covers a large diversity of structures, both in terms of specialisation (slaughterhouses of ducks, turkeys, broilers, etc.) and of production capacity expressed in TEC/d (tonnes in carcass equivalent weight per day). By contrast, operations constituting the slaughtering process are similar. Differences in general relate to the size of the equipment and the level of automation for certain steps.

Figure 5 gives the distribution by species in mainland France and per year of slaughtering activities. Broilers (> 1 million TEC), turkeys (340,000 TEC) and ducks (234,000 TEC) accounted for 94% of slaughtering in 2015 (ITAVI 2018).
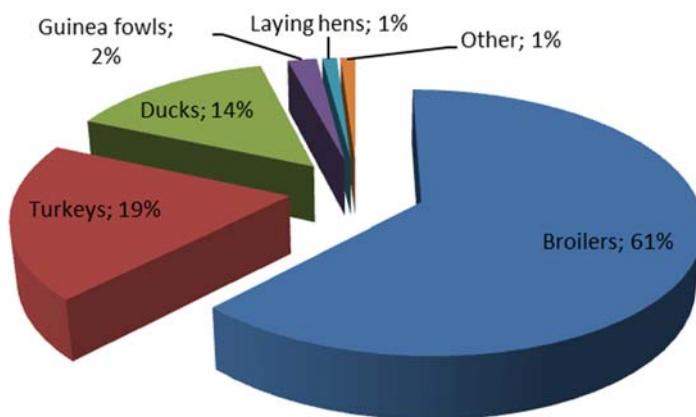
Figure 5: Distribution of species slaughtered in France (ITAVI 2018)

In France, broilers slaughterhouses vary for their capacity (number of birds slaughtered during one day) and the types of birds slaughtered. Furthermore, the line speed could be different, from one hundred to several

thousand birds slaughtered per hour. As an example, there are some industrial slaughterhouses treating 500 000 for export carcasses per day, based on two or three shifts per day with two (four for evisceration) slaughter lines running in parallel, when some establishments operate one or two days per week and treating a few hundred of birds. Nevertheless, except for this "small standard production" (higher water scalding temperature, water chilling and freezing), the slaughter process is quite similar. It consists of a succession of unitary operations. Some minor differences could be observed, depending on the type and the capacity of slaughterhouses. In the context of this report, the most important steps are described below:

1. **Scalding**: This operation is mainly done to facilitate the next defeathering process step by dilatation of feathers' follicles. Carcasses are immersed during approximately 3 minutes in a tank containing hot water, the temperature being between 52 and more than 60°C, depending on the type of production (future carcasses to be chilled or frozen). It's important to determine these parameters (time and temperature) to maintain the integrity of the skin structure, mainly for future refrigerated products. In some slaughterhouses, scalding could be achieved in 3 different successive water tanks, moving broilers against the water flow, from the dirtiest to the cleanest one; this counter current process is efficient against the spread of some pathogenic bacteria surviving the water temperature applied. Alternatively, spray scalding could be applied. This interesting system, for a hygienic point of view, should be implemented for energy cost and water consumption considerations.

2. **Plucking (Defeathering):** Scalded carcasses are plucked using rubber fingers vigourously striking them in a horizontal and vertical direction; after this process, all the feathers have been removed from the carcasses. This step provoques a pression on these uneviscerated carcasses that could lead to spread of fecal mater in the plucking cabinet. For this operation water is used to drain feathers and clean the surface of the carcass.

3. **Evisceration**: This operation allows keeping out offal's. It could be done manually or automatically, during successive steps: the first one is to remove, by elongating the head, the neck, the oesophagus and the trachea. Next step is to keep out, after opening the visceral cavity, the heart, the liver and the intestines. The cluster of viscera has to remain close to the carcass, to perform the veterinary inspection. At the end, carcasses could be cleaned, internally and externally, using potable water, to eliminate faeces, blood, etc. which could be still present.

4. **Chilling**: This process is mainly done by storing the carcasses in a ventilated room. The objective is to reach, as soon as possible, a temperature of 0 to +4°C. These products are destined to the refrigerated commercial market or for the further processing. After chilling, carcasses are packed (polyethylene bag, vacuum or modified atmosphere). Some carcasses to be processed are not packed and are transferred to the cutting plant. For the small standard production (export), carcasses could be chilled in refrigerated water, then packed and frozen.

3.4 Broiler further processing

After chilling, some types of broiler carcasses are cut, manually or mechanically. This process separates wings, legs and breast (fillets) allowing further processing before sale. This should be done in refrigerated conditions, mainly to avoid an increase of the temperature of the products. At the end of the processing, they are packed in different way (polyethylene wrap, vacuum or modified atmosphere packaging) and sold in refrigerated conditions.

3.5 Organisation of the retail sector

The main modes of presentation of the broiler at the consumption stage are given in the figure 6 (excluding offal).
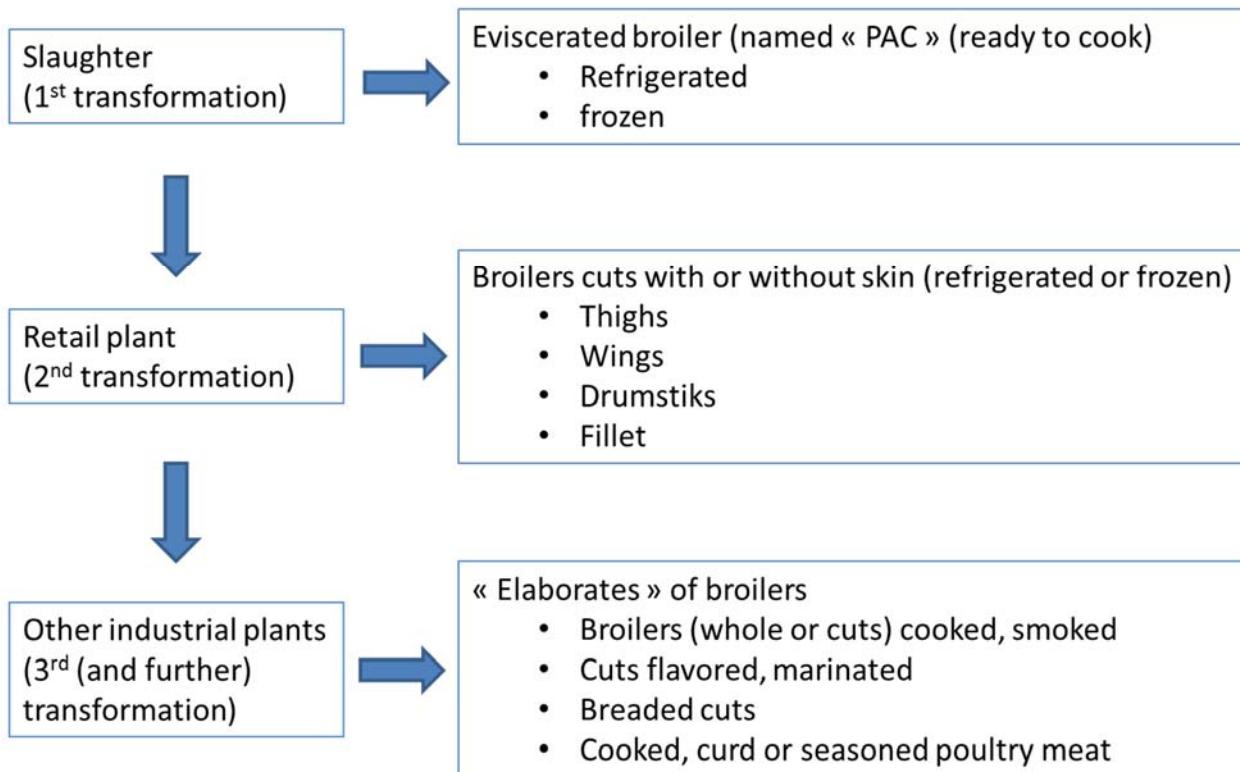
**Figure 6 : Mode of presentation of broiler at the consumption stage**

3.6 Part of imported product from EU or outside

The French self-sufficiency rate poultry meat production equalled 106% in 2015 but importations accounted for 31% of the national consumption (95% of the imported volume came from EU Member States). The share of imported products raises to 80% in catering and restaurants (Renault *et al.* 2013).

4. Key points for *Campylobacter* contamination

4.1 At the farm level

Epidemiology of *Campylobacter* contamination in broiler flocks has been widely studied since 1990's. It is generally agreed that horizontal transmission is responsible for colonisation of broiler flocks (Evans et Sayers 2000, Hansson *et al.* 2010, Hermans *et al.* 2011, Newell *et al.* 2011) and several studies have identified risk factors including rapid turnover (Lyngstad *et al.* 2008), environmental contamination during the rearing period (Gibbens *et al.* 2001), poor maintenance of housing, inadequate cleaning and disinfection, manure storage on farm, farmers not wearing farm specific clothing and the presence of other animals (Cardinale *et al.* 2004). Flock age, farm size, flock size, water quality and season are also important factors (Evans et Sayers 2000, Refrégier-Petton *et al.* 2001). Furthermore, thinning, (partial depopulation of a poultry unit) is regarded as a major risk factor for flock contamination (Hermans *et al.* 2011, Torralbo *et al.* 2014).

Identified sources of *Campylobacter* in broilers' environment include adjacent livestock (Ogden *et al.* 2009, Zweifel *et al.* 2008), staff (Ridley *et al.* 2011), insects and flies (Hald *et al.* 2008, Jonsson *et al.* 2012), pets (Whiley *et al.* 2013), rodents (Meerburg *et al.* 2006), equipment (Agunos *et al.* 2014, Battersby *et al.* 2016) and the environment around the broiler house (Ogden *et al.* 2009). Moreover, when key sites such as the tarmac apron, ante-room, house door, feeders, drinkers, walls, columns, barriers and bird weighing systems are not cleaned and disinfected properly, cross-contamination between successive flocks is inevitable (Battersby *et al.* 2016).

Age is a risk factor for *Campylobacter* colonization of broiler flocks (Evans and Sayers, 2000; Hartnett et al., 2001; Bouwknegt et al., 2004). The birds are usually *Campylobacter* free for the first 2-3 weeks but once infected these bacteria grow rapidly in the caecum of the bird, are shed in the faeces and spread rapidly throughout the house. After 8 weeks, colonisation could decrease in terms of number of bacteria and number of birds colonised which is likely to be associated with the development of an adaptive immunity and changes in the intestinal microflora (Brena 2013).

4.2 Before slaughtering and during the slaughtering process

The main reservoir of *Campylobacter* being the digestive tract, the contamination of the carcass is essentially superficial and may be provided by the living animal (during their rearing, catching, transport, lairage and hanging) or may be acquired *post-mortem*. The *Campylobacter* contamination in the depth of the muscles originating from digestive bacteraemia and/or evisceration defects is considered a very rare, if not improbable event. Therefore, digestive contents spreading is at the origin of the great majority of the contaminations and, consequently, all the steps (until the removal of the digestive tract) of the process leading to faecal dissemination are considered as critical steps with respect to the transfer of *Campylobacter* to the skin or muscle surfaces.

4.2.1 Before slaughtering

Feed withdrawal times longer than 12 hours could cause deterioration in the condition and integrity of the viscera and increase the fluidity of gastrointestinal contents, which could increase the potential for faecal contamination of carcasses. The EFSA (2011) report shows the results of various studies performed in the last years, confirming that with increasing time of fasting before slaughter, the number of *Campylobacter* increases exponentially in caeca (Byrd *et al.* 1998, EFSA 2011, Willis *et al.* 1996).

Thus, faecal excretion can occur during transport and lairage in a cage or in a crate. As an example, the norepinephrine hormone secreted by stressed birds, during the transportation, might stimulated colonisation and multiplication of *Campylobacter*, in the gut and then increased the possibility to contaminate the carcass (Cogan *et al.* 2007). Crates and cages have many niches for accumulation of contamination, exacerbated by wear after repeated use, which damages surfaces and creates more sites for accumulation of dirt and biofilm formation. They are therefore very difficult to clean and disinfect. Thus, crates are potential source of

contamination and cross-contamination of the exterior of previously *Campylobacter*-negative birds transported for slaughter.

However, in a study performed on 30 flocks followed from the farm to the slaughter, no significant differences have been found between *Campylobacter* counts in caeca at the end of the rearing, during transport and lairage and at slaughter (Chemaly *et al.* 2010).

4.2.2 During the slaughtering process

The first critical step is probably the scalding operation, during that step, many carcasses coming from many batches are immersed continuously in the same water tank. Scalding is not done for a hygienic purpose, Yetfor *Campylobacter*, this operation seems to be effective in reducing the level of contamination (Pacholewicz, Liakopoulos*, et al.* 2015), as the temperature of the water is sufficiently high to inactivate *Campylobacter*.

During plucking, an increase of the carcass contamination by *Campylobacter* sp. is frequently observed, probably due to cross contamination. Indeed, aerosols containing *Campylobacter* are formed during defeathering (Haas *et al.* 2005, Johnsen *et al.* 2007) and may cause significant carcass contamination (EFSA 2011).

Evisceration is also a source of carcass contamination and cross contamination (Corry et Atabay 2001), may be because of a defect in the process resulting in broken intestines and, consequently a spread of faecal materials to the surface of the carcass. The potential cross contamination can result from the impossibility to clean and disinfect utensils and machines between each operation. Evisceration step is described as dramatically increasing the prevalence of contaminated carcasses, mainly by cross contamination (Seliwiorstow, Baré, Van Damme*, et al.* 2016).

Air chilling seems to be a critical step to reduce the level of contamination, however contaminated carcasses remain positive.

Globaly, during slaughtering, a decrease of the level of external skin contamination of carcasses could be observed, as a result of a combination of the favourable effects of the temperature applied during scalding and air chilling and the unfavourable roles of plucking and evisceration (leakage).

4.2.3 During processing

Portioning is usually done mechanically, with more possibilities for cross-contamination among carcasses *via* the machinery. Some portions, particularly breast fillets, have the skin removed, which usually reduces the numbers of *Campylobacter* on the surface of the meat.

4.3 Cross-contamination in household kitchen

Several French studies simulated common situations that could occur in domestic kitchens demonstrating that broiler meat may serve as a source for cross-contamination to other foodstuffs and surface during meal preparation. It was shown that *Campylobacter* from naturally contaminated broiler legs (bought in retail outlets) transferred to a cutting board in 80% of the cases after 10 min of contact (Fravalo *et al.* 2009). Another study examined the transfer of *Campylobacter* present in naturally contaminated raw poultry products (bought in retail outlets) to a cooked broiler product after a contact with a cutting board (Guyard-Nicodème *et al.*, 2013). It revealed that transfer occurred in nearly 30% of the cases and that the main species implicated in human campylobacteriosis, *C. jejuni* and *C. coli,* were able to transfer from raw poultry meat to a ready to eat product *via* the cutting board. All the tested isolates were able to adhere and to invade eukaryotic cells revealing potential virulence properties for these isolates that could be in contact with the consumer (Guyard-Nicodeme *et al.* 2013).

Recently, a survey of practices during the preparation of a chicken meal was conducted. The objective was to investigate the habits of handling of chicken meat during the preparation of the meal, and also to determine the proportion of risky behaviours that could lead to either direct or indirect cross-contamination between the raw meat and food ready to eat via hands or utensils (Poisson *et al.* 2015) Annex 6). Data collected during this survey were used for the modelling of the present study.

5. Review of French data

5.1 *Campylobacter* in caeca at the farm

The European baseline survey performed in 2008 investigated the prevalence and level of contamination of *Campylobacter* in broiler caeca and on carcasses collected during the slaughtering process. Caeca samples collected during the evisceration process gave representative data reflecting the situation regarding *Campylobacter* contamination in French flocks. A pool of 10 caeca from 425 batches of broilers were sampled and analysed over a 12-month period in 58 slaughterhouses during evisceration and revealed information on *Campylobacter* prevalence and contamination level in French farms. *Campylobacter* spp. was isolated from 77.2% of caeca samples with a mean count of 8.0 ± 1.0 log10 CFU/g (Hue *et al.* 2011, Hue *et al.* 2010). Two species *C. jejuni* and *C. coli* were found in caeca with 52.5% and 47.5%, respectively (Hue *et al.* 2011). The prevalence in caeca was 69.7% (CI$_{95\%}$ [64.7-74.7], N=327) for standard broilers and 100% (CI$_{95\%}$ [95.0-100.0], N=67) for free-ranged broilers. The difference in prevalence between indoor and outdoor broilers has to be interpreted with caution due to the low number of free-ranged flocks investigated. However, the result is in line with a previous study where 100% of free-ranged flocks tested (N=73) were positive for *Campylobacter* at the end of the rearing period (Huneau-Salaun *et al.* 2007).

An additional investigation to this study was achieved on a subsample of 121 flocks produced in Brittany. On-farm information and cecal samples were collected 1-3 days before flock slaughter. Eighty-seven flocks were positive for *Campylobacter,* giving a prevalence of 71.9% with a mean count of 7.96 ± 1.0 log10 CFU/g (Allain *et al.* 2014b). *C. jejuni* was isolated in 40.5%, *C. coli* in 29.8% and both species in 1.7% of the flocks. This study also facilitated the identification of the main risk factors affecting contamination of the flocks. Rodent control, antibiotic treatment at the beginning of rearing and acidification of drinking water were associated with a decreased risk of contamination. Risk was increased during the summer months (Allain *et al.* 2014a).

Only a few numbers of studies were carried out in France as a whole since the baseline study in 2008. In 2009 Mahler et al (2011) reported that 87.1% (CI$_{95\%}$ [79.4-92.1], N=108) of the tested broiler batches carried *Campylobacter* in caeca after transport to the slaughterhouse. The mean cecal load was 8.0 ± 0.9 log10 CFU/g. *Campylobacter* prevalence in broiler flocks in Reunion Island and specific practices associated to this contamination were studied from 2007 to 2009. *Campylobacter* was recovered from 54% of the 50 flocks involved in this work (Henry *et al.* 2011). This prevalence was lower to that obtained in Metropolitan France during the EU baseline survey. However, authors suggested the required willingness of farmers to cooperate during the lifespan of the flock might have led to a selection bias (Henry *et al.* 2011). Moreover, contrary to what was observed in Metropolitan France, *C. coli* was more prevalent than *C. jejuni* as they were isolated in 30% and 17% of the flocks respectively (Henry *et al.* 2011). Both species were isolated in 8% of the flocks (Henry *et al.* 2011). Regarding within flock prevalence French data are lacking as all the above studies did not investigate this aspect. In a study involving 21 standard broiler flocks reared under commercial conditions, the within flock prevalence reached 100% (8 broilers sampled) within the two weeks after a natural infection by *Campylobacter* infection (Huneau-Salaun *et al.* 2018).

5.2 *Campylobacter* on carcasses at the slaughterhouse

The EU baseline survey conducted at the slaughter level in 2008 gave representative data regarding the contamination of carcasses of the French broiler production. One carcass from each of 425 batches of broilers was sampled after the chilling process. This study revealed that 87.5% of the carcasses were contaminated with a mean count of 2.39 ± 0.08 log10 CFU/g (Hue *et al.* 2011, Hue *et al.* 2010) and that 15.4% of the samples presented *Campylobacter* enumeration above 3 log10 CFU/g (EFSA 2010). A positive correlation between the mean of *Campylobacter* in caeca and on carcasses was found but a higher prevalence was observed in carcasses indicating that <u>cross contamination does occur during the slaughtering process</u> (Hue *et al.*, 2010; 2011). The main species identified on carcasses were *C. jejuni* and *C. coli* (57.1% and 42.5% respectively) (Hue *et al.* 2011).

This study was completed by identifying potential risk factors for *Campylobacter* contamination status of carcasses. Slaughter age of the broilers (over 68 days) appeared to have a great impact on the prevalence; older broilers presenting higher prevalence (Hue *et al.* 2010). However, this assumption needs to be taken

with caution as older broilers are from different broiler productions (free-range, "Label-Rouge", organic production) using different rearing conditions and broiler breeds.

A recent study conducted in France evaluated the mean *Campylobacter* concentration on carcasses (after chilling). Using a method accounting for censored data, the mean contamination level on pooled neck skin samples was assessed to 2.6 [2.4; 2.8] log10 CFU/g during June-to-December period, whereas this level was significantly lower during January-to-May period (1.0 [0.6; 1.3] log10 CFU/g) (Duqué *et al.* 2018).

A monitoring plan of the "Label Rouge" production focusing on *Salmonella* surveillance and other microbial quality indicators has been extended to enumeration of *Campylobacter* since 2007. Sampling was performed in every French slaughterhouse slaughtering "Label Rouge" broilers and included neck skin samples from 2007 to 2008 and leg skins samples since 2009 as leg skins are more representative of the potential exposure of the consumer. Results of this monitoring plan from 2007 to 2014 have been recently published (Salvat *et al.* 2017). From 2009 to 2014, only 2% to 5% of carcasses (from leg skins) presented more than 3 log10 CFU/g. Between 2008 and 2009 a significant decrease from 19% to 3% of heavily *Campylobacter* contaminated carcasses was noticed but was probably due to the change of analysed samples from neck skins to leg skins (Salvat *et al.* 2017).

5.3 *Campylobacter* on fresh meat at the distribution

A monitoring plan concerning fresh broiler meat was carried out in France from April to December 2009. A total of 361 broiler meat products (carcasses, legs and fillets) were collected from in retail outlets in geographic areas representing the most significant consumption patterns in France (DGAL 2010). *Campylobacter* was detected on 76% of these products. Products packed with air presented higher contamination than products packed under modified atmosphere (Rivoal *et al.* 2011). Products with skin were significantly more heavily contaminated than products without skin. Prevalence and enumeration of *Campylobacter* was 90% and 1.90 log$_{10}$ CFU/g respectively on the carcasses, 85% and 1.72 log$_{10}$ CFU/g on the legs and 53% and 0.82 log$_{10}$ CFU/g on the fillets (Guyard-Nicodeme *et al.* 2013). *C. jejuni* or *C. coli* were isolated from 46.5% or 34.9 % of the broiler meat products respectively and both *C. jejuni* and *C. coli* were isolated from 18.9% of the broiler meat products. These results indicated that French broiler meat could be an important source of exposure to these isolates.

5.4 Current measures contributing to the control of *Campylobacter* in France

In France, the first requirements for biosecurity are at farm level and were specified in the official program for prevention and control of *Salmonella* in poultry production in 1998. From that date, the official plan was regularly upgraded (2001, 2008, 2013 and a new version is in preparation). The regulation on biosecurity has strongly evolved following the Avian Influenza outbreaks during the winters 2015-2016 and 2016-2017. The new regulation enforces measures to prevent contact of birds with wildlife ones and to improve sanitary measures (before entering in poultry house, disinfection practices of poultry houses etc.). However, the measures are being implemented slowly on the farms due to the time needed for modifications of buildings; the full implementation of the new biosecurity regulation is expected for 2018.

In 2011, a Good Hygienic Practices Guide for slaughter and processing poultry was validated by the National Competent Authority (Guide des bonnes pratiques d'hygiène et d'application des principes HACCP relatif à l'abattage et à la découpe des volailles maigres (toutes espèces), agriculture.gouv.fr/ sites/minagri/files/.../pdf/GGHP_5945_valid_jo_cle89dc17.pdf). This document describes all the operations. Concerning the *Campylobacter* issue, this guide described thermotolerant *Campylobacter* as a biological hazard and proposed control measures, especially during the evisceration step.

At the retail stage, the national federation of trade and retail companies ("Fédération des entreprises du commerce et de la distribution") has published new microbiological criteria applicable from 1st January 2015 to retailers and hard discount brands. In addition to updating the criteria with regard to regulatory changes and the updating of Regulation (EC) 2073/2005, this publication includes new criteria relating to *Campylobacter* in poultry. The list of new criteria could be found via the following weblink: http://www.fcd.fr/media/filer_public/cb/d0/cbd057e4-e8b3-4ebd-b298-34f92c85267b/1201_fcd_criteres_microbiologiques_2016_produits_ls_mp_28012016.pdf

6. Review of recent literature on the efficacy of the different interventions, and selection of interventions

In the following, the interventions listed in the EFSA (2011) report are presented, complemented by knowledge acquired since.

6.1 Interventions during primary production

6.1.1 List of interventions

EFSA (2011) proposed a list of interventions against *Campylobacter* before and during slaughter and processed operations. For this WG, the list has been updated with new results from literature. Each intervention is discussed in regard of the French situation in standard and free-ranged broiler flock.

6.1.1.1   Biosecurity

In the case of *Campylobacter*, biosecurity essentially aims to prevent the introduction of the bacteria or the carryover of the bacteria from one infected flock to the following flock reared in the same poultry house. New evidence of the effect of biosecurity on *Campylobacter* prevention is mainly obtained from risk factor studies (Borck Høg *et al.* 2016, Chowdhury *et al.* 2012, Georgiev *et al.* 2017, Sommer *et al.* 2013, Sommer *et al.* 2016). Interventional studies or randomized controlled trials in farms to measure the effect of biosecurity measures on *Campylobacter* contamination of poultry flocks are generally lacking.

Hygiene barriers: in France, all commercial poultry houses are equipped with an anteroom where farmers and visitors have to change boots and clothes. For free-range broilers reared in small shelters there is no anteroom at the entrance of the shelter. A rearing area is delimited around the shelters. Farmers and visitors have to change boots or use a boot dip before entering into the rearing area. Reinforcement of hygiene barriers for avian influenza prevention since 2016 may reduce the prevalence of *Campylobacter* positive flocks. However, more time is required to evaluate this development.

Despite the high number of farms equipped with hygiene barriers in France, there is still a problem of compliance with biosecurity measures during the whole rearing period. Results are contradictory about the effect of audit on the compliance to biosecurity measures. Racicot *et al.* (2012) reported that a bimonthly audit had no impact on biosecurity compliance after a 6-months period. In contrast, Sandberg *et al.* (2017) observed a significant decrease in the prevalence of *Campylobacter* positive flocks after an audit visit for evaluating biosecurity appliance on the farms. In France, all farmers had to follow a one-day training period on biosecurity after the avian influenza crisis. In addition, an annual veterinary audit is carried out on all poultry farms housing more than 250 birds since 2013 (Ministerial Order of 26 June 2013). In 2018, the main objective of the audit was to evaluate the compliance to new biosecurity measures introduced in the regulation on avian influenza prevention in 2016.

Sommer *et al.* (2016) estimated the relative public health risk reduction from using an anteroom with hygiene barrier to be between 3 and 13% in five European countries. (Here the "public health risk" is the incidence of campylobacteriosis due to the handling and consumption of broiler meat).

Fly screen: use of fly screens to prevent *Campylobacter* introduction by flies turned out to be a protective measure in several Northern Europe countries especially during the summer period (EFSA 2011). The main challenge is to determine whether this intervention might be effective in other European countries with a high prevalence of *Campylobacter* in poultry flocks and with climatic conditions different from those in Northern Europe. Currently French poultry houses are not equipped with fly screens.

Van Wagenberg *et al.* (2016) estimated the relative public health risk reduction from the application of fly screens to be 14% in Denmark.

Cleaning and disinfection, downtime period: Battersby *et al.* (2017) investigated cleaning procedures within broiler houses and by testing the efficacy of the most commonly used methods and also evaluated the six most commonly used commercially available disinfectants and/or detergent products. Of the six disinfectant treatments checked, most were ineffective. Thermal fogging with the combination of potassium peroxymonosulfate, sulfamic acid and sodium chloride (5%, v/v) or the glutaraldehyde and quaternary ammonium complex (0.3%, v/v) were the best treatment, achieving up to 5 decimal reductions in total viable count.

According to the poultry sector representatives, cleaning and disinfection of the poultry house is done after all flocks. Thermal fogging is commonly used for final disinfection in conventional poultry houses. In free range and organic farms procedures for cleaning and disinfection are more heterogeneous than on conventional farms. In particular the range of disinfectant products available is limited for farms complying with organic farming rules. Only two-thirds of the farmers in organic farms disinfected the poultry house between flocks (Souillard *et al.* 2017).

A long downtime period before flock placement (more than two weeks) was reported as a factor increasing the risk of a flock being positive for *Campylobacter* both in Denmark (Borck Høg *et al.* 2016) and in the UK (Georgiev *et al.* 2017). The probability of poultry house contamination from exterior sources (rodents, human vectors, etc.) may increase with the downtime period if the hygiene barriers are not respected after the building has been disinfected. These results are partly in contradiction with those obtained previously (Hald *et al.* 2000, Lyngstad *et al.* 2008) making it difficult to come to a definite conclusion. In addition, the downtime period is generally shorter than two weeks in conventional farms in France. The question may be raised for free-range and organic farms as requirements for those productions impose a downtime period longer than 14 days for conventional poultry house. Sommer *et al.* (2016) estimated the relative public health risk reduction from reducing the downtime to less than ten days to be between 2 and 8% in five European countries.

Drinking water: untreated drinking water is a potential source of broiler contamination by *Campylobacter* as the bacteria is commonly isolated from surface water (Mughini-Gras *et al.* 2016). Several new studies also suggest that type of drinkers and hygiene of drinkers may play a role in broiler contamination by *Campylobacter*. Use of drinker bells and nipples with cups is a risk factor for broiler infection in comparison with nipples without cups in Denmark (Borck Høg *et al.* 2016). Improper disinfection of drinkers leads to a residual contamination of the material (Battersby *et al.* 2017) and to an increased risk of carry-over of *Campylobacter* from a contaminated flock to the following one (Battersby *et al.* 2016). Sommer *et al.* (2016) estimated the relative public health risk reduction from using drink nipples without cups to be between 5 and 24% in five European countries.

No data are available regarding the origin of drinking water (private water supplies or public water system) used in French poultry farms. However, all studies carried out by ANSES in poultry farms showed that drinking water is systematically treated (by chlorination mostly) when it comes from surface water supplies (Quatrehomme *et al.* 2001). All farms producing conventional poultry are equipped with nipples but it is not known the proportion of farms using nipples without cup. In free-range and organic farms about one half of the houses are equipped with drinker bells and one half with nipples. The new poultry houses are all equipped with nipples.

Reduction of slaughter age: reduction of slaughter age is only applicable for standard production (no specific requirement on age at slaughter). Van Wagenberg *et al.* (2016) estimated the relative public health risk reduction from reducing the slaughter age to 35 days or less to be between 10 and 18% in five European countries.

Discontinued thinning: thinning consists in a partial depopulation of a flock; a part of the broilers is sold at a younger age, one week to one month before the rest of the flock. Thinning is different from sequential depopulation at the end of the rearing period which consists in sending broilers to the abattoir in several shipments over two to three days. Thinning requires ingress into the poultry houses by poultry catchers and material (crates, vehicles). As a consequence; biosecurity is often compromised during thinning. Thinning is therefore a major risk factor of broiler contamination by *Campylobacter*. More recently, Georgiev *et al.* (2017) demonstrated that removing thinning may reduce by one third the number of heavily contaminated broiler flocks in the UK. However, poultry farmers in UK were reluctant to ban thinning as it is considerably more expensive than improving biosecurity (Fraser *et al.* 2010).

In France thinning is used in standard, heavy and certified broiler production to meet market requirements for carcasses of different sizes.

Van Wagenberg *et al.* (2016) estimated the relative public health risk reduction from a ban on thinning to be between 4 and 13% in five European countries.

6.1.1.2   Bacteriocins

No recent publications of *in vivo* studies were found in the period reviewed by the working group (2011-today). The use of bacteriocins seemed promising, but no field trials had been done to measure their effect (EFSA 2011).

6.1.1.3   Bacteriophages

Fischer *et al.* (2013) tested a single phage and a cocktail of four phages on broilers. A significant reduction (up to 2.8 decimal reductions cecal contents) was observed between one and four weeks after treatment. In field trials in three commercial broiler flocks, the phage cocktail applied in drinking during the 4 days before slaughter reduced the *Campylobacter* load in caeca by up to 3 decimal reductions in naturally contaminated broilers (Kittler *et al.* 2013). However, the results were not consistent over the three trials.

6.1.1.4   Vaccination and passive immunisation

Annamalai *et al.* (2013) undertook studies on a vaccine with or without a poly(lactide-co-glycoside) nanoparticle (NP) encapsulated outer membrane proteins (MOP) of *C. jejuni*. Chickens were vaccinated subcutaneous or orally with doses (25, 125, or 250 µg) of candidate nanoparticle vaccine. *C. jejuni* colonisation in cecal and cloacal contents at 7 days post challenge was below the detection limit in the vaccinated groups. It was concluded that the subcutaneous vaccination with or without NP encapsulated OMP of *C. jejuni* may serve as a candidate vaccine for control of *C. jejuni* colonisation in broilers.

Neal-McKinney *et al.* (2014) used recombinant surface-exposed proteins implicated in colonisation of chickens for vaccination and could obtain a reduction greater than 2 log_{10} in the level of *C. jejuni* colonisation. However, trials were performed in SPF broilers placed in isolator chambers and authors concluded that further studies are needed to test the efficacy of this strategy on field conditions. Other vaccination strategies have also been tested *in vivo*. Studies reported the use of a whole-killed *C. jejuni* vaccine (Okamura *et al.* 2012), immunisation with an attenuated *Salmonella* Typhimurium strain producing a *C. jejuni* CjaA antigen (Laniewski *et al.* 2014) or *in ovo* immunisation with flagellin (Radomska *et al.* 2016) but these strategies had no effect on *Campylobacter* colonisation.

Passive immunisation has also been evaluated these last years. Oral administration of *C. jejuni*-specific single-domain antibodies significantly reduced *C. jejuni* colonisation of day old SPF leghorns but future experiments are needed to address the effectiveness in the prevention of *C. jejuni* colonisation over the full growth cycle of the chicken (Riazi *et al.* 2013). On the other hand, oral administration of hyper-immunized egg yolk powder enriched with *C. jejuni* colonisation associated proteins had no effect on cecal colonisation of *C. jejuni* (Paul *et al.* 2014).

Recently, new vaccine candidates against *Campylobacter* have been identified following the reverse vaccinology approach (Meunier, Guyard-Nicodème, Hirchaud*, et al.* 2016). Six out of 14 new candidates have been produced and tested on live birds inoculated with *C. jejuni* and four out of them reduced significantly cecal *Campylobacter* loads by 2 to 4.2 log10 CFU/g, with the concomitant development of a specific humoral immune response (Meunier *et al.* 2017).

6.1.1.5   Feed water additives

Organic acids: organic and fatty acids have been extensively tested for the prevention and reduction of *Campylobacter* in poultry (Jansen *et al.* 2014, Meunier, Guyard-Nicodème, Dory*, et al.* 2016) tested the acidification of drinking water with a commercial organic acid mixture over three consecutive flocks in a conventional poultry house. The acidification of water tended to decrease the number of *Campylobacter* in broiler caeca at slaughter but had no significant effect on carcass contamination. The protective effect of organic acids observed in challenge trials seems to be difficult to reproduce in commercial conditions. Another strategy is to combine organic acids with other additive also exhibiting an inhibitory effect on *Campylobacter*. (Grilli *et al.* 2013) developed a combination of organic acids and plant extracts that reduced *Campylobacter* load in caeca of challenged broilers up to the time of slaughter. A combination of a cation exchange clay-based product in feed and an organic acid mixture in water significantly reduced the load of

Campylobacter on neck skin of free-ranged broilers but this experimental result needs to be confirmed in commercial conditions (Guyard-Nicodème *et al.* 2017).

(van Bunnik, Hagenaars*, et al.* 2012, van Bunnik, Katsma*, et al.* 2012) tested the effect of water acidification with a commercially available acid on the horizontal transmission of *Campylobacter* within a flock but the protective action was not repeatable over successive trials. Similarly, a commercial available acidification water treatment significantly reduced *Campylobacter* counts in drinking water *in vitro* but had no effect on *Campylobacter* load in caeca of broilers at slaughter under commercial conditions (Haughton *et al.* 2013).

Professional representatives reported that water acidification is commonly used in free-ranged broilers to improve gut health. It also used in standard flocks but apparently to a lesser extent. (Allain *et al.* 2014b) that water acidification was a protective factor for *Campylobacter* contamination in French broiler flocks (OR: 0.33, [0.13-0.86]). Based on this study, systematic application of water acidification might reduce by 20% the number of *Campylobacter* positive flocks. However, the result of Allain *et al.* was contradictory with those of a former risk-factor study in French broiler flocks: water acidification was identified as a risk factor for *Campylobacter* contamination in broilers (Refrégier-Petton *et al.* 2001).

Bügener *et al.* (2014) tested neutral electrolyzed oxidizing water as drinking water for broilers in two farms over three production cycles. The treatment tended to reduce the within-flock prevalence and significantly reduced *Campylobacter* load on carcasses of four out of five batches that were positive after processing. No further results are available on this intervention and on its applicability on farms in France.

Probiotics-prebiotics: Aguiar *et al.* (2013) developed an *in vitro* screening technique for selecting bacterial isolates with enhanced motility to be used as probiotic cultures preventing *Campylobacter* colonisation of the broiler gastro-intestinal tract. Potential probiotic bacteria from chickens were tested for increased motility and the three bacterial isolates with the greatest motility (all *Bacillus subtilis*) were tested individually and in combination. The study concluded that probiotic cultures with enhanced motility achieved significantly reduced (p<0.05) *Campylobacter* colonisation. Various probiotics including *Bacillus* spp, *Lactobacillus* spp. were tested under *in vivo* challenge conditions (Ghareeb *et al.* 2013, Guyard-Nicodème *et al.* 2016, Manes-Lazaro *et al.* 2017, Saint-Cyr *et al.* 2017, Schneitz et Hakkinen 2016, Shrestha *et al.* 2017). Some of the tested probiotics are already commercially available (Ghareeb *et al.* 2013, Guyard-Nicodème *et al.* 2016). A wide range of probiotics appeared to be effective for lowering *Campylobacter* counts in caeca from challenged broilers up to the time of slaughter. Nevertheless, repeatable results were rarely obtained due to the high variability in cecal counts observed after treatment.

Cean *et al.* (2015) investigated the use of probiotic strains *Lactobacillus paracasei* J. R, *L. rhamnosus* 15b, *L. lactis* Y, and *L. lactis* FOa to reduce *C. jejuni* infection of chicken intestinal cells *in vitro*, and to decrease colonisation of the chicken gut. Their findings suggest that *C. jejuni* invasion of chicken primary cells was reduced with the strongest inhibitory effect observed when a combination of four strains were administered. *In vivo*, these four strains prevented mucus colonisation in the duodenum and caecum and the pathogen load in the lumen was significantly reduced. However, the time of administration was important as probiotic application during the early growth period was effective while their use during the last week of growth had no effect.

6.1.2 Potential interventions selected by the working group

The interventions that are not relevant to the French situation, and those without quantitative data that could not be used for modelling, were not considered. There is no convincing evidence that interventions tested so far to reduce prevalence and/or contamination level are influenced by the season when expressed in relative risk reduction. Those that could be applicable in France are presented below:

- fly screens: Prevalence decreased from 40 to 10 % in Denmark in one field trial (indoor flocks only),
- vaccination: 1 to 4 decimal reductions (DRs) in caeca,
- phage application: 1.3 to 2.8 DRs in caeca,
- chemical and biological substances added to feed or drinking water: 0.7 to 3 DRs in caeca,
- stop thinning: a decrease of 13% in *Campylobacter* prevalence at farm is expected (thinning is used for indoor broilers only),
- slaughter age: slaughtering broiler flocks before 35 days old would reduce the prevalence of *Campylobacter* by an average 14% This measure could be applicable for indoor broilers only.

Other interventions for which no quantitative data are available are:

- Improvement of compliance to biosecurity: several epidemiological studies suggested that improving of compliance to biosecurity would reduce *Campylobacter* prevalence in broiler flocks. However, no data are available to assess the current state of application of biosecurity measures in France. In that condition assessing the potential impact of this intervention is not possible.

6.2 Interventions during transport and before slaughtering

6.2.1 List of interventions

EFSA (2011) proposed a list of interventions against *Campylobacter* before and during slaughter and processed operations.

6.2.1.1 Feed withdrawal

Feed withdrawal times should be such that, in addition to physical emptying, the integrity of the gastrointestinal tract is also maintained. For that, feed withdrawal, transport and holding time before slaughter should be between 8 and 12 hours; the 12-hour limit should not be exceeded because it is the maximum feed withdrawal time allowed by the EU regulation for animal welfare (EFSA 2011). However, feed withdrawal is not expected to affect the prevalence of infected birds, the concentration in caeca or the digestive contents. But a lower quantity of digestive content could have a marginal impact on surface contamination after scalding, defeathering, and evisceration (less than 5% decrease of the concentration on carcasses) (Pacholewicz *et al.* 2016).

6.2.1.2 Crates cleaning and disinfection

Improvement of crate washing and disinfection procedures should reduce cross-contamination between *Campylobacter* positive and negative flocks and will decrease the amount of contamination introduced in the slaughter facility. A special attention should be directed to transport trucks, crates and cages used for thinning operations.

Cleaning and disinfection of crates for broiler transport is mandatory after transport, before crate re-use (European Directive 2005/94/EC). Transport crates are frequently contaminated with *Campylobacter* even after cleaning and disinfection; this contamination could lead to the introduction of *Campylobacter* into broiler farms during thinning or the external contamination of birds during transport to the slaughterhouse (EFSA, 2011). Crate contamination is reported in France as in other European countries (Peyrat *et al.* 2008). Few studies about the impact of cleaning on *Campylobacter* contamination of crates have been carried out since 2010's. Two studies of (Berrang, Hofacre*, et al.* 2011, Berrang, Meinersmann*, et al.* 2011) demonstrated that complete drying of the crates before use is very effective for eliminating residual campylobacter contamination of crates. However, reuse of crates commonly occurs within the day after their cleaning even if they are not perfectly dry.

6.2.2 Potential interventions selected by the working group

The interventions that are not relevant to the French situation, and those without quantitative data that could not be used for modelling, were not considered. Those that are applicable in France are:

- Feed withdrawal control: optimizing the starting time of feed withdrawal may have a marginal impact on surface contamination after scalding, defeathering and evisceration (less than 5% decrease).

Another intervention for which no quantitative data are available is:

- Improvement of cleaning crates and cages before transport (no quantitative data).

6.3 Interventions during slaughter

6.3.1 List of interventions selected by the working group

6.3.1.1 Logistic slaughter

It consists in programming the slaughter of non-contaminated batches at the beginning of the day to prevent contamination of materials (plucking fingers, evisceration machines). These could also include an increase of

the scalding temperature and (or) freezing carcasses from contaminated lots. In the French situation, these procedures could be difficult to get in application as long as the information of the food chain does not inform on *Campylobacter*. Furthermore, the effect would be very small (See §7.1.1 and (EFSA 2011, Nauta *et al.* 2009)).

6.3.1.2   Counter current or spray scalding

The French Guide to GHP recommends using several successive tanks to limit cross contamination in particular by *Salmonella* spp. and *Campylobacter sp.*, especially because the water temperature used is relatively low (50-60°C) and consequently has a limited effect on bacterial cell inactivation.

Spray scalding could be an interesting option to avoid cross contamination but is not applied due to the energy cost and the water consumption.

6.3.1.3   Plucking process

The only intervention could be to clean and disinfect regularly the machines and more specifically the plucker fingers. It would be also important to envisage the frequent change of ageing fingers to avoid the formation of biofilms.

6.3.1.4   Prevention of leakage of intestinal content

According to EFSA (2011), a better control of the leakage during evisceration (batch homogeneity and machineries set-up are critical), can lead to one decimal reduction on *Campylobacter* contamination on carcasses. Nevertheless, this intervention seems to be difficult to be applied in the present condition (line speed).

6.3.1.5   Mode of chilling (temperature, air velocity, hygrometry)

The improvement of chilling process could be an option to gain one decimal reduction, depending on the prolongation of chilling and validation that the lowest counts of *Campylobacter* did not represent a loss of culturability more than a death of the bacteria (EFSA 2011). Furthermore, a recent investigation conducted in France showed that optimizing the main parameters (temperature, duration, air velocity) may achieve a maximum reduction of around 1.5 log CFU/g and was very dependent of the initial *Campylobacter* contamination: carcasses presenting more than 10^3 CFU/g cannot be significantly decontaminated during the chilling process (Rivoal *et al.* 2015, 2018).

6.3.1.6   Physical treatment

Heat treatment (immersion in hot water or steam) after evisceration and before chilling, can decrease the level of surface contamination by 0.2 to 0.5 DR (EFSA 2011).

Freezing carcasses for few days or weeks, or crust-freezing, are not compatible with the consumer's requirement to have access to fresh product. Reduction of *Campylobacter* concentration level could reach 0.5 to 2 DRs depending on the duration of the treatment (EFSA 2011).

Cooking: efficient as well, is not considered facing the requirement to have access to fresh products by consumers.

6.3.2 Potential interventions selected by the working group

The interventions that are not relevant to the French situation, and those without quantitative data that could not be used for modelling, are not considered. Those that are applicable in France are:

- Scalding: 0.1 à 0.2 DR on carcass concentration before chilling

- Steaming: 0.2 to 0.4 DR

- Prevention of leakage of intestinal contents: 0.9 DR on carcass.

- Hot water immersion post evisceration: 0.3 to 0.5 DR on carcass

- Chilling: <1.5 DRs

Different improvements should be considered by slaughter but could not be universally proposed as efforts in hygienic slaughter appear variable and plant specific.

6.4 Intervention after slaughtering and processing

Interventions to minimize the cross contamination of other foods with *Campylobacter* from poultry include; [1] education, including consumer education/information on how poultry product should be stored, handled and cooked (Kennedy *et al.* 2005) and motivation including overcoming a belief that food safety is someone else's responsibility (Redmond et Griffith 2003); [2] packaging technologies including modified atmosphere and cook-in-the-bag (Habib *et al.* 2010); [3] chilling and freezing (Eideh et Al-Qadiri 2011, Georgsson *et al.* 2006, Sampers *et al.* 2010); [4] light technologies; [5] antimicrobials and [6] irradiation.

6.4.1 List of interventions after slaughtering

6.4.1.1 Packaging technologies

Cook-in-the-package technology should, in theory, prevent direct contact between consumers and contaminated raw poultry. However, this assumes that the outside of the package is not contaminated, which is not always the case. Burgess *et al.* (2005) reported that 3% of the external surfaces of raw chicken packs were contaminated with bacteria originating from the poultry. The Food Safety Authority of Ireland (FSAI) also detected *Campylobacter* on 8.9% of the external surfaces of conventional poultry packaging and on 1.6% of leak-proof packs (FSAI 2010, Meredith *et al.* 2014) investigated the effect of different modified atmosphere packaging on *Campylobacter* both immediately and throughout 5 days storage at 2°C. None of the treatments (10%, 30%, 50%, 70% and 90% CO_2 balanced with N_2, 80:20% O_2:N_2 and 40:30:30% CO_2:O_2:N_2) achieved a reduced *Campylobacter* count at any stage throughout the experiment.

6.4.1.2 Antimicrobials

Peroxyacetic acid (0.1%) treatment of skin-on chicken breast and thigh meat resulted in a 1.5 decimal reduction in *Campylobacter* concentrations in the ground meat product derived from these poultry pieces (Chen *et al.* 2014). 0.1% peracetic acid, 1.5% acidified lactic acid and 0.1% lauric arginate decreased *Campylobacter* by 1 log/g on fresh chicken frames that were ground before evaluation of the surviving *Campylobacter* levels. Meredith *et al.* (2013) investigated the immediate and storage effects of trisodium phosphate (TSP,10% and 14%, w/v), lactic acid (LA, 1% and 5%, v/v), citric acid (CA, % and 5%, w/v), peroxyacids (POA, 100 and 200 ppm) and acidified sodium chlorite (ASC, and 1200 ppm). Dip but not spray treatments were effective. 10% TSP, 14% TSP, 1% CA, 5% CA, 1% LA, 5% LA, 100 ppm POA, 200 ppm POA, 500 ppm ASC and 1200 ppm ASC dip treatments achieved 1.3, 1.5, 0.7, 1.8, 0.7, 1.2, 0.7, 0.7, 0.9 and 1.3 log_{10} CFU/cm^2 reductions, respectively. In a processing plant, dip treatment of chicken carcasses with 14% TSP and 5% CA achieved 2.3 and 1.4 log_{10} CFU/cm^2 reductions, respectively. The combination of carvacrol (1%, v/v) and modified atmosphere packaging (95% CO_2:5%O_2) reduced *Campylobacter* counts on turkey breast cutlets by 1-2 log_{10} CFU/g after 3-7 days storage at 4°C as compared to an untreated control (Nair *et al.* 2015). Lauric arginate (400 mg/L) gave a maximum reduction of 1.5 log_{10} CFU/g of *C. jejuni* on chicken breast fillets after 7 days storage at 7°C. Koolman *et al.* (2014) inoculated chicken drumsticks with *C. jejuni* and immersed them in 12% (w/v) trisodium phosphate (TSP), 2% (w/v) citric acid (CA) or 5 % (w/v) capric acid sodium salt (CP) for 1 min, while ultrasonication was performed at 40, 60 or 80 kHz. In another experiment the same chemical solutions were administered in sequential combination (TSP+CA, TSP+CP or CA+CP) while ultrasonication was performed at the same frequencies. The sequential treatment of TSP and CP with ultrasonication at 80 kHz achieved a 4.5–4.6 log_{10} CFU/cm^2 reduction.

Lopez *et al.* (2015) estimated that the use of disinfectant wipes to clean contaminated work areas in the kitchen would decrease the risk of human infection by up to 99.2% using a Monte Carlo simulation.

6.4.1.3 Chilling and freezing

Bolton *et al.* (2014) found that freezing at -20°C for 7 days decreased *Campylobacter* by 1.73 log_{10} CFU/g and by 3.46 log_{10} CFU/g after 42 days of storage. Other similar studies have reported 1.0 to 2.7 log_{10} CFU/g *Campylobacter* reductions on chicken breast samples stored at -18°C for 20 days (Eideh et Al-Qadiri 2011), a 0.9 to 3.2 log_{10} reduction after 2 weeks storage at -20°C on naturally contaminated chicken skin and muscle (Sampers *et al.* 2010), a 1.3 to 1.8 log_{10} CFU/g reduction in *C. jejuni* on chicken wings frozen at -20°C to -30°C for 72h (Zhao *et al.* 2003b), and a 2.87 log_{10} on broiler carcasses frozen for 31 days (Georgsson *et al.* 2006). However, freezing will not guarantee the complete elimination of all *Campylobacter* cells on poultry. Sampers *et al.* (2010) detected viable *Campylobacter* cells after 60 days of frozen storage.

6.4.1.4　Light Technologies

C. jejuni and *C. coli* on poultry skin exposed to 405 nm light were reduced by 1.7 and 2.1 decimal reductions, respectively, at the maximal dose of 184–186 J/cm^2. Yet, exposure times to achieve necessary dose levels might be impractical under processing condition (Gunther *et al.* 2016).

6.4.1.5　Irradiation

Irradiation, whether by cobalt 60 source (gamma ray) or electron beams is effective against *C. jejuni.* The range of reported D10 values - D10 is the radiation dose required to eliminate 90% of a bacterial population (one logarithmic cycle reduction) - determined on meat surfaces or in chicken paste, were in the range 0.12 to 0.32 kGy, whether in vacuum or in high oxygen packaging, irrespective of the bacterial cell age, the dose rate of irradiation or the temperature (Dion *et al.* 1994, Kudra *et al.* 2012, Lambert et Maxcy 1984, Patterson 1995, Raut *et al.* 2012). The effect of radurization with a 1 kGy dose was reported to provide more than 8 decimal reductions. (Tarján 1985, Yogasundram *et al.* 1987) reported that 1 kGy completely eliminated cells initially contaminated with 10^3 CFU/cm². Yet, off-odour and sour aroma were observed for irradiated chicken breast (Raut *et al.* 2012). One author noted that "the 3-5 kGy dose generally used for meat products for the destruction of salmonellae will also destroy *Campylobacter*s" (Tarján 1985).

6.4.1.6　Other

The use of ultraviolet irradiation alone was not recommended because it is not well accepted by French consumers.

Cooking, efficient as well, is not considered facing the requirement to have access to raw products by consumers

6.4.1.7　At the consumer stage

Hygienic practice: broiler carcasses and cuts (fillets and drumsticks) are often contaminated with *Campylobacter*. However, if stored, handled and prepared properly the incidence of campylobacteriosis could be significantly reduced. Thus, hygiene practices are important in the catering and domestic kitchen (Beumer et Kusumaningrum 2003, de Jong *et al.* 2008, van Asselt *et al.* 2008) prevent poultry-borne bacteria from being transferred from the raw meat to other foods, especially ready-to-eat (RTE) products, via contaminated hands, equipment and the general kitchen environment (Fravalo *et al.* 2009, Guyard-Nicodeme *et al.* 2013, Luber *et al.* 2006, van Asselt *et al.* 2008, Verhoeff-Bakkenes *et al.* 2008).

Several studies have demonstrated the transfer of bacteria, including *Campylobacter*, from poultry to hands, oven handles, counter tops, draining boards, knife handles, knife blades, dish cloths, fridge handles, microwave handles, microwave buttons, press handles, oven handle, etc. (Bolton *et al.* 2014, Gorman *et al.* 2002). Thus cross-contamination during food preparation presents a greater risk of disease than the risk associated with undercooking poultry (Luber *et al.* 2006). Studies have also shown that washing with warm soapy water is not sufficient to effectively decontaminate kitchen surfaces and equipment (Barker *et al.* 2003, Cogan *et al.* 1999, Cogan *et al.* 2002, Kusumaningrum *et al.* 2002, Scott et Bloomfield 1990, 1993, Thormar et Hilmarsson 2010).

Consumer compliance to hygienic practice: Altekruse *et al.* (1999) reported that 19% of respondents in a US survey did not wash their hands or cutting boards properly after contact with raw meat or poultry. Frequently washing hands after contact with raw meat was associated with a decreased risk of *Campylobacter* infection (OR: 0.53). Although no data in terms of prevalence or decimal reductions were reported, Maughan *et al.* (2016) reported that only 40% of consumers in the US washed their hands properly after handling raw chicken. Moreover, Kosa *et al.* (2015) found that nearly 70% of consumers washed or rinsed poultry before cooking and only 17.5% stored raw poultry properly in the fridge. Yang *et al.* (2000) reported that only 51% of US consumers read a label with cooking instructions and of these only 37% changed their behaviour. In a related study, Sampers *et al.* (2012) reported that 11.2% of consumers store raw and cooked poultry on the same plate, 11% did not wash their hands after handling raw poultry, 6.7% use the same knife for preparing raw poultry and ready-to-eat foods, 8.2% used the same cutting board and 16% did not eat well cooked poultry.

For France, consumer compliance is described in Annex 5 (Scientific and technical support note).

Effect of public information on hygienic practice: Nauta *et al.* (2008) tested the effect of a web-based information campaign on hygiene practices by the consumers, measured by bacterial cross-contamination during preparation of a chicken meat salad. This effect was incorporated into a risk assessment for *Campylobacter* in broiler meat. It was found that there was no measurable effect of the information intervention on the risk, unless a behavioural cue, triggering the emotion 'disgust', was embedded within the

instruction for the salad preparation. This research suggests that it is unlikely that consumer education by an information campaign will be an effective tool for risk mitigation.

French situation: a recent report on the behaviour of French consumers concluded that the risk in the domestic kitchen is mainly related to cross contamination via hands and utensils that are not washed after contact with raw chicken meat, and insufficient cooking (ANSES 2015).The report recommended a multimedia communication campaign targetting the general public. Yet, based on a literature review and surveys of the consumer behaviour, the report concluded that one cannot expect more than 5 to 10% change in hygiene practices in domestic preparation of chicken meat. According to a QMRA (ANSES 2015), such a change would result in a risk reduction of 1.6 to 3.2%, while an optimum application of hygiene practices would achieve a 4.5 to 9% risk reduction.

Overall it was concluded that there are no interventions at the consumer stage that could be immediately applied to control *Campylobacter* on poultry.

6.4.2 Potential interventions selected by the working group

The interventions that are not relevant to the French situation, and those without quantitative data that could not be used for modelling, are not considered (see Annex 3). Those that could be applicable in France, with indication of the numerical values selected by the experts are mentioned below:

- Freezing: 1 to 3.2 DRs

- Visible light technologies: <2.1 DRs

- Irradiation: >8 DRs

As regards interventions at the consumer phase, the experts introduced into the model hand washing and utensils cleaning, assuming 100% compliance with hygienic practice recommendations.

7. Modelling

7.1 Existing QMRA models

7.1.1 Published QMRAs

A considerable number of quantitative microbiological risk assessment (QMRA) models for *Campylobacter* in broiler meat have been developed worldwide. Nauta *et al.* (2009) and Nauta and Christensen (2011) presented an overview of some of these models and a more recent overview has been presented by Chapman *et al.* (2016) (see Figure 7). The reader will refer to these review papers for more details on the different published QMRA studies on *Campylobacter* in broiler meat.


a   processes are coupled
b   an additional wash occurs at this stage
▲   process is included, but assumed to have no effect
    on *Campylobacter* concentration or prevalence
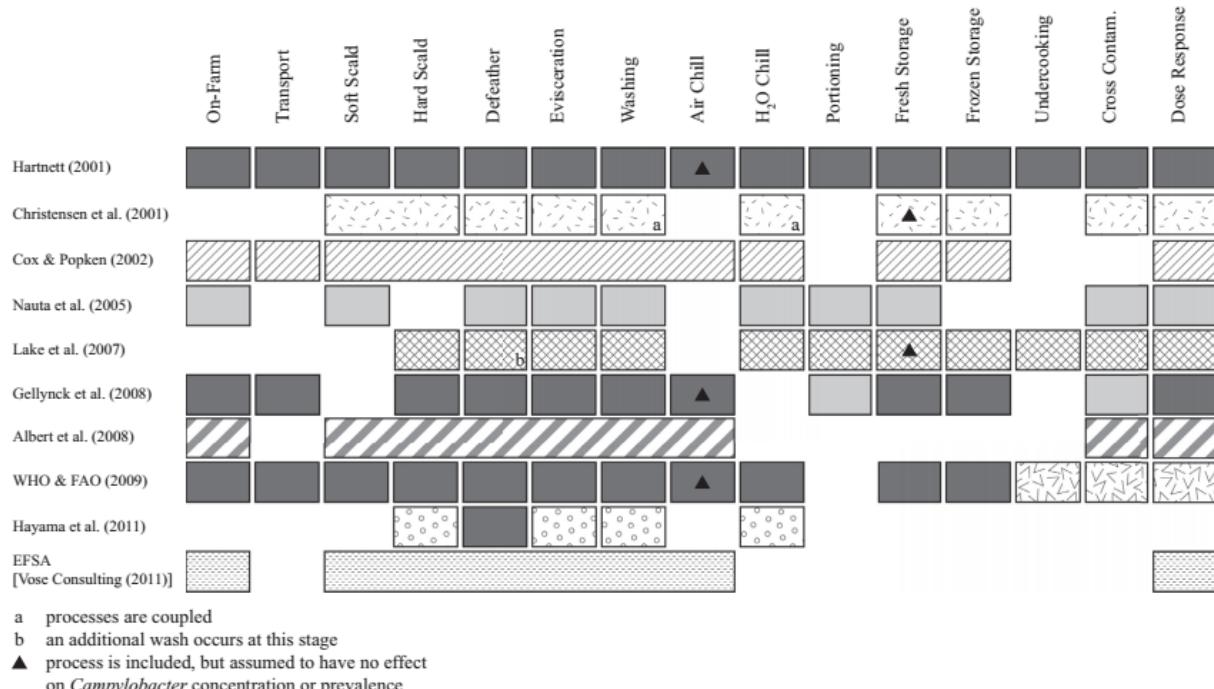
Figure 7: Overview of published *Campylobacter* risk assessments (Chapman *et al.* 2016)

The common objective of these risk assessments is to assess the impact of potential interventions in different steps of the broiler meat production chain in terms of reduced public health risk for the consumers, as a decision support for risk managers in the government and the industry. Yet, in general, the models differ in their specific objectives and scope (for example based on the available data and the interventions to be considered), the consumed chicken meat product and the region of interest. Also, the modelling approaches differ, partly because the (early) risk assessments were some of the first food chain risk assessments performed. They were developed independently by research groups with different scientific backgrounds.

Roughly, the modelling approaches can by differentiated in two types: "mechanistic" and "non-mechanistic". The "mechanistic" models use an MPRM (modular process risk modelling; (Nauta *et al.* 2008) or comparable approach, in which the relevant basic process (growth, inactivation, cross contamination, partitioning, mixing, etc.) in each step on the production process is identified and a suitable model is used to describe this process, before the data are collected (e.g. Nauta *et al.* (2005)). The "non-mechanistic" models use a data-based approach where statistical (often log-linear) models are derived from the available data (e.g. Rosenquist *et al.* (2003)). The mechanistic models have the challenge that the available data may be insufficient to feed the models, so for example expert elicitation is needed for parameterisation of the models (Nauta *et al.* 2005), but their strength is that the non-linear dynamics of transfer and survival of *Campylobacter* are specifically addressed, which is anticipated to improve the validity of the estimation of the effects of interventions. For the "non-mechanistic" models, the situation is opposite. They are clearly data

based, but the dynamics may not be modelled correctly. For *Campylobacter* in the broiler meat production chain, recent research confirms that data alone do not show a consistent pattern in terms of changes in concentrations over the different steps of the slaughter process (Pacholewicz, Swart*, et al.* 2015, Seliwiorstow *et al.* 2015) a pattern that can be well explained by the available mechanistic models.

Despite their differences, the published QMRA models show comparable results in the estimation of the effects of interventions. For example, the different models predict comparable effects of the reduction of the concentration of *Campylobacter* on carcasses, when applied to the same processing step.
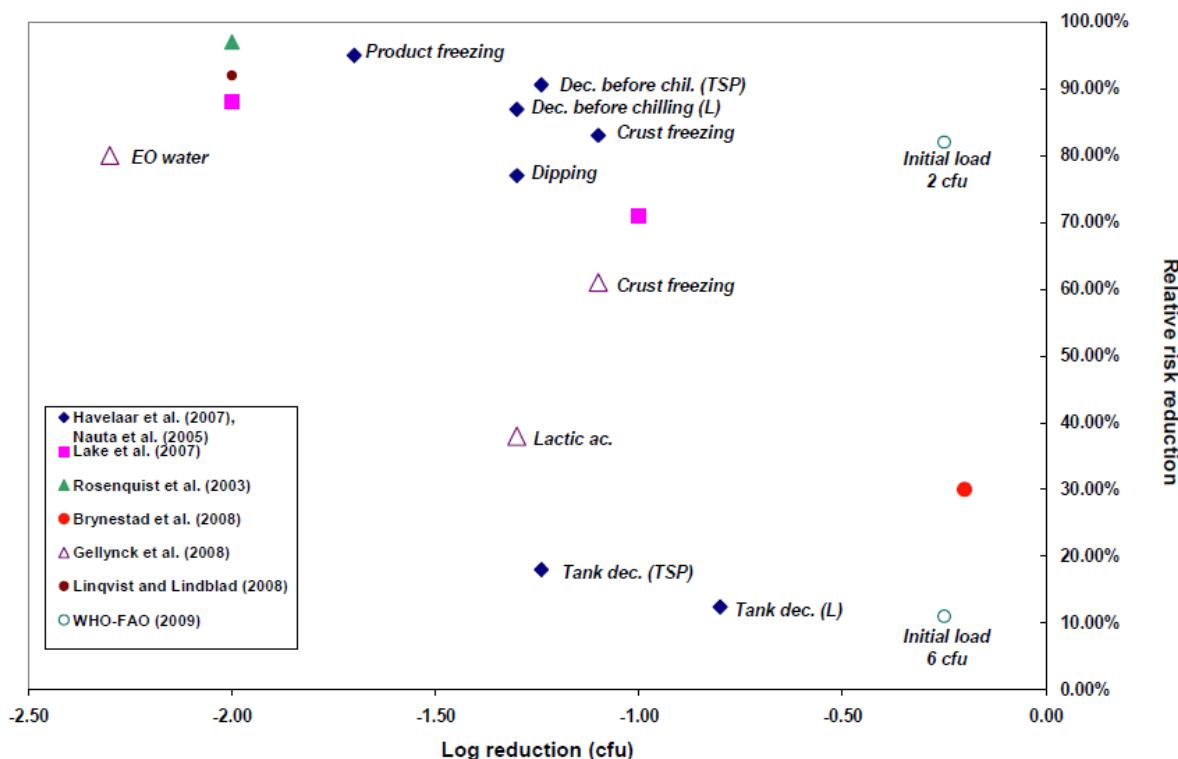
Figure 8 : Reported risk reductions as a consequence of a reduction in concentration on carcasses (EFSA 2011)

Some general conclusions that can be drawn from the published QMRA are (EFSA 2011, Nauta *et al.* 2009):

- In evaluating control strategies, all models suggest a negligible effect of logistic slaughter, the separate processing of positive and negative flocks to prevent contamination of negative flocks. Therefore, there is a proportional relation between the risk (mean probability of disease per serving from the product(s) modelled) and the true flock prevalence, if the distributions of concentrations remain the same.

- All risk assessments conclude that the most effective intervention measures aim at reducing the *Campylobacter* concentration, rather than reducing the prevalence.

- During the stage where the consumer handles the food, cross-contamination is generally considered to be more relevant than undercooking.

- The tails of the distributions describing the variability in *Campylobacter* concentrations between meat products and meals determine the risks, not the mean values of those distributions.

- There is a proportional relation between the risk and the true prevalence of contaminated carcasses after slaughter, if the distributions of concentrations remain the same.

7.1.2 Farm models

Some epidemiological models (e.g. random-effect logistic models) can generate estimates of the strength of association between management conditions and likelihood of flock colonisation at high levels (Georgiev *et al.* 2017). The results will indicate how much more likely 'a factor' contributes to the outcome (*i.e.* undesired level of high colonisation)

A stochastic model could also be employed to reproduce the dynamics of *Campylobacter* transmission in broiler flocks and explore the effects of several management conditions and/or on-farm mitigation strategies on the estimated level of contamination of infected flocks at slaughter (Crotta *et al.* 2017). In this model, the assessment was made by developing an initial baseline probabilistic model aimed at capturing the dynamics of the within flock transmission of *Campylobacter* in a 'typical broiler chicken flock' and comparing the proportion of highly contaminated flocks obtained under baseline conditions with that obtained when different strategies were implemented. The baseline model was implemented with the available information and/or data included in studies related to broiler chicken raised in intensive systems in the UK.

7.1.3 Consumer phase models (CPMs)

The consumer phase is the last part of the food chain where the actual exposure occurs. It is needed in every QMRA, and the food preparation by the consumer has an important effect on the exposure, because the meat is expected to be heat treated. Perfect hygienic food handling of the consumer would eliminate *Campylobacter*, but this is not considered feasible (Nauta *et al.* 2008). Modelling the consumer phase is challenging, because data are scarce and difficult to obtain, the variability in food handling practices between (groups of) consumers is large and the effect on transfer and survival of *Campylobacter* is not easily described. Moreover, the original concentrations of *Campylobacter*, which will vary from poultry sample to poultry sample, will have a major impact on the specific risk to a given consumer.

As reviewed by Chapman *et al.* (2016) a large variety of CPMs is available. In a comparative analysis, (EFSA 2011, Nauta *et al.* 2012) studied seven different CPMs and their performance in terms of the predicted effect of intervention measures before the consumer phase on the risk estimates.

It was found that the relative risk estimates of the different models are often small. A CPM that performs intermediate is based on the data obtained by Nauta *et al* (2008), which is therefore applied in several other studies, for example the EFSA opinion on *Campylobacter* control (EFSA 2011, Nauta *et al.* 2012).

In France, a model was developed by Poisson *et al.* (2015). The figure 9 and annex 4 illustrate the contamination pathways at the consumer stage.
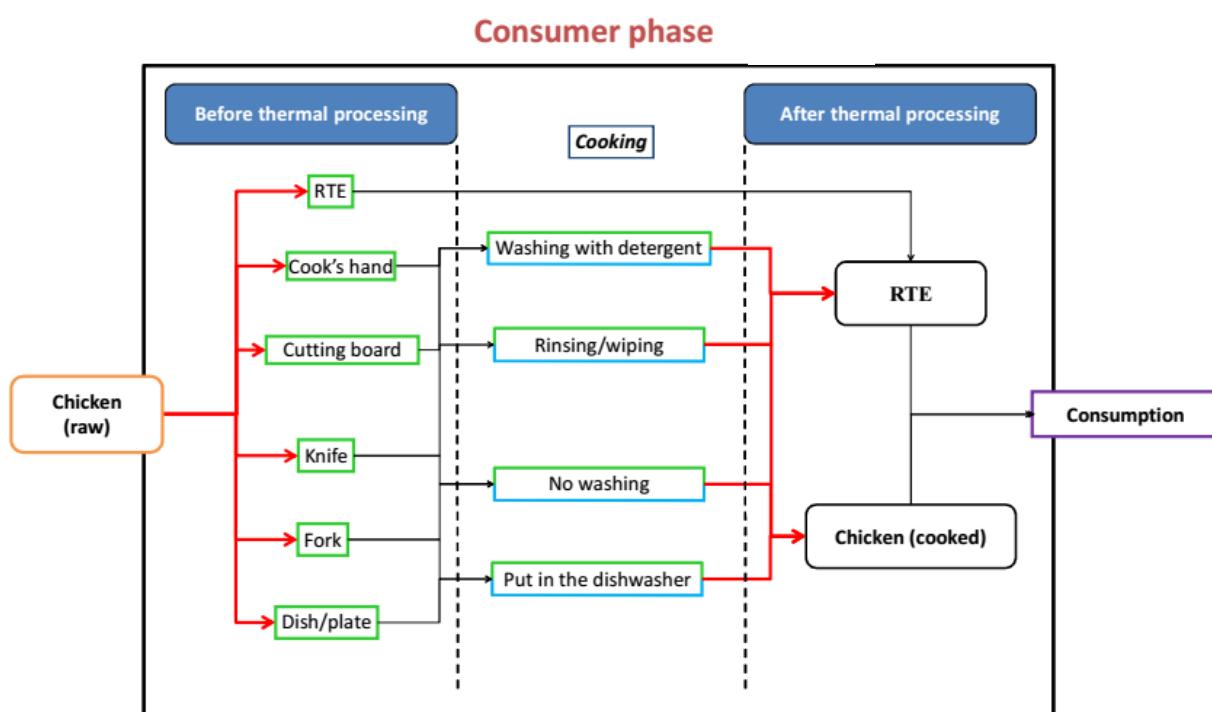
Figure 9: Model diagram of the consumer phase (Poisson *et al.* 2015) (Annex 4).

7.2 The modelling strategy of this working group

The primary objective of using a model is to evaluate the effects of potential interventions. Therefore, first a "baseline model" was developed to assess the "current risk", the mean probability of disease per serving (of a specific chicken meat product), which was used to estimate the annual number of campylobacteriosis

cases in France by multiplying it with the number of servings of the modelled chicken products. The effect of the intervention was then expressed as the <u>percentage of risk reduction,</u> $100*(1-C_{int}/C_{bas})$, where C_{bas} is the baseline estimated number of cases and C_{int} the estimated number of cases after intervention(s).

Two types of interventions were considered: those affecting the prevalence (*i.e.* flock or batch prevalence, or product prevalence) and those affecting the distribution of concentrations within a "set of units", (for example products within a batch, all products in France, chickens in a farm, etc.) Of the consumed chicken meat in France 70% are produced in France from live animals raised in France, and 97 % of them are sold on the French market. <u>The risk assessment only considered chicken meat produced and consumed in France</u>. The reason for this choice is that interventions implemented in the French production system will only impact the French products and the consumers of these products. Also, our focus is on French consumers.

The outline of the modelling strategy is illustrated by the Figure 10.
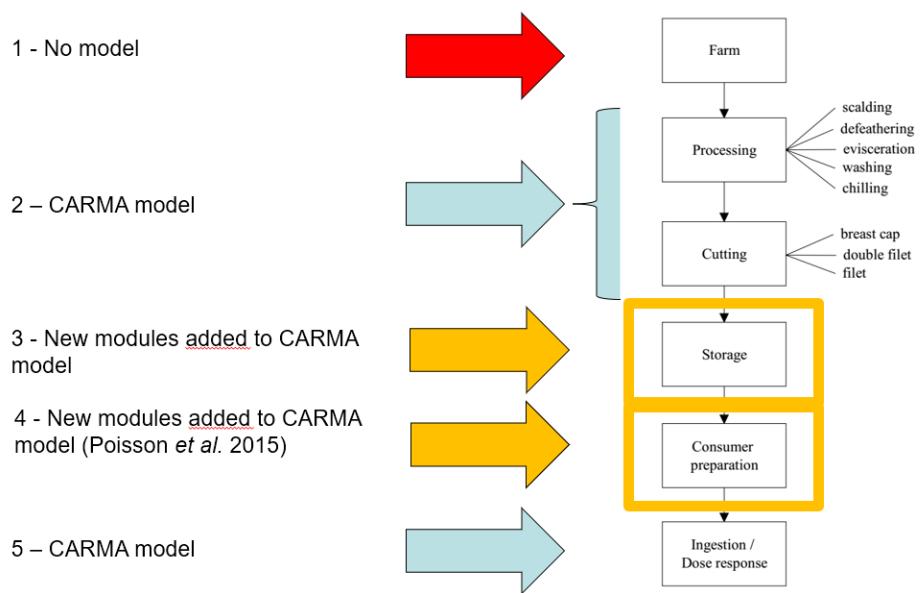
Figure 10 : Modelling strategy of this WG

No modelling was done for the <u>farm step</u> because the effect of on farm interventions was directly expressed in terms of reduction of interflock prevalence or of decimal reductions in the concentrations prior to slaughter. Only the interflock prevalence was used. Based on the bibliography, it was assumed that all chickens in an infected flock are infected (100% within-flock prevalence).

In this study, we chose to use the <u>slaughterhouse model of (Nauta *et al.* 2005, Nauta *et al.* 2009)</u> the basis for the QMRA. It was chosen because it is a mechanistic model that addresses the dynamics in terms of cross-contamination and survival during slaughter, it has been published in the peer reviewed literature and it is readily available. The model was developed for the Netherlands; it was assumed that the industrialized slaughter process is similar in France.

For the <u>Consumer phase the WG decided to use the model developed by</u> Poisson *et al.* (2015) (Annex 5) because it was based on recently acquired French data. This is a mechanistic model that adresses the dynamics in terms of cross contamination with *Campylobacter* by contacting raw chicken directly or indirectly. The different routes of contamination were modeled according to (Pouillot *et al.* 2012). French specific data resulting from a survey on consumer practices during the preparation of chicken meal that involved 659 French representative consumers were used (Poisson *et al.* 2015).

For the dose-response relationship, a dose response model from the literature (Black *et al.* 1988, Nauta *et al.* 2007, Teunis et Havelaar 2000).

7.3 Update of the CARMA model with French data

The WG agreed on the following values (see table 4) for the French baseline.

For the consumer stage, the values used are detailed in Annex 5.

Table 4 : Baseline values

	Primary production	Slaughterhouse	Transport and storage	Consumer phase (see Annexes 5 and 6)
Baseline (Indoor)	Prevalence interflock (EFSA 2010) Outdoor 100% Indoor : 70% Concentration : Caeca m = 8 SD interflock :1 SD intra flock : 0.7 External contamination m= 5.5 ((Seliwiorstow *et al.* 2015) X 100*) SD between = 1,5 SD intra :0,9	CARMA parameters	CARMA parameters	« Freezing » step Probability of freezing chicken: 0.21 Probability of buying frozen chicken: 0.2626 Probability of other behaviour: 0.5274
				For each step, the following was used: - probability of direct contact of utensils / RTE / hands with chicken - transfer coefficient from chicken to utensils / RTE / hands - frequencies of washing, rinsing, no washing of utensils / hands - Probability of survival after washing of utensils / hands - Probability of contact of utensils / hands with RTE - Transfer coefficient from utensils / hands to RTE - Probability of contact of utensils / hands with cooked chicken - Transfer coefficient from utensils / hands to RTE - Frequency of using utensils - Probability of putting utensils in dishwater <u>Prevalence chicken first</u> (percentage of consumers who do not clean the cutting board after cutting the broiler meat) = 16.26 % (Annex 6) Only fillet Filet weight : as in CARMA Number of meals : see table 5 (ANSES 2017) Those data were collected for the "Quantitative risk assessment of human Campylobacteriosis related to the consumption of chicken meat in France: focus on the consumer phase" (to be published).

*A factor of 100 was chosen by the experts to reflect the difference between caeca and faeces concentration, due to the dilution in the cloaca.

Consumption data extruded from the survey INCA are presented in Table 5.

Table 5 : Number of meals per year where chicken fillets and ready-to-eat foods are prepared at the same time for children (0-17 years old) and adults (18-79 years old)

	Number of meals/year
Children	314 000 000
Adults	1 020 000 000

7.4 Scenarios tested

The effects of the interventions were described in Section 6. In the present section, the effects of named or unnamed interventions are tested with the help of the model. Some were chosen because they affect the interflock prevalence of *Campylobacter*, some because they affect the number of CFU/g. The tested effects are listed below.

Tested effects at the farm level:

- **A1a and A1b**: reduction of the *Campylobacter* interflock prevalence from 70% to 60% or 40%,

- **A2, A3, A4 and A5**: 0.5, 1, 1.5 or 2.5 decimal reductions (DR) of *Campylobacter* concentration in caeca,

- **A6**: the combination of reduction of prevalence from 70% to 60% (A1a) and 0.5 DR of concentration (A2).

 Tested effects at the slaughterhouse, the CARMA model was used, implemented in @Risk (version 7.5), complemented with a new module for the storage stage (chilling). The following scenarios were tested:

- **B1:** 1 DR during scalding,

- **B2 and B3**: 10% reduction of the probability of leakage during plucking /defeathering or during evisceration,

- **B4**: 1 DR on the carcass during chilling,

- **B5**: the combination of 10% reduction of probability of leakage at plucking (B2) and 10% reduction of probability of leakage at evisceration (B3) and 1DR at chilling (B4).

Tested effects at the consumer stage, the model of (Poisson *et al.* 2015) (Annex 4) was inserted into the model for @Risk. The following scenarios were tested:

- **C1a**: 100% compliance to the hand washing,

- **C1b**: 100% compliance of utensil cleaning recommendations,

- **C2**: a combination of 100% compliance to both these recommendations.

In addition, were tested combinations of interventions with low or high effect among the interventions at the three stages:

- **D1**: combination of weak scenarios,

- **D2**: combination of strong scenarios.

Once a decision is made by the risk manager (RM) regarding the expected level of reduction, the RM will have to select among the potential interventions listed in the previous sections.

Some effects can be obtained by choosing among the interventions presented in the previous chapter. The table 6 shows the potential link (provided the reproducibility after field trials is verified in France) between the interventions and the scenarios tested.

It should be underlined that all scenarios cannot be linked to a potential intervention due to lack of data in literature, expressed as numbers of decimal reductions or reduction of concentration.

Table 6: Examples of potential interventions to achieve expected effect

Step of the model	Scenario	Parameter	Effect of intervention	Potential intervention
Primary production	A1a	Prevalence	-10% (70-10 = 60% prevalence interflocks)	Indoor flock only : • Fly screen **or** • Stop thinning **or** • Slaughter age
	A1b	Prevalence	-30% (70-30 = 40% prevalence interflocks)	Indoor flock only : • Fly screen
	A2	Concentration	- 0,5 log	• Vaccination <u>or</u> • Phage application **or** • chemical and biological substances added to feed or drinking water
	A3	Concentration	- 1 log	
	A4	Concentration	- 1,5 log	
	A5	Concentration	- 2,5 log	
Slaughter	B4	Chilling	- 1 log	Optimizing the main parameters (temperature, duration, air velocity) but very dependent of the initial *Campylobacter* contamination

7.5 Results

The model was first used to estimate the number of cases of disease caused by *Campylobacter* per year in France, *viz.* 272 930. It is indicated in the following tables as the Baseline number of cases. As reported in Section 2.4, the annual number of cases estimated for the consumption of poultry, based on epidemiological considerations, is 492,705. The similarity of the orders of magnitude of both numbers tends to show that the values of the variables in the present modelling are not unrealistic. Yet, the Baseline result is obviously over-estimated, as it relates only to the consumption of chicken filets produced in France, while the global estimation relates to any kind of food whether of domestic origin or not.

Then, since we aimed at comparing the effect of a variety of interventions on the risk for the consumer health, we estimated the risk reduction as follows:

- $risk\ reduction\ (\%) = 100 * (1 - \frac{number\ of\ cases\ after\ intervention(s)}{number\ of\ cases\ before\ intervention(s)})$.

Therefore, the absolute outcome of the Baseline scenario as estimated in the present model does not influence the risk reduction.

While the estimation of the reduction of risk was done considering only filets, it is assumed that the percentage of reduction applies to any part of chicken (<u>with or without skin and whether raised indoor or outdoor</u>) produced and consumed in similar conditions. <u>The risk reduction results presented below provide therefore a global estimate of the effect of the interventions tested in this modelling exercise.</u>

7.5.1 Interventions at the primary production stage

Table 7: Effect of interventions at the farm

Phase	Scenario	Variable	Reduction	Nr cases	Risk reduction (%)
	Baseline			272 930	
Primary production	A1a	Prevalence interflocks	From 70 to 60%	233 940	14
	A1b	Prevalence interflocks	From 70 to 40%	155 960	43
	A2	Concentration	0.5 decimal reduction	148 560	46
	A3	Concentration	1 decimal reduction	77 800	71
	A4	Concentration	1.5 decimal reductions	41 760	85
	A5	Concentration	2.5 decimal reductions	18 780	93
	A6	Prevalence interflocks concentration	From 70 to 60% 0.5 DR	128 570	53

To obtain more than 50% risk reduction, the concentration of *Campylobacter* in caeca should be decreased by 1.5 DRs (that is divided by more than 30), or 0.5 DR (division by 3) should be combined with a 10% reduction of the interflock prevalence. Yet, a division of the concentration by 3 only, or a 30% reduction of interflock prevalence would assure a risk reduction of more than 40%; which is not insignificant.

7.5.2 Interventions at the slaughtering stage

Table 8: Effect of the interventions at the slaughter stage

Phase	Scenario	Operation	Reduction	Nr cases	Risk reduction (%)
	Baseline			272 930	
	B1	Scalding	1 decimal reduction	264 560	3
	B2	Plucking/defeathering	Probability of leakage reduced by 10%	261 470	4
	B3	Evisceration	Probability of leakage reduced by 10%	264 520	3
Slaughter	B4	Chilling	1 decimal reduction	66 570	76
	B5	Plucking / defeathering	Probability of leakage reduced by 10%	60 030	78
		Evisceration	Probability of leakage reduced by 10%		
		Chilling	1 decimal reduction		

At this, stage, only the intervention at chilling results in a risk reduction of 76%. The other interventions tested show a risk reduction lower than 5%.

7.5.3 Interventions at the consumer stage

Table 9: Effect of interventions at the consumer stage

Phase	Scenario	Operation	Compliance	Nr cases	Risk reduction (%)
	Baseline			272 930	
	C1a	Hand washing	100%	270 260	1
Consumer	C1b	Cleaning of utensils	100%	40 080	85
	C2	C1a + C1b		35 670	87

The prevention of cross-contamination through the cleaning of the utensils (knife, board, fork, plate) appears to be by far more effective than the washing of hands.

7.5.4 Combinations of interventions

Table 10: Effect of combined interventions

Scenario	Combination			Nr cases	RR
Baseline				272 930	
D1	Weak scenarios	A1a + B2 + C1a		224 110	18
D2	Strong scenarios	A4 + B5 + C2		2 800	99

The combination of the weak scenarios leads to a risk reduction of 18%.

7.5.5 How could the risk manager use this risk assessment?

Based on the model results, the risk manager (RM) could decide on the percentage of risk reduction that is aimed at. The RM may notice that, in the present situation, it could be more effective to reduce the contamination level than the interflock prevalence. Then, to achieve that, the RM could choose among the interventions.

It has to be noticed that the estimated effects of interventions, as reported in the literature and summarised in the chapter 6 of this report, are associated with large variability and uncertainty. Results are often obtained from a smal set of experimental trials, which may not be representative for all chickens, farms, slaughterhouses and kitchens in France where they could be applied. .

Furthermore, it is difficult to know to what extent the reported experimental situations are comparable with the French one. In addition, the French practices are not precisely known and, in many cases, it is difficult to evaluate for an intervention to what extent it is already in place and what would be its actual effect when applied at the national level.

Let assume the RM chooses to intervene at the farm stage and would be interested in testing, for example, vaccination as it could achieve 1 to 4 decimal reductions in the caeca according to section 6.1.2. To support a decision made by the RM, a long term large experiment would help measure the actual reduction of faecal content, animal contamination and carcass contamination.The result of that experiment, a survey on the acceptability by the farmers and also by all actors of the food chain including the consummers, an estimation of the future farmer compliance to guidelines, etc. should be combined with those from a cost/benefit analysis (including the benefit of DALY reduction) in actual conditions. A further consideration to be

accounted for would be the influence on the final result of the imported products contamination level and the proportion of these products in the national consumption. This issue was outside the remit of the WG.

8. Conclusions

1 / Survey of control measures of *Campylobacter* in the poultry production, and of their improvement since the report of EFSA (2011)

Up-dating of the knowledge on the contamination of broiler and chicken products: almost no new data have been generated about the situation of *Campylobacter* in broiler and chicken products in France since the European baselines studies in 2008 and 2009. Various interventions at different stages of the food chain production were tested in France, in EU and in the world since 2010's. Yet, results issued from controlled trials in farms or at slaughterhouse are lacking to evaluate the efficacy and the applicability of those interventions in commercial conditions. Up to now, no single intervention has been proven to be efficient and applicable enough to be adopted by the professional sector.

Impact of consumers' behaviour on the risk: data on the French situation has been obtained. Cross contamination from poultry product to ready-to-eat food is recognized as a major source of human campylobacteriosis. Behaviours of consumers in kitchen play an important role on the risk of campylobacteriosis, particularly the practices regarding the cleaning of utensils.

Based on the review of the EFSA (2011) report and of the recent literature, the experts listed the interventions they considered to be applicable in France. They proposed, for each of them, a numerical value of their potential effect on interflock prevalence of carcasses infected by *Campylobacter*, on the number of decimal reductions (or log kills) that could be achieved by some interventions at the farm, the slaughterhouse or the consumer kitchen.

2 / Modelling of the French poultry food chain from rearing to consumption

The CARMA model, completed in this work with a chilling module and a consumer phase, enabled to estimate the effect of a number of scenarios on the risk of human campylobacteriosis compared to a baseline reflecting the situation where no intervention would be applied. The effect of the scenarios was presented as the reduction of the relative risk of campylobacteriosis.

- At the farm, the model, according to its specific hypotheses, showed that the most effective interventions are those that reduce the contamination level on carcasses (CFU/g) rather than reducing the prevalence of contaminated carcasses. Therefore, as soon as, for example, vaccination will be available, it might prove quite effective at protecting public health. If, for instance, vaccination would achieve 1.5 decimal reductions of carcass contamination level, the relative risk reduction would be 85%.

- At the slaughter plant, achieving one more decimal reduction of carcass contamination by scalding or by reducing faeces leakage at the plucking or evisceration steps would result only in a relative risk reduction of 3% or 4% in the present state of the slaughter chain technology. By contrast, the chilling process seems to be very effective and, as an example, the model shows that one DR of carcass contamination would reduce the risk by 76%.

- In the home kitchen, hand washing alone has a limited effect on campylobacteriosis incidence (1% reduction of relative risk). However, the cleaning of utensils to prevent cross contamination is effective. If, for example, recommendations on utensil cleaning were effectively applied by all consumers, the relative risk reduction would be 85%. Perfect application of good hygienic practice in the home kitchen would be highly effective. However, according to a previous ANSES report on consumer information (2015) it may be difficult to change consumer behaviour.

- The experts also tested two scenarios including operations at the farm, at the slaughterhouse and at home. The effect of a combination of interventions is not strictly cumulative. The scenario with the weakest interventions would achieve a relative risk reduction of 16% while the one with the strongest interventions would achieve a risk reduction of 99%.

3/ Final consideration

The results presented above demonstrate that there is room for improvement of public health protection. However, a major relative risk reduction would need the application of interventions that are presently at the stage of experimentation and development (such as vaccination), improvement of hygienic design of slaughter machinery, as well as better compliance to good hygienic practices all along the food chain including by the consumers.

9. Recommendations

R1 - Establish a national control plan involving all actors of the food chain (as for *Salmonella*). As seen in the conclusions, the best improvement will result from improvement at each step of the food chain.

R2 - A better knowledge of the sources of human campylobacteriosis is needed because this disease is not caused only by broilers from flocks raised in France. Imported chicken and other foods can cause the disease. The results presented above should be understood as representing only a limited proportion of cases.

R3 – Control measures on farm and during the transport should be promoted. Field experiments should be conducted to test the effect including the variability, the applicability and cost of interventions.These control measures should be in relation with the specificity of the French broiler productions.

R4 – At the slaughter plant, good hygienic pratices should be further improved and their implementation should be monitored on a regular basis, mainly to avoid carcass contamination (e.g. leakage) and cross-contamination.

R5 – Air chilled parameters (temperature, hygrometry, airflow velocity) to assure a quick and effective decrease of the carcass temperature should be controlled because the chilling process is a critical point to reduce *Campylobacter* surface contamination.

R6 – Domestic hygiene should be largely promoted including domestic hygiene training in schools.

R7– Further and regular updating of French situation is needed with respect to *Campylobacter* contamination of broilers and products thereof.

R8 – Perform field trials all along the food chain with promising interventions, including new technologies, and estimate their effect on the prevalence and contamination levels including the variability of the effect and the survival of the bacteria after chilling.

R9 – Implement a surveillance system by the competent authority of own-checks on the application of the new microbiological criterion for process hygiene, with the aim of evaluating the impact of interventions and optimizing the quantitative risk assessment.

Date of validation of the report of collective expertise collective by the Working Group: 1st June 2018.

References

Abutheraa, R., N. Hettiarachchy, G. Kumar-Phillips, R. Horax, P. Chen, R. Morawicki, et Y. M. Kwon. 2017. "Antimicrobial Activities of Phenolic Extracts Derived from Seed Coats of Selected Soybean Varieties." *J Food Sci* 82 (3):731-737. doi: 10.1111/1750-3841.13644.

Agreste. 2016. "Productions avicoles - Aviculture." http://agreste.agriculture.gouv.fr/enquetes/productions-animales-625/productions-avicoles-aviculture/.

Aguiar, V. F., A. M. Donoghue, K. Arsi, I. Reyes-Herrera, J. H. Metcalf, F. S. de los Santos, P. J. Blore, et D. J. Donoghue. 2013. "Targeting motility properties of bacteria in the development of probiotic cultures against Campylobacter jejuni in broiler chickens." *Foodborne Pathog Dis* 10 (5):435-41. doi: 10.1089/fpd.2012.1302.

Agunos, A., L. Waddell, D. Léger, et E. Taboada. 2014. "A systematic review characterizing on-farm sources of Campylobacter spp. for broiler chickens." *PLoS ONE* 9 (8). doi: 10.1371/journal.pone.0104905.

Allain, V., M. Chemaly, M. J. Laisney, S. Rouxel, S. Quesne, et S. Le Bouquin. 2014a. "Prevalence of and risk factors for Campylobacter colonisation in broiler flocks at the end of the rearing period in France." *Br Poult Sci* 55 (4):452-9. doi: 10.1080/00071668.2014.941788.

Allain, V., M. Chemaly, M. J. Laisney, S. Rouxel, S. Quesne, et S. Le Bouquin. 2014b. "Prevalence of and risk factors for Campylobacter colonisation in broiler flocks at the end of the rearing period in France." *British Poultry Science*. doi: 10.1080/00071668.2014.941788.

Altekruse, S. F., S. Yang, B. B. Timbo, et F. J. Angulo. 1999. "A multi-state survey of consumer food-handling and food-consumption practices." *Am J Prev Med* 16 (3):216-21.

Annamalai, T., R. Pina-Mimbela, A. Kumar, B. Binjawadagi, Z. Liu, G. J. Renukaradhya, et G. Rajashekara. 2013. "Evaluation of nanoparticle-encapsulated outer membrane proteins for the control of Campylobacter jejuni colonization in chickens." *Poult Sci* 92 (8):2201-11. doi: 10.3382/ps.2012-03004.

ANSES. 2011. Fiche de description de danger : Campylobacter jejuni Campylobacter coli.

ANSES. 2015. Information des consommateurs en matière de prévention des risques biologiques liés aux aliments. ANSES.

ANSES. 2017. Étude individuelle nationale des consommations alimentaires 3 (INCA 3).

Arsi, K., A. M. Donoghue, K. Venkitanarayanan, A. Kollanoor-Johny, A. C. Fanatico, P. J. Blore, et D. J. Donoghue. 2014. "The Efficacy of the natural plant extracts, thymol and carvacrol against campylobacter colonization in broiler chickens." *Journal of Food Safety* 34 (4):321-325. doi: 10.1111/jfs.12129.

Arsi, K., A. M. Donoghue, A. Woo-Ming, P. J. Blore, et D. J. Donoghue. 2015a. "The efficacy of selected probiotic and prebiotic combinations in reducing Campylobacter colonization in broiler chickens." *Journal of Applied Poultry Research* 24 (3):327-334. doi: 10.3382/japr/pfv032.

Arsi, K., A. M. Donoghue, A. Woo-Ming, P. J. Blore, et D. J. Donoghue. 2015b. "Intracloacal inoculation, an effective screening method for determining the efficacy of probiotic bacterial isolates against Campylobacter colonization in broiler chickens." *J Food Prot* 78 (1):209-213. doi: 10.4315/0362-028X.JFP-14-326.

Bahrndorff, S., L. Rangstrup-Christensen, S. Nordentoft, et B. Hald. 2013. "Foodborne disease prevention and broiler chickens with reduced Campylobacter infection." *Emerging Infectious Diseases* 19 (3):425-430.

Barker, J., M. Naeeni, et S. F. Bloomfield. 2003. "The effects of cleaning and disinfection in reducing Salmonella contamination in a laboratory model kitchen." *J Appl Microbiol* 95 (6):1351-60.

Battersby, T., D. Walsh, P. Whyte, et D. Bolton. 2017. "Evaluating and improving terminal hygiene practices on broiler farms to prevent Campylobacter cross-contamination between flocks." *Food Microbiol* 64:1-6. doi: 10.1016/j.fm.2016.11.018.

Battersby, T., P. Whyte, et D. J. Bolton. 2016. "The pattern of Campylobacter contamination on broiler farms; external and internal sources." *J Appl Microbiol* 120 (4):1108-1118. doi: 10.1111/jam.13066.

Bearth, A., M. E. Cousin, et M. Siegrist. 2013. "Uninvited guests at the table - A consumer intervention for safe poultry preparation." *Journal of Food Safety* 33 (4):394-404. doi: 10.1111/jfs.12063.

Berrang, M. E., C. L. Hofacre, et R. J. Meinersmann. 2011. "Forced hot air to dry feces and kill bacteria on transport cage flooring." *Journal of Applied Poultry Research* 20 (4):567-572. doi: 10.3382/japr.2011-00391.

Berrang, M. E., R. J. Meinersmann, et C. L. Hofacre. 2011. "Spray washing, absorbent cornstarch powder, and drying time to reduce bacterial numbers on soiled transport cage flooring." *Journal of Applied Poultry Research* 20 (3):378-382. doi: 10.3382/japr.2011-00365.

Beumer, R. R., et H. Kusumaningrum. 2003. "Kitchen hygiene in daily life." *International Biodeterioration & Biodegradation* 51 (4):299-302. doi: https://doi.org/10.1016/S0964-8305(03)00041-6.

Black, R. E., M. M. Levine, M. L. Clements, T. P. Hughes, et M. J. Blaser. 1988. "Experimental Campylobacter jejuni infection in humans." *J Infect Dis* 157 (3):472-9.

Bolton, D., H. Meredith, D. Walsh, et D. McDowell. 2014. "Poultry Food Safety Control Interventions in the Domestic Kitchen." *Journal of Food Safety* 34 (1):34-41. doi: 10.1111/jfs.12092.

Borck Høg, B., H. M. Sommer, L. S. Larsen, A. I. V. Sørensen, B. David, M. Hofshagen, et H. Rosenquist. 2016. "Farm specific risk factors for Campylobacter colonisation in Danish and Norwegian broilers." *Preventive Veterinary Medicine* 130:137-145. doi: 10.1016/j.prevetmed.2016.04.002.

Brena, Maria Camilla. 2013. "Effect of different poultry production methods on Campylobacter incidence and transmission in the broiler meat food chain." University of Liverpool.

Bügener, E. M., M. Casteel, A. W. S. Kump, et G. Klein. 2014. "Effect of electrolyzed oxidizing water on reducing Campylobacter spp. in broiler chikken at primary production." *Archiv fur Lebensmittelhygiene* 65 (1):4-9. doi: 10.2376/0003-925X-65-4.

Burfoot, D., J. Hall, K. Nicholson, K. Holmes, C. Hanson, S. Handley, et E. Mulvey. 2016. "Effect of rapid surface cooling on Campylobacter numbers on poultry carcasses." *Food Control* 70:293-301. doi: 10.1016/j.foodcont.2016.05.041.

Butzler, J.-P. . 2004. "Campylobacter, from obscurity to celebrity." *Clin Microbiol Infect* 10:868–876.

Byrd, J. A., D. E. Corrier, M. E. Hume, R. H. Bailey, L. H. Stanker, et B. M. Hargis. 1998. "Effect of feed withdrawal on Campylobacter in the crops of market-age broiler chickens." *Avian Diseases* 42 (4):802-806. doi: 10.2307/1592719.

CamCom. 2016. Data collected for risk assessment and economics. Deliverable 4.2.1. .

Cardinale, E., F. Tall, E. F. Guèye, M. Cisse, et G. Salvat. 2004. "Risk factors for Campylobacter spp. infection in Senegalese broiler-chicken flocks." *Preventive Veterinary Medicine* 64 (1):15-25. doi: 10.1016/j.prevetmed.2004.03.006.

Cean, A., L. Stef, E. Simiz, C. Julean, G. Dumitrescu, A. Vasile, E. Pet, D. Drinceanu, et N. Corcionivoschi. 2015. "Effect of human isolated probiotic bacteria on preventing Campylobacter jejuni colonization of poultry." *Foodborne Pathog Dis* 12 (2):122-30. doi: 10.1089/fpd.2014.1849.

Cha, W., R. E. Mosci, S. L. Wengert, C. V. Vargas, S. R. Rust, P. C. Bartlett, D. L. Grooms, et S. D. Manning. 2017. "Comparing the genetic diversity and antimicrobial resistance profiles of Campylobacter jejuni recovered from cattle and humans." *Frontiers in Microbiology* 8 (MAY). doi: 10.3389/fmicb.2017.00818.

Chapman, Brennan, Ainsley Otten, Aamir Fazil, Natalie Ernst, et Ben A. Smith. 2016. "A review of quantitative microbial risk assessment and consumer process models for Campylobacter in broiler chickens." *Microbial Risk Analysis* 2-3:3-15. doi: 10.1016/j.mran.2016.07.001.

Chemaly, M., V. Allain, M.J. Laisney, I. Petetin, O. Hue, N. Homo, F. Lalande, S. Rouxel, S. Quesne, P.Y. Gloaguen, et S. Le Bouquin. 2010. "Follow-up of Campylobacter spp. Contamination of Broilers from the Farms to the Slaughterhouses. ." European Poultry Conference, Tours.

Chen, X., L. J. Bauermeister, G. N. Hill, M. Singh, S. F. Bilgili, et S. R. McKee. 2014. "Efficacy of various antimicrobials on reduction of salmonella and campylobacter and quality attributes of ground chicken obtained from poultry parts treated in a postchill decontamination tank." *J Food Prot* 77 (11):1882-8. doi: 10.4315/0362-028x.Jfp-14-114.

Chintoan-Uta, C., R. L. Cassady-Cain, H. Al-Haideri, E. Watson, D. J. Kelly, D. G. E. Smith, N. H. C. Sparks, P. Kaiser, et M. P. Stevens. 2015. "Superoxide dismutase SodB is a protective antigen against Campylobacter jejuni colonisation in chickens." *Vaccine* 33 (46):6206-6211. doi: 10.1016/j.vaccine.2015.09.100.

Chintoan-Uta, C., R. L. Cassady-Cain, et M. P. Stevens. 2016. "Evaluation of flagellum-related proteins FliD and FspA as subunit vaccines against Campylobacter jejuni colonisation in chickens." *Vaccine* 34 (15):1739-43. doi: 10.1016/j.vaccine.2016.02.052.

Chowdhury, S., M. Sandberg, G. E. Themudo, et A. K. Ersboll. 2012. "Risk factors for Campylobacter infection in Danish broiler chickens." *Poultry Science* 91 (10):2701-2709.

Clark, J. D., R. D. Oakes, K. Redhead, C. F. Crouch, M. J. Francis, F. M. Tomley, et D. P. Blake. 2012. "Eimeria species parasites as novel vaccine delivery vectors: Anti-Campylobacter jejuni protective immunity induced by Eimeria tenella-delivered CjaA." *Vaccine* 30 (16):2683-2688.

Cogan, T. A., S. F. Bloomfield, et T. J. Humphrey. 1999. "The effectiveness of hygiene procedures for prevention of cross-contamination from chicken carcases in the domestic kitchen." *Lett Appl Microbiol* 29 (5):354-8.

Cogan, T. A., J. Slader, S. F. Bloomfield, et T. J. Humphrey. 2002. "Achieving hygiene in the domestic kitchen: the effectiveness of commonly used cleaning procedures." *J Appl Microbiol* 92 (5):885-92.

Cogan, T. A., A. O. Thomas, L. E. N. Rees, A. H. Taylor, M. A. Jepson, P. H. Williams, J. Ketley, et T. J. Humphrey. 2007. "Norepinephrine increases the pathogenic potential of Campylobacter jejuni." *Gut* 56 (8):1060-1065. doi: 10.1136/gut.2006.114926.

Corry, J. E., et H. I. Atabay. 2001. "Poultry as a source of Campylobacter and related organisms." *Symp Ser Soc Appl Microbiol* (30):96s-114s.

Crotta, M., M. Georgiev, et J. Guitian. 2017. "Quantitative risk assessment of Campylobacter in broiler chickens – Assessing interventions to reduce the level of contamination at the end of the rearing period." *Food Control* 75:29-39. doi: 10.1016/j.foodcont.2016.12.024.

De Haan, C. P., R. I. Kivistö, M. Hakkinen, J. Corander, et M. L. Hänninen. 2010. "Multilocus sequence types of Finnish bovine Campylobacter jejuni isolates and their attribution to human infections." *BMC Microbiology* 10. doi: 10.1186/1471-2180-10-200.

de Jong, A. E., L. Verhoeff-Bakkenes, M. J. Nauta, et R. de Jonge. 2008. "Cross-contamination in the kitchen: effect of hygiene measures." *J Appl Microbiol* 105 (2):615-24. doi: 10.1111/j.1365-2672.2008.03778.x.

DGAL. 2010. "Résultats du plan de surveillance 2009 de la contamination par Salmonella et Campylobacter des viandes fraîches de poulet au stade de la distribution. Note de service DGAl/SDSSA/N2010-8211."

DGAL. 2012. Plans de surveillance – Plans de contrôle Bilan 2012.

Dion, P., R. Charbonneau, et C. Thibault. 1994. "Effect of ionizing dose rate on the radioresistance of some food pathogenic bacteria." *Canadian Journal of Microbiology* 40 (5):369-374. doi: 10.1139/m94-060.

Dirks, B. P., D. Dobrynin, G. Fridman, Y. Mukhin, A. Fridman, et J. J. Quinlan. 2012. "Treatment of raw poultry with nonthermal dielectric barrier discharge plasma to reduce Campylobacter jejuni and Salmonella enterica." *J Food Prot* 75 (1):22-8. doi: 10.4315/0362-028x.jfp-11-153.

Duqué, B., S. Daviaud, S. Guillou, N. Haddad, et J. M. Membré. 2018. "Quantification of Campylobacter jejuni contamination on chicken carcasses in France." *Food Research International* 106:1077-1085. doi: 10.1016/j.foodres.2017.12.017.

EFSA. 2010. "Analysis of the baseline survey on the prevalence of Campylobacter in broiler batches and of Campylobacter and Salmonella on broiler carcasses, in the EU, 2008 - Part B: Analysis of factors associated with Campylobacter colonisation of broiler batches and with Campylobacter contamination of broiler carcasses; and investigation of the culture method diagnostic characteristics used to analyse broiler carcass samples." *EFSA Journal* 8 (8):1522. doi: doi:10.2903/j.efsa.2010.1522.

EFSA. 2011. Scientific Opinion on Campylobacter in broiler meat production: control options and performance objectives and/or targets at different stages of the food chain. EFSA.

EFSA, et ECDC. 2017. "The European Union summary report on trends and sources of zoonoses, zoonotic agents and food-borne outbreaks in 2016." *EFSA Journal* 15 (12). doi: 10.2903/j.efsa.2017.5077.

Eideh, A. M., et H. M. Al-Qadiri. 2011. "Effect of refrigerated and frozen storage on the survival of Campylobacter jejuni in cooked chicken meat breast." *J Food Sci* 76 (1):M17-21. doi: 10.1111/j.1750-3841.2010.01924.x.

Eustice, R. F. 2015. "Using irradiation to make safe food safer." *Stewart Postharvest Review* 11 (3). doi: 10.2212/spr.2015.3.1.

Evans, S. J., et A. R. Sayers. 2000. "A longitudinal study of campylobacter infection of broiler flocks in Great Britain." *Preventive Veterinary Medicine* 46 (3):209-223. doi: 10.1016/S0167-5877(00)00143-4.

Fischer, S., S. Kittler, G. Klein, et G. Glunder. 2013. "Impact of a single phage and a phage cocktail application in broilers on reduction of Campylobacter jejuni and development of resistance." *PLoS ONE* 8 (10):e78543. doi: 10.1371/journal.pone.0078543.

FranceAgriMer. 2016. "Données et bilans. Les produits carnés, avicoles et laitiers – Filières avicoles.". http://www.franceagrimer.fr/index.php/filiere-viandes/Viandes-blanches/Informations-economiques/Chiffres-et-bilans

Fraser, R. W., N. T. Williams, L. F. Powell, et A. J. Cook. 2010. "Reducing Campylobacter and Salmonella infection: two studies of the economic cost and attitude to adoption of on-farm biosecurity measures." *Zoonoses Public Health* 57 (7-8):e109-15. doi: 10.1111/j.1863-2378.2009.01295.x.

Fravalo, P., M. J. Laisney, M. O. Gillard, G. Salvat, et M. Chemaly. 2009. "Campylobacter transfer from naturally contaminated chicken thighs to cutting boards is inversely related to initial load." *J Food Prot* 72 (9):1836-40.

FSAI. 2010. "Third National Microbiological Survey 2008 (08NS3): Prevalence of Campylobacter spp. on (a) surface of chicken packaging and (b) surface of display cabinets." http://www.fsai.ie/uploadedFiles/Monitoring_and_Enforcement/Monitoring/Surveillance/Prevalence%20of%20Campylobacter%20spp.pdf.

Gallay, A., V. Bousquet, V. Siret, V. Prouzet-Mauleon, Hd Valk, V. Vaillant, F. Simon, Y. Le Strat, F. Megraud, et J. C. Desenclos. 2008. "Risk factors for acquiring sporadic Campylobacter infection in France: results from a national case-control study." *J Infect Dis* 197 (10):1477-84. doi: 10.1086/587644.

Georgiev, M., W. Beauvais, et J. Guitian. 2017. "Effect of enhanced biosecurity and selected on-farm factors on Campylobacter colonization of chicken broilers." *Epidemiology and Infection* 145 (3):553-567. doi: 10.1017/S095026881600251X.

Georgsson, F., A. E. Thornorkelsson, M. Geirsdottir, J. Reiersen, et N. J. Stern. 2006. "The influence of freezing and duration of storage on Campylobacter and indicator bacteria in broiler carcasses." *Food Microbiol* 23 (7):677-83. doi: 10.1016/j.fm.2005.10.003.

Ghareeb, K., W. A. Awad, M. Mohnl, G. Schatzmayr, et J. Böhm. 2013. "Control strategies for Campylobacter infection in poultry production." *World's Poultry Science Journal* 69 (1):57-76.

Gibbens, J. C., S. J. S. Pascoe, S. J. Evans, R. H. Davies, et A. R. Sayers. 2001. "A trial of biosecurity as a means to control Campylobacter infection of broiler chickens." *Preventive Veterinary Medicine* 48 (2):85-99. doi: 10.1016/S0167-5877(00)00189-6.

Gorman, R., S. Bloomfield, et C. C. Adley. 2002. "A study of cross-contamination of food-borne pathogens in the domestic kitchen in the Republic of Ireland." *Int J Food Microbiol* 76 (1-2):143-50.

Gormley, F. J., R. A. Bailey, K. A. Watson, J. McAdam, S. Avendano, W. A. Stanley, et A. N. Koerhuis. 2014. "Campylobacter colonization and proliferation in the broiler chicken upon natural field challenge is not affected by the bird growth rate or breed." *Appl Environ Microbiol* 80 (21):6733-8. doi: 10.1128/aem.02162-14.

Grilli, E., F. Vitari, C. Domeneghini, A. Palmonari, G. Tosi, P. Fantinati, P. Massi, et A. Piva. 2013. "Development of a feed additive to reduce caecal Campylobacter jejuni in broilers at slaughter age: From in vitro to in vivo, a proof of concept." *J Appl Microbiol* 114 (2):308-317.

Gunther, N. W., J. G. Phillips, et C. Sommers. 2016. "The Effects of 405-nm Visible Light on the Survival of Campylobacter on Chicken Skin and Stainless Steel." *Foodborne pathogens and disease* 13 (5):245-250. doi: 10.1089/fpd.2015.2084.

Gunther, N. W. th, J. G. Phillips, et C. Sommers. 2016. "The Effects of 405-nm Visible Light on the Survival of Campylobacter on Chicken Skin and Stainless Steel." *Foodborne Pathog Dis* 13 (5):245-50. doi: 10.1089/fpd.2015.2084.

Guyard-Nicodème, M., A. Huneau-Salaün, F. A. Tatone, F. Skiba, M. Quentin, S. Quesne, T. Poezevara, et M. Chemaly. 2017. "Effect of feed additives on productivity and Campylobacter spp. loads in broilers reared under free range conditions." *Frontiers in Microbiology* 8 (MAY). doi: 10.3389/fmicb.2017.00828.

Guyard-Nicodème, M., A. Keita, S. Quesne, M. Amelot, T. Poezevara, B. Le Berre, J. Sánchez, P. Vesseur, A. Martín, P. Medel, et M. Chemaly. 2016. "Efficacy of feed additives against Campylobacter in live broilers during the entire rearing period." *Poultry Science* 95 (2):298-305. doi: 10.3382/ps/pev303.

Guyard-Nicodeme, M., O. Tresse, E. Houard, F. Jugiau, C. Courtillon, K. El Manaa, M. J. Laisney, et M. Chemaly. 2013. "Characterization of Campylobacter spp. transferred from naturally contaminated chicken legs to cooked chicken slices via a cutting board." *Int J Food Microbiol* 164 (1):7-14. doi: 10.1016/j.ijfoodmicro.2013.03.009.

Haas, D., J. Posch, S. Schmidt, G. Wüst, W. Sixl, G. Feierl, E. Marth, et F. F. Reinthaler. 2005. "A case study of airborne culturable microorganisms in a poultry slaughterhouse in Styria, Austria." *Aerobiologia* 21 (3-4):193-201. doi: 10.1007/s10453-005-9003-x.

Habib, I., M. Uyttendaele, et L. De Zutter. 2010. "Survival of poultry-derived Campylobacter jejuni of multilocus sequence type clonal complexes 21 and 45 under freeze, chill, oxidative, acid and heat stresses." *Food Microbiol* 27 (6):829-834. doi: 10.1016/j.fm.2010.04.009.

Hakkinen, M., H. Heiska, et M. L. Hänninen. 2007. "Prevalence of Campylobacter spp. in cattle in Finland and antimicrobial susceptibilities of bovine Campylobacter jejuni strains." *Applied and Environmental Microbiology* 73 (10):3232-3238. doi: 10.1128/AEM.02579-06.

Hald, B., H. Skovgard, K. Pedersen, et H. Bunkenborg. 2008. "Influxed insects as vectors for Campylobacter jejuni and Campylobacter coli in Danish broiler houses." *Poult Sci* 87 (7):1428-34. doi: 10.3382/ps.2007-00301.

Hald, B., A. Wedderkopp, et M. Madsen. 2000. "Thermophilic Campylobacter spp. in Danish broiler production: a cross-sectional survey and a retrospective analysis of risk factors for occurrence in broiler flocks." *Avian Pathol* 29 (2):123-31. doi: 10.1080/03079450094153.

Hansson, I., E. O. Engvall, I. Vagsholm, et A. Nyman. 2010. "Risk factors associated with the presence of Campylobacter-positive broiler flocks in Sweden." *Prev Vet Med* 96 (1-2):114-21. doi: 10.1016/j.prevetmed.2010.05.007.

Hansson, I., L. P. Forshell, P. Gustafsson, S. Boqvist, J. Lindblad, E. O. Engvall, Y. Andersson, et I. Vagsholm. 2007. "Summary of the Swedish Campylobacter program in broilers, 2001 through 2005." *J Food Prot* 70 (9):2008-14.

Haughton, P. N., J. Lyng, S. Fanning, et P. Whyte. 2013. "Potential of a commercially available water acidification product for reducing Campylobacter in broilers prior to slaughter." *British Poultry Science* 54 (3):319-324.

Havelaar, A. H., J. A. Haagsma, M. J. Mangen, J. M. Kemmeren, L. P. Verhoef, S. M. Vijgen, M. Wilson, I. H. Friesema, L. M. Kortbeek, Y. T. van Duynhoven, et W. van Pelt. 2012. "Disease burden of foodborne pathogens in the Netherlands, 2009." *Int J Food Microbiol* 156 (3):231-8. doi: 10.1016/j.ijfoodmicro.2012.03.029.

Henry, I., J. Reichardt, M. Denis, et E. Cardinale. 2011. "Prevalence and risk factors for Campylobacter spp. in chicken broiler flocks in Reunion Island (Indian Ocean)." *Prev Vet Med* 100 (1):64-70. doi: 10.1016/j.prevetmed.2011.03.007.

Hermans, D., K. Van Deun, W. Messens, A. Martel, F. Van Immerseel, F. Haesebrouck, G. Rasschaert, M. Heyndrickx, et F. Pasmans. 2011. "Campylobacter control in poultry by current intervention measures ineffective: Urgent need for intensified fundamental research." *Veterinary Microbiology* 152 (3-4):219-228. doi: 10.1016/j.vetmic.2011.03.010.

Hue, O., V. Allain, M. J. Laisney, S. Le Bouquin, F. Lalande, I. Petetin, S. Rouxel, S. Quesne, P. Y. Gloaguen, M. Picherot, J. Santolini, S. Bougeard, G. Salvat, et M. Chemaly. 2011. "Campylobacter contamination of broiler caeca and carcasses at the slaughterhouse and correlation with Salmonella contamination." *Food Microbiol* 28 (5):862-8. doi: 10.1016/j.fm.2010.11.003.

Hue, O., S. Le Bouquin, M. J. Laisney, V. Allain, F. Lalande, I. Petetin, S. Rouxel, S. Quesne, P. Y. Gloaguen, M. Picherot, J. Santolini, G. Salvat, S. Bougeard, et M. Chemaly. 2010. "Prevalence of and risk factors for Campylobacter spp. contamination of broiler chicken carcasses at the slaughterhouse." *Food Microbiol* 27 (8):992-9. doi: 10.1016/j.fm.2010.06.004.

Huneau-Salaun, A., M. Denis, L. Balaine, et G. Salvat. 2007. "Risk factors for Campylobacter spp. colonization in French free-range broiler-chicken flocks at the end of the indoor rearing period." *Prev Vet Med* 80 (1):34-48. doi: 10.1016/j.prevetmed.2007.02.001.

Huneau-Salaun, A., M. Guyard-Nicodeme, G. Benzoni, X. Gautier, S. Quesne, T. Poezevara, et M. Chemaly. 2018. "Randomized control trial to test the effect of a feed additive on Campylobacter contamination in commercial broiler flocks up to slaughter." *Zoonoses Public Health* 65 (4):404-411. doi: 10.1111/zph.12447.

IARC. 2013. "Food consumption data collection methodology for the EU Menu Survey (EMP-PANEU) Final Report." *EFSA Journal* 2013 (EN-485).

Isohanni, P. M., et U. Lyhs. 2009. "Use of ultraviolet irradiation to reduce Campylobacter jejuni on broiler meat." *Poult Sci* 88 (3):661-8. doi: 10.3382/ps.2008-00259.

ITAVI. 2018. "Chiffres clés des industries d'abattage et de transformation des filières avicoles et cunicoles françaises." Consulté le 2018-04-17. https://www.qwant.com/?q=-ITAVI%202015%20:%20les%20chiffres%20cl%C3%A9s%20des%20industries%20d%E2%80%99abattage%20et%20de%20transformation%20des%20fili%C3%A8res%20avicoles%20et%20cunicoles%20fran%C3%A7aises&t=all.

Ivić-Kolevska, S., B. Miljković-Selimović, et B. Kocić. 2012. "Survival of Campylobacter jejuni in chicken meat at frozen storage temperatures." *Acta Microbiologica et Immunologica Hungarica* 59 (2):185-198.

Jansen, W., F. Reich, et G. Klein. 2014. "Large-scale feasibility of organic acids as a permanent preharvest intervention in drinking water of broilers and their effect on foodborne Campylobacter spp. before processing." *J Appl Microbiol* 116 (6):1676-87. doi: 10.1111/jam.12490.

Johnsen, G., H. Kruse, et M. Hofshagen. 2007. "Genotyping of thermotolerant Campylobacter from poultry slaughterhouse by amplified fragment length polymorphism." *J Appl Microbiol* 103 (2):271-279. doi: 10.1111/j.1365-2672.2006.03238.x.

Johnson, T. J., J. M. Shank, et J. G. Johnson. 2017. "Current and potential treatments for reducing Campylobacter colonization in animal hosts and disease in humans." *Frontiers in Microbiology* 8 (MAR). doi: 10.3389/fmicb.2017.00487.

Jonaidi-Jafari, Nematollah, Faham Khamesipour, Reza Ranjbar, et Roohollah Kheiri. 2016. "Prevalence and antimicrobial resistance of Campylobacter species isolated from the avian eggs." *Food Control* 70:35-40. doi: https://doi.org/10.1016/j.foodcont.2016.05.018.

Jonsson, M. E., M. Chriél, M. Norström, et M. Hofshagen. 2012. "Effect of climate and farm environment on Campylobacter spp. colonisation in Norwegian broiler flocks." *Preventive Veterinary Medicine* 107 (1-2):95-104.

Kennedy, J., V. Jackson, I. S. Blair, D. A. McDowell, C. Cowan, et D. J. Bolton. 2005. "Food safety knowledge of consumers and the microbiological and temperature status of their refrigerators." *J Food Prot* 68 (7):1421-1430. doi: 10.4315/0362-028X-68.7.1421.

Kittler, S., S. Fischer, A. Abdulmawjood, G. Glünder, et G. Kleina. 2013. "Effect of bacteriophage application on Campylobacter jejuni loads in commercial broiler flocks." *Applied and Environmental Microbiology* 79 (23):7525-7533.

Koolman, L., P. Whyte, et D. J. Bolton. 2014. "An investigation of broiler caecal Campylobacter counts at first and second thinning." *J Appl Microbiol*. doi: 10.1111/jam.12580.

Kosa, K. M., S. C. Cates, S. Bradley, E. Iv Chambers, et S. Godwin. 2015. "Consumer-reported handling of raw poultry products at home: Results from a national survey." *J Food Prot* 78 (1):180-186. doi: 10.4315/0362-028X.JFP-14-231.

Kudra, L. L., J. G. Sebranek, J. S. Dickson, A. F. Mendonca, Q. Zhang, A. Jackson-Davis, et K. J. Prusa. 2012. "Control of Campylobacter jejuni in chicken breast meat by irradiation combined with modified atmosphere packaging including carbon monoxide." *J Food Prot* 75 (10):1728-1733.

Kusumaningrum, H., H.D. van Putten, F.M. Rombouts, et R. R. Beumer. 2002. "Effects of Antibacterial Dishwashing Liquid on Foodborne Pathogens and Competitive Microorganisms in Kitchen Sponges." *J Food Prot* 65 (1):61-65. doi: 10.4315/0362-028x-65.1.61.

Lambert, J. D., et R. B. Maxcy. 1984. "Effect of Gamma Radiation on Campylobacter jejuni." *J Food Sci* 49 (3):665-667. doi: 10.1111/j.1365-2621.1984.tb13183.x.

Laniewski, P., M. Kuczkowski, K. Chrzastek, A. Wozniak, A. Wyszynska, A. Wieliczko, et E. K. Jagusztyn-Krynicka. 2014. "Evaluation of the immunogenicity of Campylobacter jejuni CjaA protein delivered by Salmonella enterica sv. Typhimurium strain with regulated delayed attenuation in chickens." *World J Microbiol Biotechnol* 30 (1):281-92. doi: 10.1007/s11274-013-1447-5.

Lee, N. K., B. S. Jung, D. S. Na, H. H. Yu, J. S. Kim, et H. D. Paik. 2016. "The impact of antimicrobial effect of chestnut inner shell extracts against Campylobacter jejuni in chicken meat." *LWT - Food Science and Technology* 65:746-750. doi: 10.1016/j.lwt.2015.09.004.

Lopez, G. U., M. Kitajima, S. P. Sherchan, J. D. Sexton, L. Y. Sifuentes, C. P. Gerba, et K. A. Reynolds. 2015. "Impact of disinfectant wipes on the risk of Campylobacter jejuni infection during raw chicken preparation in domestic kitchens." *J Appl Microbiol* 119 (1):245-252. doi: 10.1111/jam.12834.

Luber, P., S. Brynestad, D. Topsch, K. Scherer, et E. Bartelt. 2006. "Quantification of campylobacter species cross-contamination during handling of contaminated fresh chicken parts in kitchens." *Appl Environ Microbiol* 72 (1):66-70. doi: 10.1128/aem.72.1.66-70.2006.

Lyngstad, T. M., M. E. Jonsson, M. Hofshagen, et B. T. Heier. 2008. "Risk factors associated with the presence of Campylobacter species in Norwegian broiler flocks." *Poultry Science* 87 (10):1987-1994. doi: 10.3382/ps.2008-00132.

MacDonald, E., R. White, R. Mexia, T. Bruun, G. Kapperud, H. Lange, K. Nygard, et L. Vold. 2015. "Risk factors for sporadic domestically acquired campylobacter infections in Norway 2010-2011: A national prospective case-control study." *PLoS ONE* 10 (10). doi: 10.1371/journal.pone.0139636.

Man, S. M. 2011. "The clinical importance of emerging Campylobacter species." *Nat Rev Gastroenterol Hepatol* 8 (12):669-85. doi: 10.1038/nrgastro.2011.191.

Manes-Lazaro, R., P. M. Van Diemen, C. Pin, M. J. Mayer, M. P. Stevens, et A. Narbad. 2017. "Administration of Lactobacillus johnsonii FI9785 to chickens affects colonisation by Campylobacter jejuni and the intestinal microbiota." *Br Poult Sci*. doi: 10.1080/00071668.2017.1307322.

Manyi-Loh, Christy E., Sampson N. Mamphweli, Edson L. Meyer, Golden Makaka, Michael Simon, et Anthony I. Okoh. 2016. "An Overview of the Control of Bacterial Pathogens in Cattle Manure." *International Journal of Environmental Research and Public Health* 13 (9):843. doi: 10.3390/ijerph13090843.

Maughan, C., E. Iv Chambers, S. Godwin, D. Chambers, S. Cates, et K. Koppel. 2016. "Food handling behaviors observed in consumers when cooking poultry and eggs." *J Food Prot* 79 (6):970-977. doi: 10.4315/0362-028X.JFP-15-311.

Meerburg, B. G., W. F. Jacobs-Reitsma, J. A. Wagenaar, et A. Kijlstra. 2006. "Presence of Salmonella and Campylobacter spp. in Wild Small Mammals on Organic Farms." *Applied and Environmental Microbiology* 72 (1):960-962. doi: 10.1128/AEM.72.1.960-962.2006.

Meredith, H., V. Valdramidis, B. T. Rotabakk, M. Sivertsvik, D. McDowell, et D. J. Bolton. 2014. "Effect of different modified atmospheric packaging (MAP) gaseous combinations on Campylobacter and the shelf-life of chilled poultry fillets." *Food Microbiol* 44:196-203. doi: 10.1016/j.fm.2014.06.005.

Meredith, H., D. Walsh, D. A. McDowell, et D. J. Bolton. 2013. "An investigation of the immediate and storage effects of chemical treatments on Campylobacter and sensory characteristics of poultry meat." *Int J Food Microbiol* 166 (2):309-15. doi: 10.1016/j.ijfoodmicro.2013.07.005.

Meunier, M., M. Guyard-Nicodème, D. Dory, et M. Chemaly. 2016. "Control strategies against Campylobacter at the poultry production level: Biosecurity measures, feed additives and vaccination." *J Appl Microbiol* 120 (5):1139-1173. doi: 10.1111/jam.12986.

Meunier, M., M. Guyard-Nicodème, E. Hirchaud, A. Parra, M. Chemaly, et D. Dory. 2016. "Identification of novel vaccine candidates against campylobacter through reverse vaccinology." *Journal of Immunology Research* 2016. doi: 10.1155/2016/5715790.

Meunier, Marine, Muriel Guyard-Nicodème, Estelle Vigouroux, Typhaine Poezevara, Véronique Beven, S. Quesne, Lionel Bigault, Michel Amelot, Daniel Dory, et Marianne Chemaly. 2017. "Promising new vaccine candidates against Campylobacter in broilers." *PLoS ONE* 12 (11):e0188472. doi: 10.1371/journal.pone.0188472.

Moore, A., R. Nannapaneni, A. Kiess, et C. S. Sharma. 2017. "Evaluation of USDA approved antimicrobials on the reduction of Salmonella and Campylobacter in ground chicken frames and their effect on meat quality." *Poult Sci*. doi: 10.3382/ps/pew497.

Mughini-Gras, L., C. Penny, C. Ragimbeau, F. M. Schets, H. Blaak, B. Duim, J. A. Wagenaar, A. de Boer, H. M. Cauchie, J. Mossong, et W. van Pelt. 2016. "Quantifying potential sources of surface water contamination with Campylobacter jejuni and Campylobacter coli." *Water Research* 101:36-45. doi: 10.1016/j.watres.2016.05.069.

Nair, D. V. T., A. Kiess, R. Nannapaneni, W. Schilling, et C. S. Sharma. 2015. "The combined efficacy of carvacrol and modified atmosphere packaging on the survival of Salmonella, Campylobacter jejuni and lactic acid bacteria on Turkey breast cutlets." *Food Microbiol* 49:134-141. doi: 10.1016/j.fm.2015.01.010.

Nauta, M., et B. Christensen. 2011. "The impact of consumer phase models in microbial risk analysis." *Risk Anal* 31 (2):255-65. doi: 10.1111/j.1539-6924.2010.01481.x.

Nauta, M. J., A. R. Fischer, E. D. van Asselt, A. E. de Jong, L. J. Frewer, et R. de Jonge. 2008. "Food safety in the domestic environment: the effect of consumer risk information on human disease risks." *Risk Anal* 28 (1):179-92. doi: 10.1111/j.1539-6924.2008.01012.x.

Nauta, M. J., W. F. Jacobs-Reitsma, et A. H. Havelaar. 2007. "A risk assessment model for Campylobacter in broiler meat." *Risk Anal* 27 (4):845-61. doi: 10.1111/j.1539-6924.2006.00834.x.

Nauta, M. J., M. Sanaa, et A. H. Havelaar. 2012. "Risk based microbiological criteria for Campylobacter in broiler meat in the European Union." *Int J Food Microbiol* 158 (3):209-17. doi: 10.1016/j.ijfoodmicro.2012.07.018.

Nauta, M., W.F. Jacobs-Reitsma, E.G. Evers, W. van Pelt, et A.H. Havelaar. 2005. Risk assessment of Campylobacter in the Netherlands via broiler meat and other routes. RIVM.

Nauta, Maarten, Andy Hill, Hanne Rosenquist, Sigrid Brynestad, Alexandra Fetsch, Peter van der Logt, Aamir Fazil, Bjarke Christensen, Elly Katsma, Birgitte Borck, et Arie Havelaar. 2009. "A comparison of risk assessments on Campylobacter in broiler meat." *International Journal of Food Microbiology* 129 (2):107-123. doi: https://doi.org/10.1016/j.ijfoodmicro.2008.12.001.

Neal-McKinney, J. M., D. R. Samuelson, T. P. Eucker, M. S. Nissen, R. Crespo, et M. E. Konkel. 2014. "Reducing campylobacter jejuni colonization of poultry via vaccination." *PLoS ONE* 9 (12). doi: 10.1371/journal.pone.0114254.

Newell, D. G., K. T. Elvers, D. Dopfer, I. Hansson, P. Jones, S. James, J. Gittins, N. J. Stern, R. Davies, I. Connerton, D. Pearson, G. S. Salvat, et V. M. Allen. 2011. "Biosecurity-based interventions and strategies to reduce Campylobacter spp. on poultry farms." *Applied and Environmental Microbiology* 77 (24):8605-8614. doi: 10.1128/AEM.01090-10.

Ogden, Iain D., John F. Dallas, Marion MacRae, Ovidiu Rotariu, Kenny W. Reay, Malcolm Leitch, Ann P. Thomson, Samuel K. Sheppard, Martin Maiden, Ken J. Forbes, et Norval J. C. Strachan. 2009. "Campylobacter Excreted into the Environment by Animal Sources: Prevalence, Concentration Shed, and Host Association." *Foodborne pathogens and disease* 6 (10):1161-1170. doi: 10.1089/fpd.2009.0327.

Okamura, M., A. Tominaga, M. Ueda, R. Ohshima, M. Kobayashi, M. Tsukada, E. Yokoyama, K. Takehara, K. Deguchi, T. Honda, et M. Nakamura. 2012. "Irrelevance between the induction of anti-Campylobacter humoral response by a bacterin and the lack of protection against homologous challenge in Japanese Jidori chickens." *J Vet Med Sci* 74 (1):75-8.

Pacholewicz, E., A. Liakopoulos, A. Swart, B. Gortemaker, C. Dierikx, A. Havelaar, et H. Schmitt. 2015. "Reduction of extended-spectrum-β-lactamase- and AmpC-β-lactamase-producing Escherichia coli through processing in two broiler chicken slaughterhouses." *International Journal of Food Microbiology* 215:57-63. doi: 10.1016/j.ijfoodmicro.2015.08.010.

Pacholewicz, E., A. Swart, M. Schipper, B. G. M. Gortemaker, J. A. Wagenaar, A. H. Havelaar, et L. J. A. Lipman. 2015. "A comparison of fluctuations of Campylobacter and Escherichia coli concentrations

on broiler chicken carcasses during processing in two slaughterhouses." *International Journal of Food Microbiology* 205:119-127. doi: 10.1016/j.ijfoodmicro.2015.04.006.

Pacholewicz, E., A. Swart, J. A. Wagenaar, L. J. A. Lipman, et A. H. Havelaar. 2016. "Explanatory variables associated with campylobacter and Escherichia coli concentrations on broiler chicken carcasses during processing in two slaughterhouses." *J Food Prot* 79 (12):2038-2047. doi: 10.4315/0362-028X.JFP-16-064.

Patterson, M. F. 1995. "Sensitivity of Campylobacter spp. to irradiation in poultry meat." *Letters in Applied Microbiology* 20 (6):338-340. doi: 10.1111/j.1472-765X.1995.tb01315.x.

Paul, N. C., S. Al-Adwani, R. Crespo, et D. H. Shah. 2014. "Evaluation of passive immunotherapeutic efficacy of hyperimmunized egg yolk powder against intestinal colonization of Campylobacter jejuni in chickens." *Poult Sci* 93 (11):2779-87. doi: 10.3382/ps.2014-04234.

Peyrat, M. B., C. Soumet, P. Maris, et P. Sanders. 2008. "Recovery of Campylobacter jejuni from surfaces of poultry slaughterhouses after cleaning and disinfection procedures: Analysis of a potential source of carcass contamination." *International Journal of Food Microbiology* 124 (2):188-194. doi: 10.1016/j.ijfoodmicro.2008.03.030.

Pintar, Katarina D. M., Tanya Christidis, M. Kate Thomas, Maureen Anderson, Andrea Nesbitt, Jessica Keithlin, Barbara Marshall, et Frank Pollari. 2015. "A Systematic Review and Meta-Analysis of the Campylobacter spp. Prevalence and Concentration in Household Pets and Petting Zoo Animals for Use in Exposure Assessments." *PLoS ONE* 10 (12):e0144976. doi: 10.1371/journal.pone.0144976.

Poisson, S., F. Gauchard, L. Guillier, et M Sanaa. 2015.

Pouillot, R., B. Garin, N. Ravaonindrina, K. Diop, M. Ratsitorahina, D. Ramanantsoa, et J. Rocourt. 2012. "A risk assessment of campylobacteriosis and salmonellosis linked to chicken meals prepared in households in Dakar, Senegal." *Risk Anal* 32 (10):1798-819. doi: 10.1111/j.1539-6924.2012.01796.x.

Quatrehomme, S., A. Berthelot, et I. Bouvarel. 2001. "Gestion de l'eau de boisson en élevage avicole dans la région des Pays de la Loire." Quatrièmes journée de la recherche avicole, Nantes.

Racicot, M., D. Venne, A. Durivage, et J. P. Vaillancourt. 2012. "Evaluation of the relationship between personality traits, experience, education and biosecurity compliance on poultry farms in Quebec, Canada." *Prev Vet Med* 103 (2-3):201-7. doi: 10.1016/j.prevetmed.2011.08.011.

Radomska, K. A., M. M. Vaezirad, K. M. Verstappen, M. M. S. M. Wösten, J. A. Wagenaar, et J. P. M. Van Putten. 2016. "Chicken immune response after in ovo Immunization with Chimeric TLR5 activating flagellin of campylobacter jejuni." *PLoS ONE* 11 (10). doi: 10.1371/journal.pone.0164837.

Raut, A. D., R. Shashidhar, J. R. Bandekar, et B. P. Kapadnis. 2012. "Effectiveness of radiation processing in elimination of Campylobacter from poultry meat." *Radiation Physics and Chemistry* 81 (1):82-85. doi: 10.1016/j.radphyschem.2011.09.003.

Redmond, E. C., et C. J. Griffith. 2003. "Consumer food handling in the home: A review of food safety studies." *J Food Prot* 66 (1):130-161. doi: 10.4315/0362-028X-66.1.130.

Refrégier-Petton, J., M. Denis, N. Rose, et G. Salvat. 2001. "Incidence of Campylobacter in French broiler chicken flocks: A study of the risk factors in Campylobacter contamination." *British Poultry Science* 42 (SUPPL. 1):S37-S38.

Renault, C., P. Magdelaine, C. Cogoluenhes, T. Chever, et A. Braine. 2013. "Analyse des flux d'importation de volaille en France. ." *TeMA* 28:28-35.

Riazi, A., P. C. Strong, R. Coleman, W. Chen, T. Hirama, H. van Faassen, M. Henry, S. M. Logan, C. M. Szymanski, R. Mackenzie, et M. A. Ghahroudi. 2013. "Pentavalent single-domain antibodies reduce Campylobacter jejuni motility and colonization in chickens." *PLoS ONE* 8 (12):e83928. doi: 10.1371/journal.pone.0083928.

Ridley, A., V. Morris, J. Gittins, S. Cawthraw, J. Harris, S. Edge, et V. Allen. 2011. "Potential sources of Campylobacter infection on chicken farms: contamination and control of broiler-harvesting equipment, vehicles and personnel." *J Appl Microbiol* 111 (1):233-44. doi: 10.1111/j.1365-2672.2011.05038.x.

Rivoal, K., T. Poezevara, V. Ballan, S. Quesne, N. T. Williams, et M. Chemaly. 2015. "Optimization of air chilling process to control Campylobacter contamination on broiler legs." CHRO, New Zealand.

Rivoal, K., T. Poezevara, S. Quesne, V. Ballan, et M. Chemaly. 2018. "Varying the chilling parameters to control Campylobacter jejuni contamination of broiler carcasses."

Rivoal, K., S. Quesne, V. Rose, S. Rouxel, et M. Chemaly. 2011. "Prevalence of Campylobacter in retail broiler meat in France and distribution of C. jejuni typed by MLST. ." CHRO, Vancouver.

Rosenquist, H., L. Boysen, C. Galliano, S. Nordentoft, S. Ethelberg, et B. Borck. 2009. "Danish strategies to control Campylobacter in broilers and broiler meat: facts and effects." *Epidemiol Infect* 137 (12):1742-50. doi: 10.1017/S0950268809002684.

Rosenquist, H., N. L. Nielsen, H. M. Sommer, B. Norrung, et B. B. Christensen. 2003. "Quantitative risk assessment of human campylobacteriosis associated with thermophilic Campylobacter species in chickens." *Int J Food Microbiol* 83 (1):87-103.

Saint-Cyr, M. J., N. Haddad, B. Taminiau, T. Poezevara, S. Quesne, M. Amelot, G. Daube, M. Chemaly, X. Dousset, et M. Guyard-Nicodeme. 2017. "Use of the potential probiotic strain Lactobacillus salivarius SMXD51 to control Campylobacter jejuni in broilers." *Int J Food Microbiol* 247:9-17. doi: 10.1016/j.ijfoodmicro.2016.07.003.

Salvat, G., M. Guyot, et J. Protino. 2017. "Monitoring Salmonella, Campylobacter, Escherichia coli and Staphylococcus aureus in traditional free-range 'Label Rouge' broiler production: a 23-year survey programme." *J Appl Microbiol* 122 (1):248-256. doi: 10.1111/jam.13313.

Sampers, I., D. Berkvens, L. Jacxsens, M. C. Ciocci, A. Dumoulin, et M. Uyttendaele. 2012. "Survey of Belgian consumption patterns and consumer behaviour of poultry meat to provide insight in risk factors for campylobacteriosis." *Food Control* 26 (2):293-299.

Sampers, I., I. Habib, L. De Zutter, A. Dumoulin, et M. Uyttendaele. 2010. "Survival of Campylobacter spp. in poultry meat preparations subjected to freezing, refrigeration, minor salt concentration, and heat treatment." *Int J Food Microbiol* 137 (2-3):147-53. doi: 10.1016/j.ijfoodmicro.2009.11.013.

Sandberg, M., J. Dahl, L. L. Lindegaard, et J. R. Pedersen. 2017. "Compliance/non-compliance with biosecurity rules specified in the Danish Quality Assurance System (KIK) and Campylobacter-positive broiler flocks 2012 and 2013." *Poultry Science* 96 (1):184-191. doi: 10.3382/ps/pew277.

Schneitz, C., et M. Hakkinen. 2016. "The efficacy of a commercial competitive exclusion product on Campylobacter colonization in broiler chickens in a 5-week pilot-scale study." *Poultry Science* 95 (5):1125-1128. doi: 10.3382/ps/pew020.

Scott, E., et S. F. Bloomfield. 1990. "The survival and transfer of microbial contamination via cloths, hands and utensils." *J Appl Bacteriol* 68 (3):271-8.

Scott, E., et S. F. Bloomfield. 1993. "An in-use study of the relationship between bacterial contamination of food preparation surfaces and cleaning cloths." *Letters in Applied Microbiology* 16 (3):173-177. doi: 10.1111/j.1472-765X.1993.tb01388.x.

Seliwiorstow, T., J. Baré, D. Berkvens, I. Van Damme, M. Uyttendaele, et L. De Zutter. 2016. "Identification of risk factors for Campylobacter contamination levels on broiler carcasses during the slaughter process." *International Journal of Food Microbiology* 226:26-32. doi: 10.1016/j.ijfoodmicro.2016.03.010.

Seliwiorstow, T., J. Baré, I. Van Damme, I. G. Algaba, M. Uyttendaele, et L. De Zutter. 2016. "Transfer of Campylobacter from a positive batch to broiler carcasses of a subsequently slaughtered negative batch: A quantitative approach." *J Food Prot* 79 (6):896-901. doi: 10.4315/0362-028X.JFP-15-486.

Seliwiorstow, T., J. Baré, I. Van Damme, M. Uyttendaele, et L. De Zutter. 2015. "Campylobacter carcass contamination throughout the slaughter process of Campylobacter-positive broiler batches." *International Journal of Food Microbiology* 194:25-31. doi: 10.1016/j.ijfoodmicro.2014.11.004.

Shrestha, S., K. Arsi, B. R. Wagle, A. M. Donoghue, et D. J. Donoghue. 2017. "Ability of select probiotics to reduce enteric Campylobacter colonization in broiler chickens." *International Journal of Poultry Science* 16 (2):37-42. doi: 10.3923/ijps.2017.37.42.

Slimani, N., G. Deharveng, R. U. Charrondiere, A. L. van Kappel, M. C. Ocke, A. Welch, A. Lagiou, M. van Liere, A. Agudo, V. Pala, B. Brandstetter, C. Andren, C. Stripp, W. A. van Staveren, et E. Riboli. 1999. "Structure of the standardized computerized 24-h diet recall interview used as reference method in the 22 centers participating in the EPIC project. European Prospective Investigation into Cancer and Nutrition." *Comput Methods Programs Biomed* 58 (3):251-66.

Sommer, H. M., O. E. Heuer, A. I. Sorensen, et M. Madsen. 2013. "Analysis of factors important for the occurrence of Campylobacter in Danish broiler flocks." *Prev Vet Med* 111 (1-2):100-11. doi: 10.1016/j.prevetmed.2013.04.004.

Sommer, H. M., M. J. Nauta, et H. Rosenquist. 2016. "Translation of risk factor estimates into on-farm interventions and their effect on Campylobacter broiler flock prevalence." *Microbial Risk Analysis* 2-3:27-37. doi: https://doi.org/10.1016/j.mran.2016.06.001.

Souillard, R., J.M. Reperant, C. Experton, A. Huneau-Salaun, J. Coton, L. Balaine, R. Thomas, C. Filliat, J. Puterflam, et S. Le Bouquin. 2017. "Approche systémique de la santé : étude épidémiologique dans les élevages de poulets biologiques." Douzièmes Journées de la Recherche Avicole et Palmipèdes à Foie Gras, 05 et 06 avril 2017.

Tarján, V. 1985. "Investigation into the radiosensitivity of Campylobacter fetus subspecies jejuni in ground chicken meat." *International Journal of Food Microbiology* 1 (6):321-326. doi: 10.1016/0168-1605(85)90003-0.

Teunis, P. F., et A. H. Havelaar. 2000. "The Beta Poisson dose-response model is not a single-hit model." *Risk Anal* 20 (4):513-20.

Thépault, A., G. Méric, K. Rivoal, B. Pascoe, L. Mageiros, F. Touzain, V. Rose, V. Béven, M. Chemaly, et S. K. Sheppard. 2017. "Genome-wide identification of host-segregating epidemiological markers for source attribution in Campylobacter jejuni." *Applied and Environmental Microbiology* 83 (7). doi: 10.1128/AEM.03085-16.

Thepault, A., T. Poezevara, S. Quesne, V. Rose, M. Chemaly, et K. Rivoal. 2018. "Prevalence of Thermophilic Campylobacter in Cattle Production at Slaughterhouse Level in France and Link Between C. jejuni Bovine Strains and Campylobacteriosis." *Front Microbiol* 9:471. doi: 10.3389/fmicb.2018.00471.

Thepault, A., S. Quesne, Poezevara T., V. Rose, V. Beven, E. Hirchaud, F. Touzain, P. Lucas, G. Méric, L. Mageiros, S. K. Sheppard, M. Chemaly, et K. Rivoal. 2018. Ruminant and chicken as an important source of campylobacteriosis in France despite a variation of source attribution in 2009 and 2015.

Thormar, H., et H. Hilmarsson. 2010. "Killing of Campylobacter on contaminated plastic and wooden cutting boards by glycerol monocaprate (monocaprin)." *Lett Appl Microbiol* 51 (3):319-24. doi: 10.1111/j.1472-765X.2010.02898.x.

Torralbo, A., C. Borge, A. Allepuz, I. Garcia-Bocanegra, S. K. Sheppard, A. Perea, et A. Carbonero. 2014. "Prevalence and risk factors of Campylobacter infection in broiler flocks from southern Spain." *Prev Vet Med* 114 (2):106-13. doi: 10.1016/j.prevetmed.2014.01.019.

van Asselt, E. D., A. E. de Jong, R. de Jonge, et M. J. Nauta. 2008. "Cross-contamination in the kitchen: estimation of transfer rates for cutting boards, hands and knives." *J Appl Microbiol* 105 (5):1392-401. doi: 10.1111/j.1365-2672.2008.03875.x.

van Bunnik, B. A. D., T. J. Hagenaars, N. M. Bolder, G. Nodelijk, et M. C. M. de Jong. 2012. "Interaction effects between sender and receiver processes in indirect transmission of Campylobacter jejuni between broilers." *BMC Veterinary Research* 8.

van Bunnik, B. A. D., W. E. A. Katsma, J. A. Wagenaar, W. F. Jacobs-Reitsma, et M. C. M. de Jong. 2012. "Acidification of drinking water inhibits indirect transmission, but not direct transmission of Campylobacter between broilers." *Preventive Veterinary Medicine* 105 (4):315-319.

Van Cauteren, D., H. De Valk, C. Sommen, L. A. King, N. Jourdan-Da Silva, F. X. Weill, S. Le Hello, F. Megraud, V. Vaillant, et J. C. Desenclos. 2015. "Community Incidence of Campylobacteriosis and Nontyphoidal Salmonellosis, France, 2008-2013." *Foodborne Pathog Dis* 12 (8):664-9. doi: 10.1089/fpd.2015.1964.

Van Cauteren, D., Y. Le Strat, C. Sommen, M. Bruyand, M. Tourdjman, et N. Jourdan-Da Silva. 2018. "Estimation de la morbidité et de la mortalité liées aux infections d'origine alimentaire en France métropolitaine, 2008-2013." *Bulletin Epidémiologique Hebdomadaire* (1):2-10.

van Wagenberg, C. P. A., P. L. M. van Horne, H. M. Sommer, et M. J. Nauta. 2016. "Cost-effectiveness of Campylobacter interventions on broiler farms in six European countries." *Microbial Risk Analysis* 2-3:53-62. doi: 10.1016/j.mran.2016.05.003.

Vandamme, P., F.E. Dewhirst, B.J. Paster, et S.L.W. On. 2005. "Family I. Campylobacteraceae. ." In *Bergey's manual of systematic bacteriology*, edité par Brenner DJ, Krieg NR et Staley JT, pp. 1145–1146 Springer, New York, NY.

Verhoeff-Bakkenes, L., R. R. Beumer, R. de Jonge, F. M. van Leusden, et A. E. de Jong. 2008. "Quantification of Campylobacter jejuni cross-contamination via hands, cutlery, and cutting board during preparation of a chicken fruit salad." *J Food Prot* 71 (5):1018-22.

Voss, S., U. R. Charrondiere, N. Slimani, A. Kroke, E. Riboli, J. Wahrendorf, et H. Boeing. 1998. "[EPIC-SOFT a European computer program for 24-hour dietary protocols]." *Z Ernahrungswiss* 37 (3):227-33.

Weis, A. M., D. B. Storey, C. C. Taff, A. K. Townsend, B. C. Huang, N. T. Kong, K. A. Clothier, A. Spinner, B. A. Byrne, et B. C. Weimer. 2016. "Genomic Comparison of Campylobacter spp. and Their Potential for Zoonotic Transmission between Birds, Primates, and Livestock." *Appl Environ Microbiol* 82 (24):7165-7175. doi: 10.1128/AEM.01746-16.

Whiley, Harriet, Ben van den Akker, Steven Giglio, et Richard Bentham. 2013. "The Role of Environmental Reservoirs in Human Campylobacteriosis." *International Journal of Environmental Research and Public Health* 10 (11):5886-5907. doi: 10.3390/ijerph10115886.

Willis, W. L., C. Murray, et C. W. Raczkowski. 1996. "The influence of feed and water withdrawal on campylobacter jejuni detection and yield of broilers." *Journal of Applied Poultry Research* 5 (3):210-214. doi: 10.1093/japr/5.3.210.

Yang, S., F. J. Angulo, et S. F. Altekruse. 2000. "Evaluation of safe food-handling instructions on raw meat and poultry products." *J Food Prot* 63 (10):1321-5.

Yogasundram, K., S. M. Shane, R. M. Grodner, E. N. Lambremont, et R. E. Smith. 1987. "Decontamination of Campylobacterjejuni on chicken drumsticks using chemicals and radiation." *Veterinary Research Communications* 11 (1):31-40. doi: 10.1007/BF00361324.

Zhao, T., G. O. Ezeike, M. P. Doyle, Y. C. Hung, et R. S. Howell. 2003a. "Reduction of Campylobacter jejuni on poultry by low-temperature treatment." *J Food Prot* 66 (4):652-5.

Zhao, T., G. O. I. Ezeike, M. P. Doyle, Y. C. Hung, et R. S. Howell. 2003b. "Reduction of Campylobacter jejuni on poultry by low-temperature treatment." *J Food Prot* 66 (4):652-655. doi: 10.4315/0362-028X-66.4.652.

Zweifel, C., K. D. Scheu, M. Keel, F. Renggli, et R. Stephan. 2008. "Occurrence and genotypes of Campylobacter in broiler flocks, other farm animals, and the environment during several rearing periods on selected poultry farms." *International Journal of Food Microbiology* 125 (2):182-187. doi: 10.1016/j.ijfoodmicro.2008.03.038.

ANNEXES

Annex 1 – Referral

COURRIER ARRIVE

16 AOUT 2016

DIRECTION GENERALE

2016 -SA- 0 1 8 3

Liberté • Égalité • Fraternité
RÉPUBLIQUE FRANÇAISE

Ministère de l'agriculture, de l'agroalimentaire et de la forêt
Direction générale de l'alimentation
Service de l'alimentation
Sous-direction de la sécurité sanitaire de l'alimentation
Bureau des établissements d'abattage et de découpe
Bureau de l'appui à la surveillance de la chaîne alimentaire

Dossier suivi par : Corinne Danan / Claire Born
Tél. : 01 49 55 59 26 / 52 67
Fax. : 01 49 55 56 80
N° **2 – 0 1 5 3**
Mél. : bead.sdssa.dgal@agriculture.gouv.fr /
basca.sdssa.dgal@agriculture.gouv.fr

Le Directeur Général de l'Alimentation

à

Monsieur le Directeur Général de l'Anses

Paris, le **1 1 AOUT 2016**

Objet : Saisine relative à l'actualisation des connaissances sur la contamination par *Campylobacter* spp. des volailles de chair afin d'établir une analyse coût/bénéfice des mesures de maîtrise aux différentes étapes de la chaîne alimentaire au niveau national.

Références

•Directive n°2003/99/CE prévoit la surveillance obligatoire de *Campylobacter* dans les filières animales et la chaîne alimentaire, ainsi que la surveillance des niveaux d'antibiorésistance.

•Règlement (CE) № 178/2002 du Parlement Européen et du Conseil du 28 janvier 2002 établissant les principes généraux et les prescriptions générales de la législation alimentaire, instituant l'Autorité européenne de sécurité des aliments et fixant les procédures relatives à la sécurité des denrées alimentaires ;

•Règlement (CE) № 853/2004 du Parlement Européen et du Conseil du 29 avril 2004 fixant des règles spécifiques d'hygiène applicables aux denrées alimentaires d'origine animale ;

•Règlement (CE) № 854/2004 du Parlement Européen et du Conseil du 29 avril 2004 fixant des règles spécifiques d'organisation des contrôles officiels concernant les produits d'origine animale destinés à la consommation humaine ;

•Règlement (CE) № 2073/2005 de la Commission du 15 novembre 2005 concernant les critères microbiologiques applicables aux denrées alimentaires ;

•Note de service DGAL/SDSSA/N2010-8211 du 02 août 2010 relative aux résultats du plan de surveillance 2009 de la contamination par *Salmonella* et *Campylobacter* des viandes fraîches de poulet au stade de la distribution.

•Scientific Opinion on *Campylobacter* in broiler meat production: control options and performance objectives and/or targets at different stages of the food chain, EFSA Journal 2011; 9(4):2105

•Scientific Opinion on the public health hazards to be covered by inspection of meat (poultry), EFSA Journal 2012;10(6):2741 ;Scientific Report of EFSA on Technical specifications on harmonised epidemiological indicators for biological hazards to be coveres by meat inspection of poultry, EFSA Journal 2012;10(6):2764 ;

•Rapport « Analysis of cost and benefits of setting certain control measures for reduction of *Campylobacter* in broiler meat at different stages of the food chain », 2012, IFC GHK, ADAS.

•Rapport de l'Anses « Information des consommateurs en matière de prévention des risques biologiques liés aux aliments. Tome 1 – Hiérarchisation des couples danger / aliment et état des lieux des mesures d'information ». Mai 2014

Contexte :

Campylobacter spp. est la 1ère cause de zoonose alimentaire en UE et en France avec une augmentation constante du nombre de cas depuis une quinzaine d'année.

30% des campylobactérioses humaines auraient pour origine la viande de volailles.

La résistance aux antibiotiques de ces bactéries a également été soulignée comme facteur de risque pour la santé publique.

Les plans de surveillance et l'étude communautaire harmonisée de 2008 ont montré en France un taux de contamination élevé par *Campylobacter* chez les volailles et les produits de volaille en élevage, à l'abattoir et au stade de la distribution.

Ce taux de contamination élevé est le reflet d'un portage fréquent chez les volailles vivantes (de l'ordre de 70%) mais est aussi lié aux pratiques de l'abattoir (ressuyage et éviscération). *Campylobacter* a été détecté sur plus de 80% des carcasses de volailles. Cependant, dans le cadre des contrôles officiels, le niveau de contamination moyen observé dans les viandes fraîches au stade de la distribution est faible (< 2 log ufc/g).

L'avis de l'EFSA susvisé identifie *Campylobacter* comme un danger principal devant être pris en compte dans l'inspection de la viande de volailles. Un projet d'amendement du Règlement (CE) № 2073/2005 veut introduire un critère d'hygiène des procédés à l'abattoir sur *Campylobacter* sur les peaux de cou de poulets de chair.

A ce jour, il n'existe pas de dispositif de maîtrise national de l'infection par *Campylobacter spp* des animaux et la contamination des denrées, alors que certains États Membres ont déjà lancé depuis plusieurs années des plans de maîtrise.

La lutte contre *Campylobacter* représente également un enjeu politico-économique majeur dans les discussions relatives à la décontamination chimique des carcasses.

Objet de la saisine :

Compte tenu des éléments précités, il est demandé à l'Agence :

• **Une actualisation des connaissances sur:**
○ les nouvelles études menées depuis le dernier avis de l'EFSA 2011, sur la contamination des poulets de chair par *Campylobacter*, les différentes stratégies de maîtrise du risque et leur l'efficacité ; cette synthèse visera en particulier les résultats obtenus au niveau national ; elle pourra être également élargie aux autres filières de production de volailles de chair, si pertinent ;
○ l'impact des pratiques des consommateurs sur le risque de campylobactériose ;
○ la disponibilité et les contraintes des méthodes analytiques.

• **Une évaluation de l'impact des mesures de maîtrise sur le risque de campylobactériose attribuable à la viande de volaille.** Cette évaluation s'appuiera notamment sur le modèle d'analyse de risque quantitative développé par l'EFSA en 2011.

• **Une analyse coûts/bénéfices pour différentes mesures de maîtrise** aux différents stades de la chaîne alimentaire (de l'élevage au consommateur), adaptée à la filière française de volailles de chair, en s'appuyant notamment sur le modèle publié en 2012 par ICF GHK et ADAS pour le compte de la Commission européenne.

L'objectif poursuivi est la mise en place d'un plan national de maîtrise des *Campylobacter* dans la chaîne alimentaire en filière volaille de chair.

Délai :

Fin 2017

Destinataires pour la réponse mail
Destinataire DGAL : -boîte institutionnelle BEAD (bead.sdssa.dgal@agriculture.gouv.fr)
               -boîte institutionnelle BASCA (basca.sdssa.dgal@agriculture.gouv.fr)

Mes services se tiennent à votre disposition pour vous apporter toute information complémentaire.

Je vous remercie de bien vouloir accuser réception de la présente demande.

Le Directeur Général de l'Alimentation,
Patrick DEHAUMONT

Annex 2 – Reading grid template

ANSES-DER-2017   CAMPYLOBACTER in POULTRY meat sector   [New article]   [Save]   [Exit]

Study identification

Reviewer's name [ ] ▾   Paper's source [ ] ▾   Authors' name of grey literature : [ ]

Year (grey literature): [ ] ▾

Article ID [ ] ▾   Type (grey literature (book, report...)): [ ]

Country [ ] ▾   Title (grey literature): [ ]

Poultry species: [ ]

First control measure studied | Second control measure studied | 3th CM studied | 4th CM studied | 5th CM studied | 6th CM studied | 7th CM sudied | 8th CM studied | 9th CM studied

Where the control measure (CM) is applied?   Where the CM effect is measured? [ ] ▾   Type of study: [ ] ▾   Type of CM: [ ] ▾

- ☐ Feeding
- ☐ Rearing
- ☐ Transport
- ☐ Slaughtering
- ☐ Processing
- ☐ Distribution
- ☐ Consumption

Description of CM: [ ]

Sample description (e.g: skin, caeca, etc.) [ ]   Sampling (eg size) [ ]

Analytical method: [ ]

How the CM effect is measured? (e.g RR, OR, contamination reduction...) [ ]   Confidence appraisal in the method:

Opinion on the CM effect [ ] ▾   Quantitative result: [ ]   Unit of the result: [ ]   [ ] ▾

Confidence interval (Quant. result): [ ]

Study quality

Potential conflict of interest if any are declared by authors? [ ] ▾   CM applied or applicable in France? [ ]

Bias identified by the authors: [ ]   Bias identified by the reviewer(not declared in the paper: [ ]   Comments: [ ]

! Opinion on the bias! : [ ] ▾
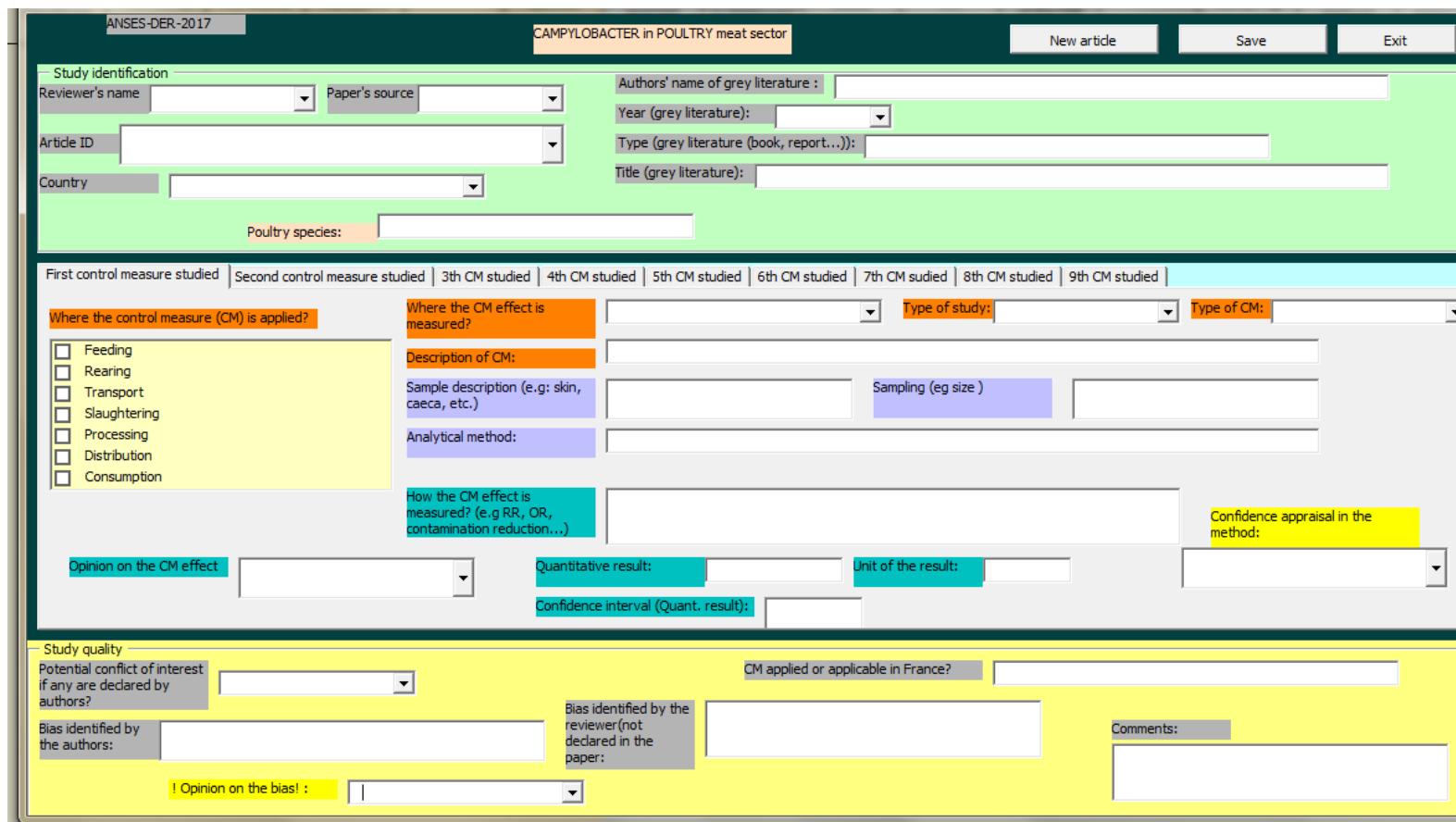
Annex 3 – Literature update of interventions

The following lists are reduced to interventions that showed some efficacy. A lot of papers are not considered in the tables as no significant results were obtained.

Table 11 – List of interventions in primary production

Intervention	Efficacy for *Campylobacter* reduction at the point of application as reported in EFSA (2011)	New (quantitative) knowledge as from 2012	Intervention selected by the WG to be applied in France
Hygiene/biosecurity	At 21 days: from 20.0% to 7.7% between-flock prevalence (BFP) At 28 days: from 32.0% to 12.0% BFP At 35 days: from 44.0% to 30.8% BFP At 42 days: from 70.8% to 38.5% BFP Implemented in model as the beta coefficient that corresponds to a hazard ratio of 0.40, (0.15, 1.09) p=0.06	• **Age of the poultry house** less than 5 years vs. more than 30 years: Reduction in prevalence measured as regression parameter: -072 [-1.06;-0.37] (Sommer *et al.* 2013) • Use **designated tools** per farmhouse. Have an **anteroom and barrier** in houses < 15 years CamCon (6 EU countries). Effect on *Campylobacter* prevalence measured as odds ratio: 0.69 [0.54; 0.88] (Borck Høg *et al.* 2016) • **Proper cleaning of drinkers and feeders** to prevent *Campylobacter* carryover between flocks: up to 5 log reduction in count (Battersby *et al.* 2017)	+
Days between flocks		Georgiev *et al.* (2017): less than 2 weeks of empty period is associated to a reduced risk of broiler contamination (OR 0·69, 95% CI 0·49–0·96) Borck Høg *et al.* (2016): less than 20 days of empty period is associated to a reduced risk (OR 0·27, 95% CI 0·12–0·61)	

Intervention	Efficacy for *Campylobacter* reduction at the point of application as reported in EFSA (2011)	New (quantitative) knowledge as from 2012	Intervention selected by the WG to be applied in France
Fly screens	At 21 days: from 11.4% to 5.8% BFP At 28 days: from 28.6 to 5.8% BFP At 35 days: from 45.5% to 7.7% BFP Implemented in model as a slaughter age-weighted k-factor of 0.47 (21 days of slaughter age), 0.15 (28 days of slaughter age) and 0.10 (35 days of slaughter age)	Prevalence 41.4% to 10.3% (Bahrndorff *et al.* 2013)	+ Indoor broilers only
Discontinued thinning	BFP estimate OR = 1.74, implemented in model as regression coefficient (0.5521)	CamCom (2016): 1.5 to 12.9% of relative reduction for *Campylobacter* infection in broiler flocks from 6 European countries	+ Indoor broilers only
Slaughter age	BFP estimate OR = 1.98 per 10 days increase, implemented in model as regression coefficient 0.06742)	CamCom (2016): 0.4 to 21.9% of relative reduction for *Campylobacter* infection in broiler flocks from 6 European countries (if the age at slaughter < 35 days)	+
Vaccination	2 log10 reduction in caecal contents	Clark *et al.* (2012): 1 log reductionAnnamalai *et al.* (2013): 100% protection of broilers to challenge (Gormley *et al.* 2014): 2 log red Chintoan-Uta *et al.* (2015): 1 log reduction Chintoan-Uta *et al.* (2016): 2 log reduction Neal-McKinney *et al.* (2014): 2-3 log reduction	+
Bacteriocins	5.1-5.9 log10 reduction in caecal contents		
Bacteriophages	3 log10 reduction in caecal contents	Fischer *et al.* (2013): Phage application (single and cocktail): average reduction of 1.3 log/g with a max. of 2.8 log/g	
Probiotics		Aguiar *et al.* (2013): 1-2 log reduction of *Campylobacter* in poultry faeces (Arsi *et al.* 2015a, b): 1-3 log	+ Possibly but validation work is required

Intervention	Efficacy for *Campylobacter* reduction at the point of application as reported in EFSA (2011)	New (quantitative) knowledge as from 2012	Intervention selected by the WG to be applied in France
		reduction of *Campylobacter* in poultry faeces Guyard-Nicodème *et al.* (2016): max 3 log reduction in poultry cecal contents Manes-Lazaro *et al.* (2017): max 2 log reduction in cecal contents	
Drinking water treatment with organic acids	0.5-2 log10 reduction in caecal contents	(van Bunnik, Katsma, *et al.* 2012): reduction in transfer rate from seeders to receivers : 0.00044 (0.00023 - 0.00085) in treated group vs 0.00175 (0.00129 - 0.00239 (Haughton *et al.* 2013): no impact of water acidification during a field-trial (Grilli *et al.* 2013): acid organic + probtiotics: up to 4 log reduction in broiler caeca at 42 days old Guyard-Nicodème *et al.* (2016): acid organic + clay-based compounds in feed: -0.8 log UFC/g in caeca	+
Drinking water treated with EO water		(Bügener *et al.* 2014): drinking water was treated with a 3% solution of neutral electrolyzed oxidizing water (as an additive). Effect : 4 log reduction in *Campylobacter* count on carcasses	No more research required
Feed additives	No effect to complete inhibition	(Arsi *et al.* 2014): 0.7 to 3 log reduction in caecal Campylobacter concentration (but low confidence) (Abutheraa *et al.* 2017): Antimicrobial activities of phenolic extracts derived from seed coats selected soybean varieties. Effect : 2.1 log /ml reduction in *Campylobacter*	No
Genetic		(Georgiev *et al.* 2017): Epidemiologic evidence suggests low risk in a hybrid type (e.g. Cobb500) and potential to	No

Intervention	Efficacy for *Campylobacter* reduction at the point of application as reported in EFSA (2011)	New (quantitative) knowledge as from 2012	Intervention selected by the WG to be applied in France
		prevent between 4.0% and 27.0% of batches colonized > 3 log 10. (Gormley *et al.* 2014) found no difference	

Table 12 – List of interventions during transport and before slaughter

Intervention	Efficacy for *Campylobacter* reduction at the point of application as reported in EFSA (2011)	New (quantitative) knowledge as from 2012	Intervention selected by the WG to be applied in France
Feed withdrawal	Various results and various outcomes	No expected effect on prevalence No expected effect on concentration in caeca or digestive contents. But a lower quantity of digestive content could have marginal impact on surface contamination after scalding, defeathering and evisceration (less than 5% decrease of the concentration on carcasses) Pacholewicz *et al.* (2016)	+
Crate treatment	7.5 log10 per crate compartment; 5.5 log per crate surface; 40-60% reduction of crate positivity		+ (only for thinning)

Table 13 – List of interventions during slaughter and post slaughter

	Efficacy for *Campylobacter* reduction at the point of application as reported in EFSA (2011)	New knowledge	Intervention selected by the WG to be applied in France
Interventions at slaughter		Pacholewicz *et al.* (2016): 1 decimal reduction on carcass concentration including chilling Best combination of slaughter practices without additional intervention.	
scalding		Pacholewicz *et al.* (2016): 0.1 à 0.2 Log reduction on carcass concentration before chilling	+ (spray scalding instead of immersion less cross contamination
Prevention of leakage of intestinal contents	0.9 log10 CFU reduction on carcass		+
Detection/re-processing of highly (faecally)-contaminated carcasses	1.75 log10 CFU on carcass Kemp et al., 2001		
Cloacal plugging	0.53-1.7 log10 CFU reduction Musgrove et al. 1997		
Scheduled slaughter (positive batches are scheduled to a risk reducing procedure such as freezing or heat treatment)	Depends on risk reducing procedure Hofshagen et al., 2008.	Not applicable today in French situation due to the high *Campylobacter* prevalence in broilers.	
Logistic slaughter (the slaughter of negative batches before the positive)	Very little effect. Havelaar et al., 2007	(Seliwiorstow, Baré, Berkvens, *et al.* 2016): Reduction of 1,8 log on carcasses after chilling when caecal concentration is 1 log lower Not applicable today in French situation due to the high *Campylobacter* prevalence in broilers.	
Interventions post slaughter			
Chemical decontamination of carcasses			not allowed in Europe
Physical decontamination of carcasses			
Freezing for few days	0.91 -1.44 log10 reduction Sandberg *et al.* 2005		
Freezing for 3 weeks	1.77 - 2.18 log10 reduction		

	Efficacy for *Campylobacter* reduction at the point of application as reported in EFSA (2011)	**New knowledge**	**Intervention selected by the WG to be applied in France**
	Sandberg *et al.* 2005		
Hot water immersion	1.25 log10 reduction Corry *et al.* 2006		
Irradiation	6 log10 reduction Farkas, 1998 or expert opinion		
Cooking	6 log10 reduction Whyte *et al.* 2006		
Crust-freezing	0.42 log10 reduction Boysen and Rosenquist, 2009		
Steam	0.46 log10 reduction Whyte *et al.* 2003		
Steam ultrasound	1.3-2.51 log10 reduction Boysen and Rosenquist, 2009		
Chilling		Rapid surface cooling: 0,9-1,5 log10 (Burfoot *et al.* 2016)	+

Table 14 – List of interventions at the storage and consumption stages

Intervention	New knowledge	Intervention selected by the WG to be applied in France
Education & motivation	(Lopez *et al.* 2015): using disinfectant wipes decreased risk of human infection by up to 99.2% MacDonald *et al.* (2015) identified 8 factors associated with an increased risk of Campylobacteriosis; drinking water directly from a stream or lake (OR: 2.96), drinking purchased bottle water (OR: 1.78), consuming chicken (OR: 1.69), eating undercooked meat (OR: 1.77), eating barbequed food (OR: 1.55), living on a farm with livestock (OR: 1.74), having a dog (OR: 1.39) and living in a house where the water supply served less than 20 houses (OR: 1.92). (Bearth *et al.* 2013): No hard data but concludes that the detailed delivery of food safety information in a carefully designed brochure is an effective form of communication and motivation to change behaviour.	
Packaging technologies	Bolton *et al.* (2014): Cook in the pack technology would achieve a significant reduction in *Campylobacter* cases. No hard data but several studies showing cross-contamination in the kitchen is the cause of most Campylobacteriosis cases. (Meredith *et al.* 2014): MAP does not achieve a reduction in *Campylobacter* on poultry.	Cook-in-the-bag technology
Antimicrobials	(Chen *et al.* 2014): Peroxyacetic acid (0.1%) treatment of skin-on chicken breast and thigh meat resulted in a 1.5 log reduction in *Campylobacter* concentrations in the ground meat product derived from these poultry pieces. 0.1% peracetic acid, 1.5% acidified lactic acid and 0.1% lauric arginate decreased *Campylobacter* by 1 log/g on fresh chicken frames that were ground before evaluation of the surviving *Campylobacter* levels. (Meredith *et al.* 2014): 10% TSP, 14% TSP, 1% CA, 5% CA, 1% LA, 5% LA, 100ppm POA, 200ppm POA, 500ppm ASC and 1200ppm ASC dip treatments achieved 1.3, 1.5, 0.7, 1.8, 0.7, 1.2, 0.7, 0.7, 0.9 and 1.3 $\log_{10}$ cfu/cm^2 reductions, respectively. In a processing plant, dip treatment of chicken carcasses with 14% TSP and 5% CA achieved 2.3 and 1.4 $\log_{10}$ cfu/cm^2 reductions, respectively. (Nair *et al.* 2015): The combination of carvacrol (1%, v/v) and MAP (95% CO_2:5%O_2) reduced *Campylobacter* counts on turkey breast cutlets by 1-2 $\log_{10}$ cfu/g after 3-7 days storage at 4°C as compared to an untreated control. Lauric arginate (400mg/L) gave a maximum reduction of 1.5 $\log_{10}$ cfu/g of *C. jejuni* on chicken breast fillets after 7 days storage at 7°C. (Koolman *et al.* 2014): inoculated chicken drumsticks with *Campylobacter jejuni* and immersed in 12%(w/v) trisodium phosphate (TSP), 2%(w/v) citric acid (CA)	14% TSP in a dip treatment and/or sequential treatment of 12% TSP and 5% CP with ultrasonication at 80 kHz

Intervention	New knowledge	Intervention selected by the WG to be applied in France
	or 5 % (w/v) capric acid sodium salt (CP) for 1 min, while ultrasonication was performed at 40, 60 or 80 kHz. In another experiment the same chemical solutions were administered in sequential combination (TSP+CA, TSP+CP or CA+CP) while ultrasonication was performed at the same frequencies The sequential treatment of TSP and CP with ultrasonication at 80 kHz achieved a 4.5–4.6 $\log_{10}$ cfu/cm2 reduction.	
Chemicals	(Lee *et al.* 2016) >3log red (Meredith *et al.* 2013) >2.5 log (Moore *et al.* 2017) >0.9 log red (Nair *et al.* 2015)>1 log red	
Chilling and freezing	(Ivić-Kolevska *et al.* 2012): 3.5 log reduction (Bolton *et al.* 2014): freezing at -20°C for 7 days decreased *Campylobacter* by 1.73 $\log_{10}$ CFU/g and by 3.46 $\log_{10}$ CFU/g after 42 days of storage. (Eideh et Al-Qadiri 2011)1.0 to 2.7 $\log_{10}$ CFU/g *Campylobacter* reductions on chicken breast samples stored at -18°C for 20 days. (Sampers *et al.* 2010): 0.9 to 3.2 $\log_{10}$ reduction after 2 weeks storage at -20°C on naturally contaminated chicken skin and muscle (Zhao *et al.* 2003a): 1.3 to 1.8 $\log_{10}$ CFU/g reduction in *C. jejuni* on chicken wings frozen at -20°C to -30°C for 72h (Georgsson *et al.* 2006): 2.87 $\log_{10}$ on broiler carcasses frozen for 31 days.	Freezing and frozen storage
Light technologies	(N. W. Gunther *et al.* 2016): max 2.1 log reduction	
Irradiation	(Eustice 2015): no data (Tarján 1985): 1 kGy dose will provide more than 8 decimal reductions. 3-5 kGy dose generally used for meat products for the destruction of salmonellae will also destroy *Campylobacter*s (Yogasundram *et al.* 1987): reported that 1 kGy completely eliminated cells initially contaminated with 10^3 cfu/cm². (Dion *et al.* 1994, Kudra *et al.* 2012, Lambert et Maxcy 1984, Patterson 1995, Raut *et al.* 2012): D10 between 0.12 and 0.32 kGy	Arrêté du 20 août 2002 relatif aux denrées et ingrédients alimentaires traités par ionisation (NOR: ECOC0200067A Version consolidée au 27 février 2017) : 5 kGy permitted for poultry meat (and mechanically separated poultry meat, poultry offals)
Other	(Isohanni et Lyhs 2009): The use of ultraviolet irradiation alone achieved only 0.4 decimal reduction on carcasses, 0.7 on broiler meat and 0.8 on broiler skin. (Dirks *et al.* 2012): The effect of a 3 min exposure to dielectric barrier discharge plasma was measured by 1.3 to 3.11 log reductions were observed on chicken breast or chicken skin.	UV irradiation Dielectric barrier discharge plasma

Annex 4 – Consumer stage model

Quantitative risk assessment of human Campylobacteriosis related to the consumption of chicken meat in France: focus on the consumer phase

Poisson, S.*, Gauchard, F., Guillier, L. and Sanaa, M. [1]ANSES – French Agency for Food, Environmental and Occupational Health and Safety, Maisons Alfort, France.

*Corresponding author: **sonia.poisson@anses.fr**

Campylobacter is a major cause of foodborne disease in humans in European Union and in France. Chicken meat is considered as one of the main sources of infection. During the handling of contaminated chicken eat in domestic kitchen, cross-contamination between raw meat and ready-to-eat food can occur via hands or utensils. In order to estimate the risk during this preparation in France, a model of the consumer phase was developed. The model was constructed with data from a survey about practices of consumers during the reparation of a chicken meal. Moreover, it was tested for different pieces of chicken (carcass, leg or escalope), for various concentrations and for different scenario. It appears that, for the different pieces of chicken, the risk reduction increases when the initial concentration of *Campylobacter* decreases. If all consumers wash their utensils and hands with detergent, the risk reduction is equal to 50% for carcass, 20% for legs and 70% for escalope when we take the highest initial concentration. In the case of nobody cleans, the risk increase of 330% for carcass, 340% for leg and 510% for escalope. The next step of this work is to construct the "farm to fork" quantitative risk assessment model by adding the primary module and the slaughter module to the consumer phase.

Keywords: *Campylobacter*; chicken; risk assessment; consumer phase; cross contamination.

INTRODUCTION

In 2013, *Campylobacter* continued to be the most commonly reported gastrointestinal bacterial pathogen in the European Union with 214 779 human cases of Campylobacteriosis reported (EFSA, 2015). The French notification rate was 39.6 per 100 000 habitants. Raw poultry meat is often contaminated with *Campylobacter* since the bacterium can live in the intestines of healthy birds. It is also found in pigs and cattle. Eating undercooking chicken, or ready-to-eat (RTE) foods that have been in contact with raw chicken, is the most common source of infection (Kittl *et al.*, 2013).

In order to determine the impact of different control measures on public health risk, a "farm to fork" quantitative risk assessment model (QRAM) was developed. This model integrates three different modules describing contamination pathways during: primary production, slaughtering and consumer poultry meat handling. The model was built upon existing models (Nauta *et al.*, 2009) and populated with newly collected French specific data. In instance, for consumer module, we conducted a survey on consumer practices during the preparation of chicken meal that involved 659 French representative consumers.

MATERIALS AND METHODS

During the preparation of a chicken meal, foods prepared in the kitchen can become cross contaminated with *Campylobacter* by contacting raw chicken directly or indirectly. The different ways of contamination were modeled according to Pouillot *et al.* (2012) consumer phase model. All steps from the raw meat entering in the kitchen to the consumption of the meal are described in the figure 1.

Initial concentration on raw chicken. The initial concentration of *Campylobacter* on the raw meat was assessed from DGAl (French directory general for food) study conducted in 2009. In this study, *Campylobacter* concentration was measured on different part of chicken (leg, escalope and carcass) at the stage of distribution. Based on this study, the mean and standard deviation of the *Campylobacter* concentration were estimated for the three parts of chicken meat.

Transfer rate. Two routes of transfer from the fresh chicken meat to the meals were considered: ready-to-eat food can be directly contaminated by the raw meat by contact, or RTE and cooked meat can be contaminated via cook's hands or utensils (cross-contamination). For this latter contamination source, there were contacts between raw meat to RTE or to hands or utensils (cutting board, knife, fork or dish/plate) and contacts between this different utensils or hands to RTE or cooked chicken.

Estimates of the different transfer rates, needed for the modelling, were directly based on literature (Mylius, 2007) or estimated from published crude data (Fravalo *et al.*, 2009; Luber *et al.*, 2006; Montville, 2003).

Use of hands and/or utensils and washing. In order to define the proportion of people who touch the raw chicken or use utensil during a chicken meal, a study was conducted. An online questionnaire was administered to a representative sample of French population (n=659 persons, carried out at the end of 2012). With this survey, we had defined the habits of handling chicken during the preparation of the meal. We also obtained information about their habits about washing of hands and utensils (washing with detergent, rinsing or wiping, no washing, put in the dishwasher).

Survival after washing. During the washing step, *Campylobacter* can survive or not according to the kind of washing (washing with detergent or just wiping or rinsing). The survival rates were taken in the literature (Van Asselt *et al.*, 2008). In the case of no washing, the survival rate was equal to 1.

Consumption and risk. In order to calculate the risk due to the consumption of a meal contaminated by *Campylobacter*, we used dose response model from the literature (Black *et al.*, 1988; Nauta *et al.*, 2007).

We run the full model considering three different scenarios. The first scenario (scenario 0) corresponds to observed data on French consumers habits, the second scenario (scenario 1) simulates a situation where 100% of people wash with detergent theirs utensils and hands, the third scenario (scenario 2) corresponds to a situation in which nobody washes his/her hands and utensils. We calculated the risk for the different pieces of chicken, starting with the concentration take from the study of DGAl and further we were decreasing the concentration by $0.2\log_{10}$ in order to see how the risk is changing if the initial concentration decreased.

RESULTS AND DISCUSSION

For the three types of chicken pieces and for the three scenarios, small changes of the initial concentration can lead to significant reduction of the risk (Figure 2). The lower the initial concentration, more the percentage of risk reduction is near 100%. Also we can see differences between the three scenarios. The scenario 1 has the lowest risk compared to the scenario 0. For example, in the case of the carcass, when all the consumers wash with detergent, the risk is 50% lower for a concentration of $1.4\log_{10}$ CFU/g than the scenario 0. The scenario 2 has, on the contrary, the highest risk compared to the scenario 0. For the escalope, when the initial concentration is equal to $0.1\log_{10}$ CFU/g, the risk is 405% higher when no washing (scenario 2).
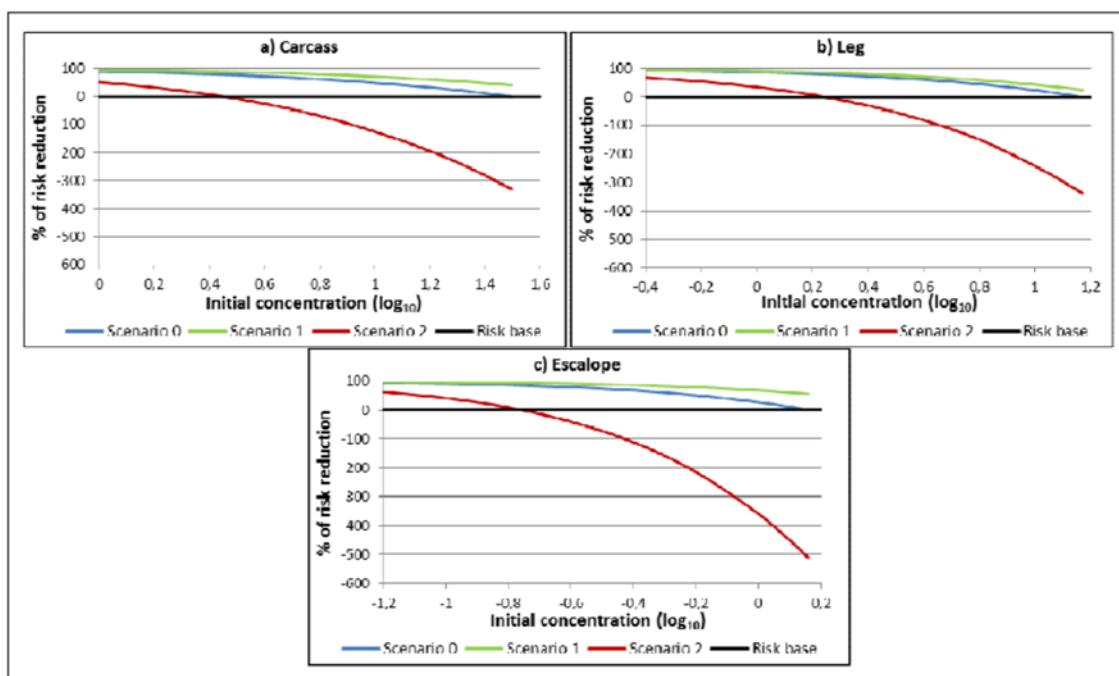

Figure 2: Relationship between the percentage of risk reduction and the initial concentration of *Campylobacter* for the different scenarios and pieces of chicken

Moreover, when the concentration is equal to -1.2log$_{10}$ CFU/g, the risk reduction is equal to 80% when no washing, whereas it is equal to 100% when everybody washes their hands and utensils with detergent. In the case of legs, for an initial concentration of 1log10 CFU/g, when everyone cleans their utensils and hand with detergent, the risk reduction is equal to 45%, whereas when nobody cleans the risk increase of 250%.

In conclusion, with this model of consumer phase, we determined the impact on the risk of changing the habits of French consumers during the preparation of a chicken meal. The next step of this study, will be to complete this consumer phase with the primary production module and slaughterhouse module in order to obtain a "farm to fork" risk assessment model. This QRAM will, at the end, be used to benchmark management scenarios on the final risk.

References

BLACK R.E., LEVINE M.M., CLEMENTS M.L., HUGHES T.P. and BLASER M.J. (1988) Experimental *Campylobacter jejuni* infection in humans. Journal of Infectious Diseases. 157(3):472-479.

EUROPEAN FOOD SAFETY AUTHORITY and EUROPEAN CENTER FOR DISEASE PREVENTION AND CONTROL (2015) The European Union summary report on trends and sources of zoonoses, zoonotic agents and food-borne outbreaks in 2013.

FRAVALO P., LAISNEY M-J, GILLARD M-O, SALVAT G. and CHEMALY M. (2009) *Campylobacter* Transfer from Naturally Contaminated Chicken Thighs to Cutting Boards Is Inversely Related to Initial Load. Journal of Food Protection 72(9):1836-1840.

KITTL S., HECKEL G., KORCZAK B.M. and KUHNERT, P. (2013). Source Attribution of Human *Campylobacter* Isolates by MLST and Fla-Typing and Association of Genotypes with Quinolone Resistance. PLoS ONE, 8(11), e81796. doi: 10.1371/journal.pone.0081796

LUBER P., BRYNESTAD S., TOPSCH D., SCHERER K. and BARTELT E. (2006) Quantification of *Campylobacter* species cross-contamination during handling of contaminated fresh chicken parts in kitchens. Applied and Environmental Microbiology 72(1):66-70.

MONTVILLE R. and SCHAFFNER D.W. (2003) Inoculum size influences bacterial cross contamination between surfaces. Applied and Environmental Microbiology 69(12):7188-7193.

MYLIUS S.D., NAUTA M.J. and HAVELAAR A.H. (2007) Cross-contamination during food preparation: a mechanistic model applied to chicken-borne *Campylobacter*. Risk Analysis 27(4):803-813.

NAUTA M.J., JACOBS-REITSMA W.F. and HAVELAAR A.H. (2007) A risk assessment model for *Campylobacter* in broiler meat. Risk Analysis. 27(4):845-861.

NAUTA, M., HILL A., ROSENQUIST H., BRYNESTAD S., FETSCH A., VAN DER LOGT P., FAZIL A., CHRISTENSEN B., KATSMA E., BORCK B. and HAVELAAR A. (2009) A comparison of risk assessments on *Campylobacter* in broiler meat. International Journal of Food Microbiology, 129, 107-123.

POUILLOT R., GARIN B., RAVAONINDRINA N., DIOP K., RATSITORAHINA M., RAMANANTSOA D., and ROCOURT J. (2012) A risk assessment of Campylobacteriosis and salmonellosis linked to chicken meals prepared in households in Dakar, Senegal. Risk Analysis,

VAN ASSELT E.D., DE JONG A.E.I., DE JONGE R. and NAUTA M.J. (2008) Cross contamination in the kitchen: Estimation of transfer rates for cutting boards, hands and knives. Journal of Applied Microbiology105(5):1392-1401.

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anses
French agency for food, environmental and occupational health & safety

Sonia POISSON, Françoise GAUCHARD, Laurent GUILLIER and Moez SANAA

ANSES – French Agency for Food, Environmental and Occupational Health & Safety, Maisons Alfort, France, sonia.poisson@anses.fr

Introduction

Campylobacter is reported as the major cause of bacterial food-borne illness in The European Union with 214 779 humans cases of campylobacteriosis reported in 2013. The French notification rate was 39,6 per 100 000. Broiler meat is considered to be the main source of human campylobacteriosis. Eating undercooked chicken, or ready-to-eat (RTE) foods that have been in contact with raw chicken directly or indirectly (cross-contamination) is the most common source of infection.

In order to determine the impact of different control measures on reduction in public health risk, a "farm to fork" QRAM (Quantitative Risk Assessment Model) can be use. Until now, this model that details changes in prevalence and number of campylobacter on chicken throughout the production line from primary production to consumption, does not exist for France. In order to construct a QRAM, we adapted existing models for primary production and slaughterhouse modules to current French practices data. Concerning the consumer phase, French data were not available so a survey of practices during the preparation of a chicken meal was conducted. The objective of this survey was to investigate the habits of handling of chicken meat during the preparation of the meal, and also to determine the proportion of risky behaviors that could lead to either direct or indirect cross-contamination between the raw meat and food ready to eat via hands or utensils.

### The « farm to fork » Quantitative Risk Assessment model

Module primary production → Transportation → Module slaughter and cutting rooms → Distribution → Module consumer → Dose response

Consumer phase

Before thermal processing | *Cooking* | After thermal processing

Chicken (raw) → RTE, Cook's hand, Cutting board, Knife, Fork, Dish/plate

Washing with detergent, Rinsing/wiping, No washing, Put in the dishwasher → RTE, Chicken (cooked) → Consumption

Initial concentration on raw chicken

- **Source:** The surveillance plan 2009 of *Salmonella* and *Campylobacter* contamination of fresh chicken meat at the stage of distribution, DGAl (the French directory general for food) study[1]
- **Distribution of the concentration for the different chicken pieces**

Concentration (log₁₀) — Escalope, Carcass, Leg

Consumption and outputs

- **Dose-response relationship:**
  - Black et al., 1988, Experimental *Campylobacter jejuni* infection in humans / **Nauta et al., 2007,** A risk assessment model for campylobacter in broiler meat
- **Outputs of the model:**
  - Reduction of the risk related to the initial concentration for the different pieces of chicken and for different scenario:
    - Scenario 0: observe data
    - Scenario 1: 100% of the people wash with detergent theirs utensils and hands
    - Scenario 2: nobody washes his/her hands and utensils

Transfert rates

- Directly from the literature or estimated from data from ANSES studies or from literature :
  - Montville and Schaffner, 2003 , Inoculum size influences bacterial cross contamination between surfaces
  - Fravalo et al., 2009 , *Campylobacter* transfer from naturally contaminated chicken thighs to cutting boards in inversely related to initial load
  - Mylius et al., 2007 , Cross contamination during food preparation: a mechanistic model applied to chicken-borne campylobacter
  - Luber et al., 2006 , Quantification of *Campylobacter* species cross-contamination during handling of contaminated fresh chicken parts in kitchen

#### Use of hands and/or utensils and washing

- **Source :** survey in situ about practices of consumer with regards to the risk of *Campylobacter*, conducted by ANSES with CREDOC (Research institute for the study and monitoring of living standards)
- **Values:** for the 659 consumers interviewed online, profile of using utensils and habits about cleaning

Q0	Pb	Pbw1	Pbw1rte	Pbw1cc	Pbr	...
15	1	0	0	0	1	
72	0	0	0	0	0	
79	1	1	0	0	0	
141	1	0	0	0	0	
168	1	0	0	0	0	
176	1	0	0	0	1	
182	0	0	0	0	0	
...						

Q0: individual number
Pb: use of cutting board (0=not using, 1=using)
Pbw1: cutting board washed with detergent (0=unwashed, 1=washed)
Pbw1rte: contact between the cutting board washed with detergent and RTE (0=no contact, 1=contact)
Pbw1cc: contact between the cutting board washing with detergent and chicken cooked (0=no contact, 1=contact)
Pbr: cutting board rinsed or wiped (0=not rinsed, 1=rinsed)

Survival after washing

- Values from the literature: Van Asselt et al., 2008, Cross contamination in the kitchen: estimation of transfer rates for cutting boards, hands and knives

Results

Relationship between the percentage of risk reduction and the initial concentration of *Campylobacter*

Carcass

% of risk reduction — Initial concentration (log₁₀)

Scenario 0 — Scenario 1 — Scenario 2 — – 50% risk reduction — Current initial concentration
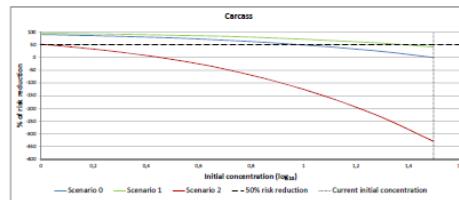
- Same results for the three types of chicken pieces
- Small changes of the initial concentration (compared to current mean concentration) can lead to significant reduction of the risk. The lower the initial concentration, the closer of 100% the percentage of risk reduction
- Differences between scenarios:
  - scenario 1 (better consumer practices): for an initial concentration of 1,4 log₁₀ cfu/g, the risk would be 50% lower than the scenario 0
  - scenario 2 (worst consumer practices): for an initial concentration of 1,4 log₁₀ cfu/g, the risk is 300% higher than the scenario 0
- 50 % of risk reduction would be obtained by changing 100% of consumer practices (scenario 1) or by reducing the initial concentration by 0,4 log₁₀ cfu/g

Conclusion

Our study proposes a new consumer phase module for campylobacteriosis risk assessment based on representative data on the consumer habits and relevant transfer data. This module allowed us to assess the impact of consumer changing habits on the risk of campylobacteriosis.

This work will be completed with the primary production module and slaughterhouse module in order to obtain a « farm to fork » risk assessment model. This QRAM will, at the end, be use to benchmark management scenarios on the final risk.

Nantes2015

Reference
1. Guyard-Nicodème et al. 2015, IJFM

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Annex 5 – Scientific and technical support note of the French Agency for Food, Environmental and Occupational Health & safety

relating to « the updating of knowledge on the contamination of poultry meat with *Campylobacter spp.* in order to establish a cost/benefit analysis of control measures at different stages of the food chain in France (2016-SA-0183) »

The Methodology and Survey Studies Unit (UME) has been solicited on November 10, 2017 by the Food Risk Assessment Unit (UERALIM) from the Risk Assessment Department (DER) to achieve a scientific and technical support (AST) relating to statistical analysis of data on chicken and *Campylobacter* (consumption, handling, *campylobacter* transfer rate) (**2017-ASTDER-39**). The results of this AST will be used in a quantitative risk assessment model for *Campylobacter* in broiler chicken from farm to fork in order to establish a cost/benefit analysis of control measures at different stages of the food chain in France (**Request 2016-SA-0183**).

1. CONTEXT AND PURPOSE OF THE REQUEST

Anses has been solicited on August 16, 2016 by the French Directorate General for Food (DGAL) to review the most recent data on the contamination by *Campylobacter* in the poultry meat sector (from farm to fork), the applicable control measures and their effectiveness. The DGAL, also, mandated Anses to conduct a cost-benefit analysis of different control scenarii.

In that context UERALIM has asked to UME to provide data that can be used for modeling of the French food chain from rearing to consumption. This different data are:

- Probability of people buying a frozen chicken or freezing it at home
- Frequency of chicken cut on the same board as ready–to-eat food
- Hand washing frequency
- Frequency of board washing
- Several *Campylobacter* transfer rates: chicken to hand, chicken to board, hand to salad, board to salad
- Data about the consumption of chicken: consumer rate, frequency of consumption for consumers only and serving sizes for consumers only.

This data has been provided for different chicken pieces: carcass, fillet and leg.

2. DATA AND METHOD

Several studies and publications have been used to gather the different data and are presented above.

2.1. Survey *in situ* about consumer practices during handling of chicken

The survey was conducted with the CREDOC (Research institute for the study and monitoring of living standards) in 2012-2013.

This survey is declined in two parts:

- An online questionnaire of a representative sample of French population. The questionnaire included questions about chicken meat preparation habits and knowledge on bacteria and food safety. People were selected with the quota method and 659 persons responded to the questionnaire.
- An observation of 30 people at home during the preparation of a meal with chicken, raw vegetables and fruits salad. People were recorded on video during all the preparation and after the meal preparation, they had to respond to the questionnaire about chicken meat preparation habits and knowledge on bacteria and food safety.

The data collected in the first part (the online questionnaire) are used to calculate the parameters below:

- The probability of people buying a frozen chicken

- The probability of people freezing the chicken at home

- The frequency of chicken cut on the same board as ready-to-eat food

- The hand washing frequency after handling raw chicken meat (with detergent or just rincing them)

- The cutting board washing frequency after using it with raw chicken meat (with detergent or just rincing it)

All results are provided for three types of chicken pieces: carcass, fillet and leg.

2.2. Study of transfer rates of *Campylobacter*

Many studies and experiments have been conducted to estimate the transfer rate between the raw meat to ready-to-eat food through various surfaces and hands. During these experiments, the quantity of microorganisms is determined using methods whose result is given as the detection limit. Generally, when the observation is under the detection limits (censored data) it is replaced by the detection limit. So in these studies, the estimation of the transfer rate is biased.

A work was conducted at ANSES in order to take into account the censored data in the estimation of the transfer rate for use in quantitative risk assessment model and more specifically at the consumer phase (Poisson, 2015). Estimates of the different transfer rates were directly based on literature (Mylius, 2007) or estimated from published crude data (Fravalo et al, 2009, Montville, 2013). In order to estimate the several transfer rates a Bayesian model was used with the MCMC (Markov chain Monte Carlo) procedure from SAS® and the censorship was taken into account in the likelihood calculation.

2.3. Third Individual and National Survey on Food Consumption (INCA3) data

The INCA3 survey was conducted between February 2014 and September 2015, in metropolitan France, among 5855 individuals (2698 children and adolescents from birth to 17 years old, and 3157 adults from 18 to 79 years old. The INCA3 survey population is representative of all individuals living in an ordinary household[1] in metropolitan France (excluding Corsica).

Individuals were selected according to a three-stage (geographical units, households and individuals) random sampling method. The geographical units and the households were randomly selected by the National Institute for Statistics and Economic Studies (INSEE) from the 2011 national annual population census, taking into account a geographical stratification (region, size of the urban area) in order to ensure national representativeness. One individual per household (one adult or one child) was then selected from the eligible individuals during the first home visit.

Detailed information on the consumption of food and beverages was collected for three non-consecutive days (2 weekdays and 1 weekend day) spread over around three weeks, using the 24h recall method for individuals aged from 15 to 79 years, and the 24h record method (*via* a food record) for individuals aged from 0 to 14 years. For the three selected days, individuals were asked to describe their food consumption by identifying all the food and beverages consumed during the day or night. They were asked to describe them in as much detail as possible (brand, cooking method, preservation method, sugar/fat/salt content, etc.) and quantify them with the help of a book of photographs of food servings and household measures. The data were collected by telephone by specially-trained interviewers, using standardised software (GloboDiet) developed by the International Agency for Research

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[1] According to the National Institute for Statistics and Economic Studies (INSEE), an "ordinary household", within the meaning of the census, is defined as all the people who share the same primary residence, these people non-necessarily being united by family ties (for example in the case of cohabitation or flat-sharing). People living in mobile homes (including seamen and the homeless) or in communal accommodation (workers' hostels, retirement homes, hospitals, detention centres, boarding schools, university halls of residence or military barracks, etc.) are considered to be living "outside ordinary households".

on Cancer (IARC) (Slimani *et al.* 1999, Voss *et al.* 1998). Individuals aged from 15 to 79 were not informed in advance of the days of the phone calls, unlike the children aged 0-14 who were asked in advance to note their consumption information in a food record for a specific day.

Under this scientific and technical support, only individuals who validated the consumption component by responding to at least two 24 hours recalls/recordings were considered, that being 4114 individuals (2121 adults and 1993 children).

To ensure the national representativeness of the results, the data have been adjusted according to a method defined in consultation with INSEE. In particular, a weight was assigned to each individual in the two samples (Children 0-17 and Adults 18-79).

Due to sampling constraints, every statistical analysis was conducted separately for children and adults.

The several calculations have been achieved for three different types of chicken pieces:

- Carcass: correspond in the INCA3 nomenclature to the aliment "whole chicken"

- Fillet: correspond in the INCA3 nomenclature to aliments "chicken tenderloin", "chicken skewer" and "chicken escalope"

- Leg: correspond in the INCA3 nomenclature to aliments "chicken leg", "chicken thigh" and "chicken drumstick".

The different statistics analysis provided for the different chicken pieces are:

- Consumers rates

- Frequency of consumption: estimated from consumers only

- Portion size: estimated from consumers only.

3. RESULTS

3.1. Model parameters

The various parameters related to French data are presented in the table 15 for chicken fillet. When they are available, the parameters are provided in green.

Table 15 : Parameters for the consumer phase model for chicken fillet

Stage	Parameter	Description	Unit	Default Value	Source	Comment	French data
(cool) storage	$r_{storage}$	reduction by storage Type of packaging? Modified atmosphere… 2009: comparison of 2 types of packaging. Significant difference between the two	log red.	BetaPert (0.1,0.9,2.1)	Jacobs-Reitsma et al. (in prep.)		**Probability of freezing chicken=0.1568 Probability of buying frozen chicken=0,0558**
consumer prep.	$t_{C,H}$	transfer chicken to hand		0.0415	Montville et al. (2001)	refitted raw data.	**LogNormal (-1.3994, 0.0703)** (Montville, 2013)
	$t_{C,B}$	transfer chicken to board		0.0125	Kusumaningrum et al. (2004)		**LogNormal (-1.5298, 0.2370)** (Fravalo, 2009)
	$t_{H,S}$	transfer hand to salad		0.207	Montville et al. (2001)	id	**LogNormal (-1.9183, 0.1540)** (Montville, 2013)
	$t_{B,S}$	transfer board to salad		0.343	Kusumaningrum et al. (2004)		**Log (0.343)** (Mylius, 2007)
	$t_{H,H}$	hand washing effect		0.0347	Chen et al. (2001)		
	$t_{B,B}$	board washing effect		0.0000464	Cogan et al. (2002)		
	$t_{S,S}$	salad washing effect		0.367	Smith et al. (2003)		
	fcf	frequency of chicken cut before salad on same board		50%	guess		**13,94%**
	fhw	hand washing frequency		80%	Doorduyn et al. (in prep a)	rough average	**Washing with detergent=64,98% Rincing=33,76%**
	fnsb	frequency of not using same boardside unwashed		95%	Doorduyn et al. (in prep a)	rough average	
	fbw	frequency board washing		65%	Doorduyn et al. (in prep a)	rough average	**Washing with detergent=56,03% Rincing=6,19%**
	fsw	salad washing frequency		60%	Worsfold and Griffith (1997)	rough average	

anses

Agence nationale de sécurité sanitaire
de l'alimentation, de l'environnement et du travail
14 rue Pierre et Marie Curie
F94701 Maisons-Alfort cedex
www.anses.fr
@Anses_fr