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Summary

To conclude our studies on GE3LS (genomics and its ethical, environmental, economic, legal, and social aspects) and the acceptance of Syst-OMICS methods, we held a stakeholder’s workshop with 13 experts and industry representatives, and 7 members of the research team. The workshop was held in Montreal on February 14, 2020. The objective was to validate the research results of the GE3LS studies on the technological acceptance of approaches to use genomics to control Salmonella on fresh produce, as developed by the Salmonella Syst-OMICS project through its methods of (1) virulence subtyping and classification and (2) biocontrol using bacteriophages. The intent was also to develop “Points to Consider” for policy makers to better inform implementation and communication strategies around the technology and its applications. This workshop was designed as a deliberative workshop, using group discussions to allow participants to discuss the issues at hand to arrive at an informed position. The Salmonella Syst-OMICS project was briefly introduced, followed by the results of the GE3LS sub-studies, namely a Delphi survey, stakeholder interviews, and a national consumer survey. Next, the group discussed how to translate these results into “Points to Consider” and examined how this research fits into a broader international context.

Summary of findings presented at the workshop

Delphi Survey

The Delphi survey recruited a panel of 27 participants based on their diverse expertise in the field of food security. Most survey respondents (89%) were government employees. The issues that generated the strongest consensus among participants were: (1) the need to demonstrate the reliability of the subtyping method and (2) its ability to meet quality assurance criteria. Indeed, 100% of respondents to the third round of the survey rated these items as high priority. The need for the Syst-OMICS subtyping method to meet regulatory requirements to ensure correlation between results and pathogenicity was rated as a high priority by 94% of respondents. The need for a monitoring mechanism was also agreed upon with 94% of respondents considering it a moderate priority.

The cost-benefit of using the subtyping method must be demonstrated according to 81% of respondents. There was also consensus on issues related to international relations. Ninety-four percent of respondents considered it very important to consider harmonizing data sharing between countries to make international efforts to mitigate foodborne disease risks more effective. In addition, 81% of respondents felt it was very important to consider expertise, best practices, and lessons learned in other countries. With respect to bacteriophages, 88% of respondents consider obtaining more scientific evidence of the effectiveness of bacteriophages in controlling Salmonella on a variety of fruits and vegetables to be a high priority. Finally, when asked what type of stakeholders should be involved in the implementation of subtyping and bio-control methods, the categories that received a strong consensus of over 80% among respondents were: growers (94%), scientists (88%), regulators (88%), and public health experts and epidemiologists (81%).

Interviews with stakeholders in the agri-food sector

Between February and June 2019, we conducted interviews with 19 representatives of consumer associations or institutions interested in food safety (26%), representatives of organic agriculture (26%), and the Canadian agri-food industry (52%). Interviewees were from British Columbia (3), the Prairies (3), Quebec and Ontario (10). Most interviewees agreed that contamination can occur
at any stage of the supply chain and that it can be difficult to find the source. With respect to current regulations and practices for preventing *Salmonella* outbreaks, most interviewees seemed satisfied. The implementation of Good Agricultural Practices (CanadaGAP®) seemed to elicit the most trust from stakeholders. The implementation of the *Canada Food Safety Act and Regulations* was mentioned by many as a good practice insofar as it is enforced. Finally, many interviewees from both the agri-food industry and the organic sector stressed the importance of border control and inspection.

Several food industry representatives emphasized the importance of policy makers consulting with stakeholders when developing regulatory frameworks. Opinions differed somewhat, however, on the types of stakeholders that should be involved, with some mentioning government, industry, producers, experts, academics and scientists, or organic producers, while opinions were more divided on the role of consumers and the organizations that represent them. These results echo those of the Delphi survey.

Interviewees mentioned that Syst-OMICS approaches, if implemented, would foster greater accountability and knowledge. During the interviews, however, interviewees identified several issues that should be considered before Syst-OMICS approaches are adopted in practice. These concerns included, but were not limited to, the following themes: (1) additional burden on the agri-food industry; and (2) scientific concerns regarding validity, reliability, and the possibility of unintended effects. With respect to the use of bacteriophages in particular, many mentioned concerns about potential environmental impacts.

Interviewees supported the use of the Syst-OMICS subtyping detection method either at the time of production or in real time throughout the supply chain. Regarding the use of bacteriophages to treat fresh produce for *Salmonella*, interviewees mentioned the production, processing, distribution, and retail stages and some even considered their use by consumers.

In terms of communication with the public and consumers, several mentioned that limitations in the public's understanding of science and agri-food could negatively impact the adoption of Syst-OMICS methods. According to interviewees, what will make a difference in consumer acceptance of the Syst-OMICS approaches is the degree of trust the public has in governments and how these approaches are communicated.

**National Survey**

We surveyed 1,000 randomly selected participants from the Ipsos eNation Canada Omnibus online panel. The distribution of men (47%) and women (53%) was representative of the general population. The representation of the different Canadian provinces was also proportional with 14% of respondents from British Columbia, 11% from Alberta, 6% from Saskatchewan and Manitoba combined, 38% from Ontario, 24% from Quebec and 7% from the Atlantic. The age and income distributions are balanced and reflect the general trends of the population in general. However, the education level of participants was higher than that of the general population, which is not unusual for an online panel.

A majority (80%) of respondents show a positive and favorable view of science. Regarding trust in the food industry, a slight majority (57%) said they trust the food industry to minimize the risks of the biotechnology processes they use. Similarly, a slight majority (56%) have trust in legislators and policy makers to adequately regulate biotechnology processes in the agri-food sector.
Just under two-thirds of respondents (59%) identified “the safety of fresh produce for consumption and public health” as the agri-food industry's top priority. In comparison, 19% chose the use of environmentally friendly methods as the most important industry priority and 16% chose reducing waste as the top industry priority, while economic concerns were only highlighted by the top 7% of respondents.

The data confirmed our intuition as a total of 59% of all respondents in both groups were reluctant to consume fresh produce that had been identified as carrying Salmonella, even if the specific subtype did not pose a risk to human health. Survey respondents’ willingness to consume bacteriophage-treated foods was evenly divided between those who indicated they were inclined to consume such products and those who were not.

Opinions were almost evenly split between those who had a positive view (46%) of the health care and public health applications of a new genomics-based testing method and those who said they had a neutral view on the subject (48%). The percentage of respondents who would like to be informed if fresh produce processed with Syst-OMICS methods were made available are similar for the use of bacteriophages (60%) and for the use of the subtyping method (57%). Opinions on the potential of genomics to improve detection of Salmonella and control its presence on fresh produce were almost evenly split between those who were hopeful (43%) and those who were neutral (41%).

We also analyzed the data using logistic regressions. We considered two dependent variables: (1) willingness to consume fresh produce carrying non-pathogenic Salmonella and (2) willingness to consume fresh produce treated with bacteriophages. Each independent variable (e.g., sociodemographic variables, trust in legislators, personal values) was individually tested by binomial logistic regression with each of these two dependent variables. Five independent variables had a significant effect on respondents’ willingness to consume non-pathogenic Salmonella products: gender (p < 0.0005), education level (p = 0.026), group (i.e., received additional information or not) (p < 0.0005), trust in legislators (p < 0.0005), and personal values (p < 0.0005). Five independent variables also had a significant effect on respondents’ willingness to consume bacteriophage-treated products: gender (p = 0.001), education level (p = 0.025), group (i.e., received additional information or not) (p = 0.011), trust in legislators (p < 0.0005), and age (p = 0.001). In contrast to the results for willingness to consume fresh produce with a non-pathogenic Salmonella strain, personal values were not significant (p = 0.265).

**Points to consider**

The considerations are threefold: (1) Considerations for policy makers and scientists; (2) considerations for public engagement and communication strategies; and (3) integration of Canadian and international considerations.

Among the considerations for policy makers and scientists, the most discussed points during the working session were risk management concerns, including the need to integrate a plan for protecting vulnerable populations into policy strategies. Related to the issue of risk management, there was a call for clear criteria and virulence thresholds for the evaluation of policies related to this technology. A third point of discussion was cost analyses and other challenges that may hinder industry acceptance. Cost-effectiveness analyses were seen as a critical element for industry adoption. Finally, participants discussed several regulatory considerations for policymakers.

In discussing public engagement and communication strategies, participants raised three main questions: how to communicate, who the target audience is, and what the content of communication
strategies should be. With respect to the question of how to communicate, several people raised the importance of using social media to reach consumers from all walks of life and to reach different populations, as it has been shown that mainstream media alone is not enough to inform Canadians about food safety. Participants noted the importance of clarifying exactly who the target audience is, including consumers, retailers, and producers, so that the message can be tailored accordingly. One of the key areas of discussion in communication is risk communication strategies. There is a need for an effective risk communication strategy that relies on the best risk communication professionals, with an emphasis on effective communication with parties who do not have a strong scientific background.

The final segment of the workshop was devoted to discussing the integration of Canadian and international considerations. Participants discussed the importance of understanding the regulatory frameworks and scientific research taking place internationally, with a focus on the United States and Europe. It was noted that if realized, these new regulatory approaches could help Canada become a leader in the integration of genomics for all products.
Sommaire

Pour conclure nos études sur les GE3LS (la génomique et ses aspects éthiques, environnementaux, économiques, juridiques et sociaux) et l’acceptation des méthodes Syst-OMICS, nous avons tenu un atelier des parties prenantes réunissant 13 experts et représentants de l’industrie et 7 membres de l’équipe de recherche. L’atelier a eu lieu à Montréal le 14 février 2020. L’objectif était de valider les résultats de recherche des études GE3LS sur l’acceptation technologique des approaches visant à utiliser la génomique pour lutter contre la Salmonella sur les produits frais, telles que développées par le projet Salmonella Syst-OMICS par le biais de méthodes (1) de sous-typage et de classification de la virulence et (2) de bio-contrôle par l’utilisation de bactériophages. L’objectif était également de développer des « points à considérer » pour les décideurs politiques afin de mieux informer les stratégies de mise en œuvre et de communication autour de la technologie et de ses applications. Cet atelier a été conçu comme un atelier délibératif, utilisant des discussions de groupe pour permettre aux participants d'examiner et de débattre les questions en jeu pour parvenir à une position éclairée. Le projet Salmonella Syst-OMICS a été brièvement présenté, suivi des résultats des sous-études GE3LS, à savoir une enquête Delphi, des entretiens avec les parties prenantes et une enquête nationale auprès des consommateurs. Ensuite, le groupe a discuté de la manière de traduire ces résultats en « points à considérer » et examiné comment cette recherche s’inscrit dans un contexte international plus large.

Résumé des résultats présentés lors de l’atelier

Enquête Delphi

L’enquête Delphi a recruté un panel de 27 participants sur la base de leur expertise diversifiée dans le domaine de la sécurité alimentaire. La plupart des répondants (89%) à l’enquête étaient des employés du gouvernement. Les points ayant suscité le plus fort consensus parmi les participants sont les suivants: (1) la nécessité de démontrer la fiabilité de la méthode de sous-typage et (2) sa capacité à répondre aux critères d'assurance qualité. En effet, 100% des répondants au troisième tour du sondage ont jugé ces éléments comme étant hautement prioritaires. La nécessité, pour la méthode de sous-typage Syst-OMICS, de répondre aux exigences réglementaires afin de garantir la corrélation entre les résultats et la pathogénicité a, quant à elle, été considérée comme une priorité élevée par 94% des répondants. La nécessité d’un mécanisme de surveillance a également fait l’objet d’un consensus, alors que 94% des répondants considèrent qu’il s’agit d'une priorité modérée.

Le rapport coûts-bénéfices de l'utilisation de la méthode de sous-typage doit être démontré selon 81% des répondants. Les questions concernant les relations internationales ont aussi été consensuelles. En particulier, 94% des répondants considèrent qu’il est très important d'envisager l'harmonisation du partage des données entre les pays afin de rendre plus efficaces les efforts internationaux visant à atténuer les risques de maladies d'origine alimentaire. En outre, 81% des répondants estiment qu’il est très important de tenir compte de l’expertise, des meilleures pratiques et des leçons apprises dans d’autres pays. En ce qui concerne les bactériophages, 88% des répondants considèrent qu’obtenir davantage de preuves scientifiques de l’efficacité des bactériophages dans la lutte contre la salmonelle sur une variété de fruits et légumes est une hautement prioritaire. Enfin, lorsqu'on leur a demandé quel type d'acteurs devrait être impliqué dans la mise en œuvre des méthodes de sous-typage et de bio-contrôle, les catégories qui ont fait l’objet d’un fort consensus à plus de 80% parmi les répondants sont les suivantes : les producteurs (94%), les scientifiques (88%), les organismes de réglementation (88%), et les experts en santé publique et les épidémiologistes (81%).
Entrevues auprès d’acteurs du secteur agro-alimentaire

Entre février et juin 2019, nous avons mené des entrevues auprès de 19 représentants d’associations de consommateurs ou d’institutions intéressées par la salubrité alimentaire (26%), de représentants de l’agriculture biologique (26%) et de l’industrie agroalimentaire canadienne (52%). Les personnes interrogées provenaient de la Colombie-Britannique (3), des Prairies (3), du Québec et de l’Ontario (10). La plupart ont convenu que la contamination peut survenir à n’importe quelle étape de la chaîne d’approvisionnement et qu’il peut être difficile d’en trouver la source. En ce qui concerne la réglementation et les pratiques actuelles de prévention des éclosions de salmonelles, la plupart des personnes interrogées semblaient satisfaites. La mise en œuvre des bonnes pratiques agricoles (CanadaGAP®) semblait susciter le plus de confiance de la part des intervenants. La mise en œuvre de la Loi sur la salubrité des aliments au Canada et de son règlement d’application a été mentionnée par plusieurs comme une bonne pratique dans la mesure où elle est appliquée. Enfin, de nombreuses personnes interrogées, tant dans l’industrie agroalimentaire que dans le secteur de l’agriculture biologique ont souligné l’importance du contrôle et de l’inspection aux frontières.

Plusieurs représentants de l’industrie alimentaire ont souligné l’importance pour les décideurs politiques de consulter les parties prenantes lors de l’élaboration des cadres réglementaires. Les opinions diffèrent quelque peu, cependant, quant aux types d’intervenants qui devraient être impliqués, certains mentionnant le gouvernement, l’industrie, les producteurs, les experts, les universitaires et les scientifiques, ou les producteurs biologiques, tandis que les avis sont plus partagés quant au rôle des consommateurs et des organisations qui les représentent. Ces résultats font écho à ceux de l’enquête Delphi.

Les personnes interrogées ont mentionné que les approches Syst-OMICS, si elles étaient mises en œuvre, favoriseraient une plus grande responsabilisation et un accroissement des connaissances. Au cours des entretiens, les personnes interrogées ont cependant identifié plusieurs problèmes qui devraient être pris en considération avant l’adoption des approches Syst-OMICS dans la pratique. Ces préoccupations comprenaient, sans s’y limiter, les thèmes suivants : (1) le fardeau supplémentaire pour l’industrie agroalimentaire ; (2) des préoccupations scientifiques concernant la validité, la fiabilité et la possibilité d’effets indésirables. En ce qui concerne l’utilisation des bactériophages en particulier, plusieurs ont mentionné des inquiétudes concernant les impacts potentiels sur l’environnement.

Les personnes interrogées sont favorables à l’utilisation de la méthode de détection du sous-typage Syst-OMICS soit au moment de la production, soit en temps réel tout au long de la chaîne d’approvisionnement. En ce qui concerne l’utilisation des bactériophages pour traiter les produits frais contre certaines salmonelles, elles ont mentionné les étapes de production, de transformation, de distribution, de vente au détail et certaines ont même envisagé leur utilisation par les consommateurs.

En ce qui concerne la communication avec le public et les consommateurs, plusieurs ont mentionné que les limites de la compréhension de la science et de l’agroalimentaire par le public pourraient avoir un impact négatif sur l’adoption des méthodes Syst-OMICS. Selon les personnes interrogées, ce qui fera une différence dans l’acceptation des méthodes Syst-OMICS par les consommateurs est le degré de confiance que le public accorde aux gouvernements et la façon dont ces approches sont communiquées.
Sondage national

Nous avons sondé 1000 participants sélectionnés au hasard à partir du panel en ligne Ipsos eNation Canada Omnibus. La répartition des hommes (47%) et des femmes (53%) était représentative de ce que l’on peut trouver dans la population générale. La représentation des différentes provinces canadiennes était également assez proportionnelle avec 14% des répondants de la Colombie-Britannique, 11% de l’Alberta, 6% de la Saskatchewan et du Manitoba combinés, 38% de l’Ontario, 24% du Québec et 7% de l’Atlantique. La répartition par âge et par revenus est assez équilibrée et reflète les tendances générales de la population en général. Cependant, le niveau d’éducation des participants était plus élevé que celui de la population générale, ce qui n'est pas inhabituel pour un panel en ligne.

Une majorité (80 %) de répondants montrent une opinion positive et favorable à la science. En ce qui concerne la confiance envers l’industrie agroalimentaire, une faible majorité (57%) affirmait avoir confiance en l’industrie agro-alimentaire pour minimiser les risques des procédés biotechnologiques qu’elle utilise. De même, une faible majorité (56%) fait confiance aux législateurs et décideurs politiques pour réglementer adéquatement les processus biotechnologiques dans le secteur agroalimentaire.

Un peu moins du deux-tiers des répondants (59%) ont identifié « la sécurité des produits frais destinés à la consommation et la santé publique » comme la priorité numéro un de l’industrie agroalimentaire. En comparaison, 19% ont choisi l’utilisation de méthodes respectueuses de l’environnement comme étant la priorité la plus importante de l’industrie à leurs yeux et 16 % ont choisi la réduction du gaspillage comme devant être la priorité principale de l’industrie, alors que les préoccupations économiques n'ont été mises en avant que par les 7 % de répondants.

Les données ont confirmé notre intuition puisqu’un total de 59% de tous les répondants des deux groupes étaient réticents à consommer des produits frais qui avaient été identifiés comme porteurs de salmonelles, même si le sous-type spécifique ne présentait pas de risque pour la santé humaine. La volonté des répondants à l’enquête de consommer des aliments traités par des bactériophages était divisée de manière égale entre ceux qui ont indiqué être enclins à consommer de tels produits et ceux qui ne l’étaient pas.

Les opinions sont presque également réparties entre ceux qui ont une opinion positive (46%) des applications en matière de soins de santé et de santé publique d'une nouvelle méthode de test basée sur la génomique et ceux qui disent avoir une opinion neutre à ce sujet (48%). Les pourcentages de répondants qui souhaiteraient être informés si des produits frais traités avec les méthodes Syst-OMICS étaient mis sur le marché sont similaires pour l’utilisation des bactériophages (60%) et pour l’utilisation de la méthode de sous-typage (57%). Les opinions sur le potentiel de la génomique pour améliorer la détection de salmonelles et contrôler leur présence sur les produits frais étaient presque également partagées entre ceux qui se disaient optimistes (43%) et ceux qui étaient plutôt neutres (41%).

Nous avons aussi analysé les données en utilisant des régressions logistiques. Nous avons considéré deux variables dépendantes : (1) la volonté de consommer des produits frais porteurs de salmonelles non pathogènes et (2) la volonté de consommer des produits frais traités avec des bactériophages. Chaque variable indépendante (par exemple, les variables sociodémographiques, la confiance envers le législateur, les valeurs personnelles) a été testée individuellement par une régression logistique binomiale avec chacune de ces deux variables dépendantes. Cinq variables indépendantes ont eu un effet significatif sur la volonté des répondants de consommer des produits porteurs de salmonelles non-pathogènes : le sexe (p < 0,0005), le niveau d’éducation (p = 0,026),
le groupe (c.-à-d. ayant reçu ou non des informations supplémentaires) (p < 0,0005), la confiance envers le législateur (p < 0,0005) et les valeurs personnelles (p < 0,0005). Cinq variables indépendantes ont également eu un effet significatif sur la volonté des répondants de consommer des produits traités par des bactériophages : le sexe (p = 0,001), le niveau d’éducation (p = 0,025), le sexe (c.-à-d. ayant reçu ou non des informations supplémentaires) (p = 0,011), la confiance envers le législateur (p < 0,0005) et l’âge (p = 0,001). Contrairement aux résultats concernant la volonté de consommer des produits frais porteurs d’une souche de Salmonella non-pathogène, les valeurs personnelles n’étaient pas significatives (p = 0,265).

Points à considérer

Les points à considérer sont de trois ordres : (1) les points à considérer pour les décideurs politiques et les scientifiques; (2) les considérations relatives à l’engagement du public et aux stratégies de communication; et (3) l’intégration des considérations canadiennes et internationales.

Parmi les points à considérer pour les décideurs politiques et les scientifiques, les points les plus discutés au cours de la session de travail figurent les préoccupations relatives à la gestion des risques, notamment la nécessité d’intégrer dans les stratégies politiques un plan de protection des populations vulnérables. En lien avec la question de la gestion des risques, un appel a été lancé en faveur de critères clairs et de seuils de virulence pour l’évaluation des politiques relatives à cette technologie. Un troisième point de discussion a été celui des analyses de coûts et d’autres défis susceptibles de freiner l’acceptation par l’industrie. Les analyses coût-efficacité ont été considérées comme un élément crucial pour l’adoption par l’industrie. Enfin, les participants ont examiné plusieurs considérations réglementaires pour les décideurs politiques.

En discutant des stratégies d’engagement du public et de communication, les participants ont soulevé trois grandes questions : comment communiquer, quel est le public visé, et quel devrait être le contenu des stratégies de communication. En ce qui concerne la question de savoir comment communiquer, un certain nombre de personnes ont soulevé l’importance d’utiliser les médias sociaux pour atteindre les consommateurs de tous les horizons et toucher différentes populations, car il a été démontré que les médias grand public ne suffisent pas à eux seuls à informer les Canadiens sur la salubrité des aliments. Les participants ont noté l’importance de clarifier exactement quel public est visé, y compris les consommateurs, les détaillants et les producteurs, afin que le message puisse être adapté en conséquence. L’un des principaux domaines de discussion en matière de communication est celui des stratégies de communication des risques. En particulier, il est nécessaire de mettre en place une stratégie de communication des risques efficace qui s’appuie sur les meilleurs professionnels de la communication des risques, tout en mettant l’accent sur la communication efficace avec les parties qui n’ont pas une formation scientifique approfondie.

Le dernier segment de l’atelier a été consacré à la discussion de l’intégration des considérations canadiennes et internationales. Les participants ont notamment discuté de l’importance de comprendre les cadres réglementaires et la recherche scientifique qui se déroulent à l’échelle internationale, en mettant l’accent sur les États-Unis et l’Europe. On a fait remarquer que si elles se concrétisent, ces nouvelles approches réglementaires pourraient aider le Canada à devenir un chef de file dans l’intégration de la génomique pour tous les produits.
Introduction

Foodborne illness constitutes a serious health and economic concern for the Canadian public; Canada sees an estimated 4 million domestically acquired foodborne illnesses annually.\(^1\,\,\,2\) The cost of foodborne disease stemming from *Salmonella* alone is estimated to be as high as $1 billion annually in Canada, with costs stemming from both direct costs, such as medical care and lab tests, and indirect costs, such as work absenteeism and loss to food companies and restaurants.\(^3\,\,\,4\) The impact of such illnesses is not borne equally and may disproportionately burden communities already facing challenges in food and water access and safety; for instance, Indigenous populations are at higher risk for foodborne illness than the general Canadian population, in part due to the lack of clean water availability in First Nations communities.\(^5\) Furthermore, as climate change continues to bring complex changes along the food chain, researchers predict an increasing public health burden.\(^6\)

Salmonellosis is a foodborne disease caused by the subspecies *enterica* of the species *Salmonella enterica* (*S. enterica* subsp *enterica*). Of the ~2600 *S. enterica* subsp *enterica* serotypes, only a small group of serotypes is responsible for causing the great majority of illnesses. Current methods of analysis for *Salmonella* are designed to detect *S. enterica* subsp *enterica* without differentiating the virulence potential. The *Salmonella* Syst-OMICS project is investigating, among other questions, whether the virulence potential of *S. enterica* subsp *enterica* strains can be differentiated to high, medium, low, and non-virulent by genomic analysis (Syst-OMICS subtyping). The ability to identify and differentiate virulent from non-virulent *S. enterica* subsp *enterica* would provide additional information to public health officials and regulators to support the governance of *Salmonella* contaminated food (i.e., risk assessment, management, and communication), as this could potentially reduce the number of product recalls associated with *Salmonella*, which currently has a significant economic impact on the food industry. The *Salmonella* Syst-OMICS project is also investigating the potential for *Salmonella* infecting bacteriophages to be used as a biocontrol to reduce contamination of fresh produce (Syst-OMICS biocontrol). Bacteriophages could be potentially applied in the field or to harvested produce, with potential benefits of a reduction in the number of illnesses and the costs to industry of responding to *Salmonella* contaminated products.

*Salmonella* is among the foodborne illnesses with the widest-reaching impact, with approximately 88,000 Canadians becoming sick from *Salmonella*-contaminated food each year.\(^7\) Although foods such as poultry have long been linked to *Salmonella*-based food poisoning, more recently fresh fruits and vegetables have also been identified as significant sources, in part due to

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4. https://www.genomecanada.ca/en/systomics/ensuring-food-safety-and-reducing-economic-burden-salmonellosis?fbclid=IwAR3xLKWe56uUoHDQIrtUkuo0Y2Db-N7E89LeFg7JTGSm2_1r9hCS-b2WeEU
5. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5757704/
6. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6587690/
7. https://www.canada.ca/en/public-health/services/food-borne-illness-canada/yearly-food-borne-illness-estimates-canada.html?fbclid=IwAR3_j-a4yGFLT-W8o53BEiuKrSHZixyDh6CDgSAiiJJOzAlcu0b9-P6_kA
animal and non-potable water-based contamination in the soil where produce is grown. The result is that consumption of contaminated fresh produce is now the leading cause of foodborne illness, and the majority of these can be linked back to the salmonella bacteria. Finding ways to identify, track, and treat these produce-based salmonella outbreaks is therefore of increasing concern.

**Background**

To facilitate the identification, tracking, and treatment of foodborne pathogens, researchers have begun to develop and employ novel rapid testing methods, employing genomics data to understand infectious disease epidemiology. Emerging genomics technology allows for omics treatment and tracking to be applied to outbreaks, in addition to creating biocontrol methods to limit the formation of salmonella at the source. By increasing the speed at which specific outbreaks can be traced and their sources identified, contaminated food can be removed from the consumption chain and limit the number of people infected and associated economic and social costs.

The salmonella syst-omics project aimed at addressing the problems associated with salmonella contamination of fresh produce through the development of natural solutions (e.g., using bacteriophages) to control the presence of salmonella on fruits and vegetables as they are growing in the field. New tests, using genomic subtyping to identify specific strains of salmonella and their virulence, were also developed so that fresh produce can be quickly and efficiently tested for the presence of salmonella before being sold to consumers. Finally, new tools were developed to allow public health officials to better determine the source of salmonella illnesses when they occur, which in turn will allow for contaminated food to be removed from grocery stores, before being purchased by consumers. The salmonella syst-omics project has many social and economic benefits for Canadians. The results of this project will decrease the amount of people who become ill from salmonella, thereby increasing the health and well-being of Canadians, and alleviating the economic burden of foodborne diseases caused by these bacteria.

*Addressing the ethical, legal, and social issues raised by the syst-omics methods*

The salmonella syst-omics project is based on a systems approach, applying whole genome sequencing to the analysis of pathogens in order to transform the practice of salmonella diagnostics, epidemiology, and surveillance with the development of a foodborne syst-omics database. The use of such technology, however, is partly dependent on the willingness of the main stakeholders (i.e., regulators from the public health sector as well as the various players in the agri-food industry, along the supply chain, including the support of Canadian consumers) to allow genomics technologies to be employed in the service of food safety.

It was therefore crucial to evaluate the viability of implementing a novel genomic test for salmonella that can determine the pathogenic status of a given isolate and assess the need to shift to a risk-based approach to food safety that classifies foodborne microbial adulterants based on their pathogenicity, in contrast to the current regulatory practice of classifying a microbial adulterant based on species determination alone. To this end, the Centre of Genomics and Policy used an anticipatory governance approach that included a regulatory assessment integrating a careful consideration of the evidentiary requirements; the economic, legal, ethical, regulatory, and global policy constraints; and the trade implications of supporting such a paradigm shift.

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9 https://academic.oup.com/nar/article/43/W1/W104/2467901
First, the team produced an overview of the current regulatory framework for the approval of testing methodologies for *Salmonella* discussing considerations related to (1) the development of a new test for *Salmonella*, (2) the potential establishment of a *Salmonella* risk virulence classification scheme, and (3) the development of a biocontrol method to reduce the presence of *Salmonella* on fresh produce. It concluded that, as of 2018, the regulatory framework was flexible enough to allow for the research and development of improved *Salmonella* detection and control methods. It is anticipated that the new tools developed in the context of the Syst-OMICS project will receive regulatory approval provided they are mature enough for translation and that robust scientific data demonstrate that they meet regulatory requirements. However, a risk-based virulence classification scheme may create a need to review and/or refine current regulatory mechanisms to ensure an adequate regulatory response to address each *Salmonella* virulence category. The use of bacteriophages as a *Salmonella* biocontrol method on fresh produce may provide a more environmentally sustainable alternative to chemical approaches. Nevertheless, the approval of agricultural applications of bacteriophages for routine use in fresh produce destined for human consumption may require more scientific evidence and regulatory oversight. Such a bacteriophage governance framework could be put in place in Canada by considering the experiences of other institutions such as the U.S. Food and Drug Administration (FDA). Although the legal framework is flexible enough to allow the development of Syst-OMICS methods for the detection and control of *Salmonella*, many other factors, including social ones, come into play when it comes to the adoption of such novel tools. The three main ones are integration into the practices of Canadian agri-food and public health experts; interest and uptake by agri-food industry stakeholders; and buy-in from Canadian consumers.

Indeed, a key factor in the successful implementation of the novel Syst-OMICS methods is to demonstrate their added value in better meeting the needs and expectations of the agri-food and public health community. An effective exchange of expertise across disciplines is essential to enable successful translation of pathogen genomics into public health practice. To this end, we engaged relevant experts’ stakeholders in a consensus building exercise in the form of a Delphi survey. From an implementation perspective, potential barriers to wider industry uptake of the novel Syst-OMICS methods must be identified at the outset. Indeed, the practicality, simplicity and cost of a method must be considered before contemplating the implementation of new subtyping methods that use omics technologies. To better understand pre-implementation considerations from the perspective of the Canadian agri-food industry, we conducted in-depth interviews with its representatives. Additionally, the use of genomics technologies along the food chain has proven in recent years to stir controversy in public opinion, and significant gaps exist between actual and perceived risks of such technology. Media reporting on food technologies, lack of accessible scientific information for lay consumers, and individual attitudes toward risk-benefit analyses all play a role in shaping consumer opinions on and trust in the application of genomics technology to food safety. An understanding of these factors is integral to the efficient and effective implementation of such technologies. To better understand the concerns of Canadian consumers, a consumer survey was conducted.

In addition to the analysis of the legal and regulatory framework, the three angles of approach mentioned above, i.e., the opinion of experts, the needs of agri-food industry stakeholders as well

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13 https://bmcpublichealth.biomedcentral.com/articles/10.1186/s12889-020-09428-4
as consumer perceptions, were addressed by the team from the Centre of Genomics and Policy at McGill University, under the direction of prof. Yann Joly. Three empirical sub-studies were conducted to analyze the perspectives of each group of stakeholders: 1) a Delphi study of experts’ opinions, 2) in-depth interviews of industry stakeholders, and 3) a national survey of Canadians consumers. The results of these sub-studies were presented and discussed at a stakeholder workshop held in early 2020. This report summarizes the data presented at that event and the discussions that followed.

1. Workshop

To conclude our stakeholder engagement and GE3LS (Genomics and its Ethical, Environmental, Economic, Legal and Social Aspects) studies on technology acceptance through various social sciences methodologies including: 1) a three-round Delphi survey of experts and decision-makers; 2) in-depth qualitative interviewing with representatives of the Canadian agri-food industry, representatives of groups interested in food safety, and representatives of environmental agri-food practices such as organic farming; and 3) a general population survey, we held a stakeholder’s workshop with 13 experts and industry representatives and 7 members of the research team. The workshop was held in Montréal on February 14, 2020. The goal of this workshop was to further validate the research findings from the GE3LS studies on technology acceptance of the approaches to use genomics to address Salmonella on fresh produce, as developed by the Salmonella Syst-OMICS project through its (1) subtyping and virulence classification method and (2) bacteriophage-based biocontrol. The intention was to accomplish this by developing a set of points to consider for policymakers, and proposing a set of points to consider to better inform implementation, communication strategies and applications around the technology.

1.1 Methods

This workshop was conceived as a deliberative workshop, using facilitated group discussions to allow the participants to consider the issues at hand, challenge each other’s positions, and develop their views to reach an informed position. Findings were first presented to the group on the overall trajectory and deliverables of the Salmonella Syst-OMICS project as well as the accompanying GE3LS research in the form of a Delphi Study, Stakeholder Interviews, and a National Survey (methodologies for each project outlined in the appropriate sections below). After this, the group held discussions on how to parlay these findings into points to consider for stakeholders and public engagement, as well as to examine how this research fits into the larger international context.

2. Delphi study

The adoption and implementation of the Syst-OMICS approaches to support the governance of Salmonella contaminated food requires an understanding of the legal, ethical, regulatory, and socio-economic drivers and barriers that can facilitate or hinder the uptake of this type of innovation. To identify important issues concerning the uptake of Syst-OMICS approaches, it is essential to solicit the engagement of stakeholders in food safety regulation such as researchers, microbiologists, inspectors, policymakers, and members of the food industry.

2.1 Methodology
To this end we conducted a study using a 3-round Delphi survey methodology to explore the points of view of key stakeholders and decision-makers on the new Syst-OMICS subtyping and biocontrol approaches. More specifically, we set out to identify the following: 1) drivers and potential barriers to the uptake of the new Syst-OMICS subtyping and biocontrol approaches; 2) scientific and evidentiary regulatory requirements that needs to be met for the new Syst-OMICS approaches to be adopted; and 3) priority issues and possible solutions as well as areas of agreement and disagreement among the experts.

The Delphi survey recruited a panel of 27 participants based on their diversified expertise in the field of food safety: researchers, scientists, policy makers involved in food safety and high-standing members of the food industry. Participants were recruited using a purposive sampling approach that mixes warm and cold invitations sent to food safety experts, which were identified with the help of our collaborators. The questionnaire and responses were hosted by the website SurveyMonkey.

Those who chose to participate in the first-round Delphi study were asked to answer a few demographic questions, followed by multiple choice and open-ended questions about their views and perceptions on the shift to Syst-OMICS subtyping and biocontrol approaches. All nominal information was kept confidential throughout the study. The survey responses collected in the first round were analyzed for themes and patterns with the help of a qualitative research software (NVivo). The thematically coded data was then organized to propose specific questions for inter-round feedback to participants (round two and three). At the end of round-three, we identified areas of consensus and divergence about important issues identified by our participants.

2.2 Results from the Delphi survey

2.2.1 Socio-demographic information and panel composition

Most respondents (89%) who participated in our expert Delphi survey were government employees. Scientific expertise is well represented with 78% of respondents identifying themselves as scientists and 19% as academic researchers. Although the respondents did not provide details on this topic, it can be hypothesized that respondents identifying themselves as “scientists” were mostly professionals employed by governments, while those identifying themselves more as “academic researchers” were probably employed mainly by higher education and research institutions. Respondents identifying themselves as policymakers or regulators were slightly less numerous, with 41% and 30% respectively. Industry representatives are in the minority (7%) in the sample for the panel of experts solicited for the Delphi survey. However, industry representatives were solicited more extensively during the stakeholder interviews and took an active part in the stakeholder workshop. Finally, 4% of the experts who responded to the Delphi survey selected the “other” category, which includes, for example, consultants.
2.2.2 The *Salmonella* Syst-OMICS subtyping method

We have chosen to report the selected results of the Delphi survey by dividing them into two sections devoted to each of the two Syst-OMICS methods proposed, namely: subtyping to identify and classify *Salmonella* strains according to their level of virulence and the use of bacteriophages to eliminate *Salmonella* present on fresh produce. This first section is dedicated to the presentation of the most relevant results of the Delphi survey regarding the subtyping method specifically. The potential benefits of the *Salmonella* Syst-OMICS subtyping method will first be discussed. Then, key evidentiary considerations and long-term preoccupations that would need to be addressed before the adoption and implementation of the *Salmonella* Syst-OMICS subtyping method will be presented. Potential drivers as well as financial and policy barriers to the adoption of the *Salmonella* Syst-OMICS subtyping method will be covered. Selected results about how the experts anticipate the acceptability of the *Salmonella* Syst-OMICS subtyping method from the point of view of the public will also be presented. Finally, international considerations regarding the use of the *Salmonella* Syst-OMICS subtyping method will be highlighted.

### a. Potential benefits of the *Salmonella* Syst-OMICS subtyping method

First, we questioned the experts who responded to the Delphi survey to determine their perception of the potential benefits associated with the use of the *Salmonella* Syst-OMICS subtyping method. Respondents identified four main benefits of the method: 1) a better understanding of the virulence of *Salmonella* strains; 2) the possibility to influence future food safety policies; 3) the potential to better inform risk assessment and management decisions; and 4) the subtyping method could allow industry to focus on a selected number of pathogens. The general theme is that the benefits are primarily around knowledge and that this knowledge could potentially improve and make more efficient the policies and procedures already in place for the detection and prevention of *Salmonella* on fresh produce. However, there is no strong consensus on any of the benefits put forward.

Regarding the first statement "the Syst-OMICS sub-typing method may lead to a better understanding of the virulence of the *Salmonella* strains", in the third round 76% of the respondents considered this to be a very important (38%) or moderately important (38%) benefit. There is a slight increase in the number of respondents who consider this benefit to be very or moderately important compared to the number of respondents in the second round (67%). There is also a more balanced distribution between the very and moderately important categories in the third round, 38% and 38% respectively. Thus, fewer respondents in the third round responded that this benefit was
very important (38%) compared to the second round (43%). At the same time, there was an increase in the number of respondents in the third round who considered this benefit to be moderately important (38%) when compared to the response rate in the second round (24%). The number of people viewing this benefit as slightly important also decreased between the second (29%) and third (19%) round. Finally, the number of individuals reporting this benefit as not at all important remained around 5% between rounds.

The Syst-OMICS subtyping method may lead to a better understanding of the virulence of Salmonella strains.

In response to the statement that “Syst-OMICS sub-typing method could influence future policies by Canadian health and food agency”, a total of 63% respondents to the second round considered this to be a very important (13%) or moderately important (50%) benefit. There is a clear decrease in the number of respondents who perceive this benefit as “very important”, from 38% in the second round to 13% in the third round. In comparison, the number of individuals who perceive this benefit to be moderately important increased from 38% in the second round to 50% in the third and final round. The number of respondents who answered that this benefit is slightly important increased from 24% in the second round to 38% in the third round. It therefore appears that respondents revised their assessment of the importance of the potential impact of the Syst-OMICS subtyping method on future policies downwards between the second and third rounds. It is interesting to note, however, that no respondents indicated that this benefit was not at all important to them.
When giving their opinion about the possibility that “Syst-OMICS sub-typing method could yield information that would help with risk assessment and management decisions” 88% of respondents in the third round responded that this benefit was either very important (38%) or moderately important (50%). Considering these two categories combined as an indicator that the statement is generally important to respondents, the role that the Syst-OMICS subtyping method could play in facilitating risk assessment and management decisions can be considered as the most consensual benefit in the third and final round of the Delphi survey. While the percentage of respondents who stated this benefit was very important remained the same between the first (38%) and second (38%) round, the number of respondents who considered this benefit to be moderately important increased between the second (38%) and third (50%) round. Concomitantly, the percentage of people who responded that this benefit was slightly important to them decreased between the first and second rounds, from 24% to 13%. No respondents indicated that this benefit was not at all important to them.

Only 44% of respondents in round three found the statement that “the Syst-OMICS subtyping method would allow industry to focus on a sub-set number of pathogens” to be very important (13%) or moderately important (31%). There was a clear decrease in those perceiving
this benefit as very important between the second (38%) and third (13%) rounds. The percentage of respondents considering this benefit to the industry as moderately important increased between the second (19%) and third (31%) round. There was also an increase in the percentage of individuals considering this benefit to be slightly important between the second (29%) and third (44%) round. It is also important to note that this benefit is considered not at all important by about 13% of the experts surveyed and that this number remains stable between rounds.

The Syst-OMICS subtyping method would allow industry to focus on a sub-set number of pathogens, rather than the whole diversity encountered in the genus.

<table>
<thead>
<tr>
<th>Category</th>
<th>Round 2</th>
<th>Round 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very important</td>
<td>13%</td>
<td>38%</td>
</tr>
<tr>
<td>Moderately important</td>
<td>19%</td>
<td>31%</td>
</tr>
<tr>
<td>Slightly important</td>
<td>29%</td>
<td>44%</td>
</tr>
<tr>
<td>Not at all important</td>
<td>14%</td>
<td>13%</td>
</tr>
</tbody>
</table>

b. Evidentiary considerations that would need to be addressed before the adoption and implementation of the Salmonella Syst-OMICS subtyping method

One of the core elements of our survey are the evidentiary considerations to be addressed for the adoption and implementation of the Syst-OMICS subtyping approach. We therefore solicited the opinion of experts on this subject. The experts identified several elements to consider, including issues related to reliability, quality assessment, regulatory validation, oversight mechanisms, nuances of subtyping classification, assessment of health impact on at-risk populations and variations in individual susceptibility to Salmonella sub-types, appropriate time-effectiveness with regards to recalls, incentives and disincentives and traceability. Issues of training and strategies for public communication were also discussed.

The need to demonstrate the reliability of the subtyping method and its capacity to meet quality assurance criteria were the items that 100% of respondents in the third round rated as high priority. The need for the Syst-OMICS subtyping method to meet regulatory requirements to ensure that findings correlated with pathogenicity also generates consensus with 94% of respondents in the third round considering this to be a high priority. The need for an oversight mechanism also generates a consensus with 94% of respondents in the third-round rating this as a moderate priority. The statement that “classification of the level of virulence should integrate information about the association between virulence and the presence of specific genes” also met with some consensus with 75% of respondents in the third round agreeing that this is a high priority.

In the second round, there was a strong consensus on the importance of demonstrating the reliability of the Syst-OMICS subtyping classification, with 90% of respondents considering it a high priority and only 10% a moderate priority. In the third round, 100% of respondents agreed that it was a high priority.
Similarly, there was a strong consensus on the importance of determining whether the *Salmonella* Syst-OMICS subtyping method would meet quality assurance requirements across laboratories with 90% of the survey participants to the second round agreeing that it is a high priority and only 10% a moderate priority. In the third round, 100% of respondents agreed that it was a high priority.

The results are somewhat mixed with respect to the importance, for the Syst-OMICS subtyping method, of meeting regulatory validation requirements to ensure that genotypic findings correlate with phenotypic pathogenicity. Indeed, 71% of respondents in the second round considered this issue as high priority, while 24% perceived it as moderate priority and 5% as low priority. In the third round, however, 94% of respondents considered this issue to be a high priority. The percentage of respondents considering this issue as a moderate priority dropped from 24% in the second round to only 6% in the third round, while the percentage of those considering it a low priority dropped from 5% to 0%.
There is a consensus on the need for oversight mechanisms to ensure compliance, with 94% of respondents in the third-round rating this as a moderate priority. The second-round results were much more varied with 40% of respondents considering it to be a high priority, 50% perceiving it to be more of a moderate priority, and 10% indicating that in their view it was more of a low priority. We therefore note a significant decrease in the percentage of respondents who consider the implementation of oversight mechanisms to be a high priority, from 40% in the second round to only 6% in the third round. Interestingly, the number of respondents considering it a low priority dropped from 10% to 0% in the third round.

Regarding the need for classification of the level of virulence to integrate information about the association between virulence and specific genes, 75% of respondents in the third round considered this to be a high priority. Combined with the 19% of respondents who rated this as a moderate priority, 94% of respondents in Round 3 rated this issue as a moderate to high priority. While the number of individuals indicating that they consider this issue to be a high priority increased from 62% to 75% between the first and second rounds, the number of persons rating this issue as a moderate priority declined slightly from 24% to 19% between the two rounds. The number of survey respondents who considered it to be a low priority dropped from 10% to 0% between rounds.
Regarding the need to assess how the Syst-OMICS subtyping method may affect the health outcomes of at-risk groups a total of 94% of third-round respondents rated this as a high priority (50%) or a moderate priority (44%). This consensus around high to moderate importance was already present in the second round, with 48% of respondents indicating that they felt it was a high priority and 48% that it was a moderate priority. There was a very slight increase in the importance given to this issue between the second and third rounds. It should be noted that a percentage of approximately 5%, constant between rounds, considers it to be a low priority.

Opinions were more divided when it came to the question about the need to integrate the impact(s) of host factors on Salmonellosis. Generally, this was considered a moderate priority (31%), a low priority (50%) or not a priority at all (6%) by the respondents in the third round of the survey. Concomitantly, only 13% of the respondents in the third round felt that it was a high priority in the third round of the survey. Thus, the importance given to this issue appears to decrease between Round 2 and Round 3. The percentage of respondents who consider it a high priority drops slightly from 19% to 13% and the percentage who consider it a moderate priority also drops from 38% to 31%. At the same time, the number of respondents who responded that they felt it was a low priority increased from 38% to 50% between the two rounds.
Opinions were somewhat divided regarding the need for the Syst-OMICS subtyping method to consider variability in individual susceptibility to low virulence strains within the general population. Indeed, in the third round, a total of 69% of respondents considered it a high priority (19%) or a moderate priority (50%), while 31% considered it a low priority. There was a slight decrease in the percentage of respondents who felt it was a high priority between the second and third rounds, as this number dropped from 24% to 19%. The percentage of those who answered that it was a moderate priority, or a low priority increased subtly from 48% to 50% and from 29% to 31% respectively. However, none of the respondents indicated that this issue was not a priority at all.

When the two categories high priority (44%) and moderate priority (50%) are combined, there is a 94% consensus in the third round regarding the relative importance of evaluating the time-effectiveness of the Syst-OMICS method. In comparison, the results of the second round were much more varied with 38% of respondents rating this issue as high priority, 33% rating it as moderate priority, 19% rating it as low priority and 10% rating it as not a priority at all. There was a significant increase in the responses to the high priority and moderate priority categories, from 38% to 44% and 33% to 50% respectively between the two rounds. The “low priority” and “not a
priority” categories are on the decline, with a marked drop in responses from 19% to 6% for the low priority category and from 10% to 0% for the not a priority category.

There is a need to assess the time-effectiveness of the Syst-OMICS subtyping method regarding the timeframe for recalls of fresh produce that would be contaminated with virulent *Salmonella*.

Regarding the importance of integrating support, incentives, and disincentives to oversee the application of control steps 87% of respondents in the third round responded that it was either a moderate priority (56%) or a low priority (31%). It can therefore be concluded that this issue is not among the top concerns prioritized by the experts who responded to the survey. Indeed, only 13% of the participants in the third round rated it as a high priority. What's more, these figures do not change much between rounds. The number of respondents increases from 15% to 13% for the high priority category, from 55% to 56% for the moderate priority category and from 30% to 31% for the low priority category. However, none of the respondents felt that this issue was not a priority at all.

If the *Salmonella* Syst-OMICS subtyping method is to be implemented, support, incentives, and suitable disincentives need to be integrated within the primary site control models to oversee the application of control steps.

When asked about the need for the developer laboratory to ensure traceability of all information related to software interpretation and decision-making rules 100% of respondents in Round 3 agreed that it was either a high priority (44%) or a moderate priority (56%). A similar trend was observed as early as the second round, when 95% of respondents had judged this issue to be a high priority (50%) or moderate priority (45%) and only 5% had stated that they considered
it to be a low priority. However, there were slight changes between rounds, particularly with the low priority category, which went from 5% to 0%.

Responses to the question about clarifying the responsibilities of the different laboratories and organisations involved in the production and analysis of data were particularly split with 31% of respondents in the third round seeing this as a high priority and 56% seeing it as a low priority. Interestingly, only 13% of respondents in the third round considered it to be a moderate priority. Also, noteworthy, the distribution of responses was much less divided in the second round with 25% of survey participants rating this issue as a high priority, 40% as a moderate priority and 35% as a low priority. This shows a significant decrease in the percentage of respondents rating this issue as a high priority from 40% to 13%, while the other categories are on the rise. Indeed, while there was a slight increase in the percentage of respondents who indicated that clarification of responsibilities was a high priority between the second (25%) and third (31%) rounds, the largest increase was in the number of respondents who rated it as a low priority, from 35% in the second round to 56% in the third and final round. No respondents indicated that they did not consider this issue to be a priority at all.

Most (88%) respondents in the third round agree that the development of a detailed plan about how changes in method, software, interpretation, etc. will be communicated should be considered a high (44%) or moderate (44%) priority. A minority (13%) of respondents in the third
round consider it a low priority. These figures are stable and differ little from the percentages observed in the second round: 45% of participants who consider it a high priority, 40% who consider it a moderate priority and 15% who responded that they consider it a low priority. No respondents chose the answer not at a priority.

A majority (81%) of respondents in the third round consider the development of a detailed plan about how training will be delivered as a low priority (31%) or moderate priority (50%). A minority (19%) of respondents in the third round consider it a high priority. No respondents chose the answer not at a priority. There was a decrease in the percentage of respondents considering the development of such a plan about training as a high priority between round 2 where 30% of the respondents considered it a high priority and round 3 where only 19% of respondents considered it a high priority. This difference is explained by a 10% increase in the number of respondents who consider the development of a detailed training plan as a moderate priority between round 2 and round 3. The percentage of respondents considering this as a low priority remained stable between rounds with a percentage around 30%.

Determining a strategy for communicating information regarding the subtyping method to the public was perceived as a priority by few stakeholders: 10% in the second round, which dropped to 6% in the third round. Most respondents considered “the need to determine which information
regarding the subtyping method will be presented to the public, how and when this information will be communicated” to be of moderate to low priority. A total of 90% of the second-round respondents indicated that this was either a moderate (55%) or low priority (35%). We notice a slight increased with 94% of the third-round respondents answering that it was either a moderate (50%) or low priority (44%). Additionally, there is an increase of about 10% between the number of people who ranked determining a communication strategy to the public as a low priority between the second (35%) and third (44%) rounds.

There is a need to determine which information regarding the subtyping method will be presented to the public, how and when this information will be communicated.

Respondents were asked to rank the five following statements in order of priority: a) subtyping methods should meet the regulatory validation requirement to ensure that genotypic findings correlate with phenotypic pathogenicity; b) reliability of subtyping classification should be demonstrated; c) the time-effectiveness of subtyping regarding the timeframe for recalls should be assessed; d) how subtyping may affect the health outcomes of at-risk groups should be assessed; and e) variability in individual susceptibility to low virulence strains within the Canadian population should be considered. It is noticeable that the order of priority given to the statements changes little between the second and third rounds. The statements “subtyping methods should meet the regulatory validation requirement to ensure that genotypic findings correlate with phenotypic pathogenicity” and “reliability of subtyping classification should be demonstrated” are the two statements who ranked higher for both rounds, with scores above 4.3 in the third round.
The next two figures show qualitative statements made by respondents in the second round of the survey, which is why quantitative data is not available for the second round. These statements were then ranked by respondents in the third round of the survey. For the first statement “there is a need for performing a quantitative risk assessment modelling on the Syst-OMICS subtyping virulence classification, especially with regards to low virulence (non-pathogenic) *Salmonella*”, most respondents consider this to be a moderate (38%) or low priority. Only one-quarter (25%) of respondents consider this to be a high priority, but no respondents indicated that this was not a priority at all.

In contrast, the second statement “the Syst-OMICS subtyping method needs to ensure high correlation between the absence of specific genes associated with virulence for different subtypes and non-pathogenicity, rather than just demonstrate a positive correlation between subtypes and pathogenicity” is considered a high priority by half (50%) of the respondents in the third round. In addition, 38% of respondents consider this to be a moderate priority and only 13% consider it to be a low priority.
c. Long-term considerations that would need to be addressed before the implementation of the Salmonella Syst-OMICS subtyping method

Respondents in the first round identified a few long-term considerations that would need to be addressed before the implementation of the Salmonella Syst-OMICS subtyping method. Whether it is the possibility that subtyping method may create a reliance on serotyping; the likelihood that users misuse the subtyping method or the risk that Salmonella may mutate, respondents in the first round of the Delphi survey highlighted different aspects, which could have long-term, often undesirable, effects.

Regarding the “need to evaluate whether the Syst-OMICS subtyping method may create an entrenched reliance on serotyping”, most (81%) third round participants rated it to be a low priority concern and 6% considered it was not a priority at all. Only 13% of third-round participants considered it to be a moderate priority, while none of the third-round participants considered it to be a high priority. Results from the third round differ from the second-round results since 20% of the second-round participants ranked the evaluation of the possibility that Syst-OMICS subtyping create an entrenched reliance on serotyping as a high priority and 35% of these participants ranked it a moderate priority. We also note that the percentage of respondents who answered that it was a low priority went from 45% in the second round to 81% in the third round, while the percentage of people who considered that it was not a priority rose from 0% to 6% between the second and third rounds.
There is a need to evaluate whether the Syst-OMICS subtyping method may create an entrenched reliance on serotyping.

The need to evaluate and mitigate the risk that users may approach subtyping as a pass-fail method instead of using the information more systematically for trend-analysis and early warning purposes was raised by the participants in the second round. A majority (75%) of the participants in the third round consider this to be a moderate priority. The balance of opinion is divided between 6% who considers it a high priority, 13% who considers it a low priority, and 6% who consider it not to be a priority at all.

Respondents generally agree that the need to monitor virulence and evolution of subtypes for mutation is either high or moderate priority. Indeed, in the second round 55% of respondents ranked this issue as a high priority, while 40% ranked it as a moderate priority, and only 5% considered it to be a low priority. In the third round, a majority (69%) of respondents rated this issue as a moderate priority. There is a decrease in the percentage of respondents who consider it a high priority from 55% to 31%. On the other hand, the percentage of people who consider it a low priority goes from 5% to 0% in the third round.
d. Potential drivers to the adoption of the *Salmonella* Syst-OMICS subtyping method

The next section presents the different potential drivers that could help the adoption of the *Salmonella* Syst-OMICS subtyping method. These drivers relate to whole genome sequencing policies and uptake by industry stakeholders. Unsurprisingly, the integration of whole genome sequencing into routine laboratory testing practices is seen by a majority of survey respondents as being very relevant. This is true for the two rounds where the slight change in results going from 68% in the second round to 69% in the third round only accounts for dropout rate between rounds. It is also noticeable that the percentage of people who consider this to be a moderately relevant issue goes from 26% in the second round to 19% in the third round. A difference that could be explained by the fact that the percentage of respondents who consider it to be a slightly relevant issue goes from 0% in the second round to 6% in the third round. The percentage of people considering that the integration of whole genome sequencing into laboratory testing practices is not relevant at all remains stable with 5% of respondents in the second round and 6% in the third and final round.

Interestingly, federal investment in systematic whole genome sequencing of *Salmonella* strains was perceived as very relevant by 63% of respondents to the second round of the Delphi
survey - a percentage that dropped to 50% in the third round. Accordingly, the percentage of respondents who answered that this was moderately relevant went from 26% to 31% between the second and third rounds. Similarly, the percentage of people who consider federal investment to be a slightly relevant driver to the adoption of the *Salmonella* Syst-OMICS subtyping method went from 11% to 19% between rounds.

![Bar chart showing current federal investment in systematic whole genome sequencing of *Salmonella* strains.]

**e. Potential drivers that may influence the uptake of the *Salmonella* Syst-OMICS subtyping method by industry stakeholders**

Uptake by industry stakeholders is a key aspect of the adoption of the *Salmonella* Syst-OMICS subtyping method. We therefore invited respondents to consider different drivers that could influence the industry's perception of the *Salmonella* Syst-OMICS method. The most consensual driver is, without a doubt, the demonstration of the cost-effectiveness of this approach with 75% of respondents to the third round agreeing that this is a very relevant aspect. By contrast, we see that only 13% of third-round survey participants deemed this aspect to be moderately relevant and another 13% considered it to be slightly relevant. There is an upward trend between the second and third rounds in the percentage of respondents who consider cost-effectiveness to be a very relevant issue, rising from 58% in the second round to 75% in the third round. Accordingly, there is a slight decrease in the number who deem it to be moderately important going from 26% to 13%. Interestingly, there was 5% of second-round participants who considered cost-effectiveness as not at all relevant, this number drops to 0% in the third and last round.
Ongoing farm to fork collaborative efforts to reduce the risk of outbreaks and illness was mentioned by respondents to the first round of the Delphi survey and 53% of respondents to the second round believe it to be a very relevant driver to the adoption of the Salmonella Syst-OMICS method. In the third round, however, 56% of participants consider it to be moderately relevant. Accordingly, the percentage of participants who consider it to be very relevant goes from 53% to 38% between round two and three, while the number of people who consider it to be moderately important increases from 37% to 56% from one round to the next. The number of people who deem farm to fork collaborative efforts to be a slightly relevant facilitating factor in the adoption of the subtyping method remains relatively stable, going from 11% to 6% between the second and third rounds.

Respondents to the first round mentioned that concerns of industry stakeholders regarding liability could influence the uptake of the subtyping method by industry stakeholders. This could act either as a barrier or a driver depending on the context and industry stakeholders’ perceptions. Responses to the second round of the Delphi survey were mixed with 42% of respondents identifying this issue as being very relevant, 37% as being moderately relevant, 16% as slightly relevant and 5% as not relevant at all. These results become somewhat clearer in the second round where a majority (50%) of participants answered that liability concerns were moderately relevant, while 38% considered it to be very relevant and 13% deemed it to be slightly relevant. No respondents to the third round believed this was irrelevant.
A slight majority (61%) of third-round respondents agreed that the practicality and ease of use of the Syst-OMICS subtyping method could also influence its uptake by industry stakeholders, 28% deemed that it was moderately relevant and 11% believed that it was slightly relevant. We do not notice significant differences with round two responses where 58% of participants considered that practicality and ease of use was a very relevant driver to industry stakeholders adopting the Syst-OMICS subtyping method and 32% believed that it was moderately relevant. The most remarkable inter-round differences are that in the second-round 5% of participants considered practicality as slightly relevant and 5% believed it was not at all relevant, while in the third round 11% of participant believed it was slightly relevant and 0% deemed it not relevant at all.

f. Potential financial barriers that may hinder the adoption of the Salmonella Syst-OMICS subtyping method

Among the barriers to the adoption of a new technology, the financial and economic stakes can have a significant impact. Therefore, respondents addressed different resources-related issues
that could negatively influence the adoption of the *Salmonella* Syst-OMICS subtyping method. There was a consensus among third-round respondents with 81% of them agreeing that the cost-benefits ratio of using the subtyping method should be demonstrated. Only 13% of third-round participants believed it was moderately important and 6% considered it to be slightly important. By contrast, 68% of the second-round participants considered demonstrating that the subtyping method is cost-beneficial to be very important, 26% considered it to be moderately important, 6% believed it was slightly important, and 5% felt that it was not important at all.

The cost/benefit ratio of using the Syst-OMICS subtyping method needs to be demonstrated.

Responses from participants were much more mixed regarding the need for support from private industry lab. Indeed, 31% of respondents to the third-round deemed this issue to be very important; 31% perceived it as moderately important; 25% believed it was slightly important; and 13% estimated that it was not at all important. Interestingly, these results do not differ greatly from the second-round results where 26% of participants estimated that support from private laboratories was very important; 31% answered that it was moderately important; 32% considered it to be slightly important; and 11% considered it not to be important at all.

The uptake of this method would require the support of private industry labs.

Results were similarly mixed regarding the need to determine how the costs of implantation of the test will be allocated along the supply-chain. Only 19% of third-round respondents consider this to be very important with the bulk (50%) of respondents considering the allocation of implantation costs to be of moderate importance and 31% estimating that it is slightly important.
Although the majority of responses in both rounds relate to the moderate importance of this issue, there is a reversal of trends in the number of respondents who consider it to be very important, decreasing from 32% to 19% and the number of respondents who think it is slightly important, increasing from 21% to 31% between rounds.

The need to determine how the costs of implantation of the test will be allocated along the supply-chain.

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<th>Importance</th>
<th>Round 2</th>
<th>Round 3</th>
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<tbody>
<tr>
<td>Very important</td>
<td>32%</td>
<td>19%</td>
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<tr>
<td>Moderately important</td>
<td>47%</td>
<td>50%</td>
</tr>
<tr>
<td>Slightly important</td>
<td>21%</td>
<td>31%</td>
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Another issue the majority of respondents felt was moderately important is the potential impact of fresh produce desirability if prices are affected by the integration of the method. Indeed, a clear majority (69%) of third-round respondents deemed this issue to be of moderate importance, while 25% estimated that it was very important and 6% that it was slightly important. These results are somewhat similar to round two results where 58% of respondents believed the issue of produce prices and desirability was moderately important, 21% considered it to be very important, and 11% answered that it was slightly important. The most notable difference between rounds is the change in the number of respondents who answered that it was not at all important going from 11% to 0% between round two and three.

The potential impact on fresh produce desirability, if prices are increased or otherwise affected by the integration of the method, from a consumer perspective.

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<th>Importance</th>
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<tr>
<td>Very important</td>
<td>21%</td>
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<tr>
<td>Moderately important</td>
<td>58%</td>
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\[g. \text{Potential policy barriers that may hinder the adoption of the} \text{Salmonella Syst-OMICS subtyping method}\]

In addition to resource-related issues, several policy barriers could potentially hinder the adoption of the Salmonella Syst-OMICS subtyping method. Among those is the fact that policy
considerations may not be fully aligned across jurisdictions (e.g., provincial, and federal governments). The results of round two and round three are similar with the bulk of respondents – 74% and 75% respectively – agreeing that misalignment of policy considerations across jurisdictions is moderately important. Similarly, 11% of second-round participants and 13% of third-round participants agreed that this issue was very important, while 16% of respondents to round two and 13% of round-three participants considered it to be slightly important.

| Policy considerations in different jurisdictions may not be fully aligned. |
|---------------------------------------------------------------|-------------------|
| Very important                                                | Round 2: 11%       | Round 3: 13%      |
| Moderately important                                          |                   |                   |
| Slightly important                                            | Round 2: 16%       | Round 3: 13%      |
| Not at all important                                           | 0%                | 0%                |

Respondents to the second-round brought up the fact that some regulatory bodies may be reluctant to allow differential treatment based on the subtyping method until there is a public health consensus supporting such a method. 63% of third-round respondents considered that this policy issue was very important, while 31% deemed it to be of moderate importance and 6% only thought it was slightly important.

| Regulatory bodies will be reluctant to allow differential treatment based on the Salmonella Syst-OMICS subtyping method until there is a robust consensus in the public health community supporting this method. |
|---------------------------------------------------------------|-------------|
| Very important                                                | Round 3: 63%|
| Moderately important                                          | 31%         |
| Slightly important                                            | 6%          |
| Not at all important                                           | 0%          |

In relation to the previous concern, respondents in the second round of the survey highlighted the need to clarify whether public health agencies such as the Public Health Agency of Canada would consider the uptake of the Syst-OMICS subtyping method. A majority of 73% third-round participants agreed that this was a very important issue, while 20% considered it to be moderately important and 7% believed it was slightly important. As for the issue mentioned above, no respondents thought it was not important at all.
The need to clarify whether Public health agencies such as the Public Health Agency of Canada would consider the uptake of the Syst-OMICS subtyping method.

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<tr>
<td>Very important</td>
<td>73%</td>
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<td>Moderately important</td>
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<td>7%</td>
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### h. Public acceptance of the *Salmonella* Syst-OMICS subtyping method

If uptake by industry stakeholders and support from public health regulatory bodies is paramount, the public acceptance of the *Salmonella* Syst-OMICS subtyping method also raises a number of questions and concerns. A majority of 75% of third-round respondents considered that the objective risk of ingesting low-virulence *Salmonella* may be too high for some consumers due to their individual susceptibility, and 25% of third-round participants believed it to be moderately important. Interestingly, the relative consensus shown by third-round results differ from the mixed results of the second round. Indeed, in the second-round survey, 37% of respondents considered the risk associated with individual susceptibility to be very important, 32% believed it to be moderately important, 21% believed it to be slightly important and 11% believed it was not important at all.

For some, the objective risk of ingesting low-virulence *Salmonella* may be too high due to their individual susceptibility.

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<tr>
<td>Very important</td>
<td>37%</td>
<td>75%</td>
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<tr>
<td>Moderately important</td>
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Results are slightly more mixed when it comes to concerns about the public acceptance of non-pathogenic *Salmonella* on food. Indeed, 50% of respondents to the third-round and 37% of second round participants considered it to be a very important concern, while 19% of third-round participants and 32% of second-round participants believed it was moderately important, 31% of third-round participants and 26% of second-round respondents estimated that this issue was only slightly important. Finally, the number of participants who considered the public acceptance of
non-pathogenic *Salmonella* on food not to be important at all went from 5% in round two to 0% in the third round.

The general public may not accept the presence of non-pathogenic *Salmonella* on their food.

![Bar chart showing the percentage of respondents who consider the presence of non-pathogenic *Salmonella* to be very important, moderately important, slightly important, or not at all important in rounds 2 and 3.]

There were also concerns about public understanding of the differences between *Salmonella* strains. Responses were also mixed regarding this issue with 44% of third-round respondents and 37% of second round participants considering it to be very important, while 19% of third-round participants and 26% of second-round participants considered it to be of moderate importance. Meanwhile, 38% of third-round participants and 32% of second-round respondents considered this issue to be slightly important. Finally, the number of participants who considered public understanding of the differences between *Salmonella* strains not to be important at all went from 5% in round two to 0% in the third round.

The general public may not understand that not all *Salmonella* strains are the same.

![Bar chart showing the percentage of respondents who consider the understanding of the differences between *Salmonella* strains to be very important, moderately important, slightly important, or not at all important in rounds 2 and 3.]

Finally, the impact of the implementation of the *Salmonella* Syst-OMICS subtyping method on the cost of fresh produce sold to consumers was raised by participants to the second-round survey. This was considered a very important issue by 50% of the third-round respondents, while 31% deemed it to be moderately important and 19% considered it to be only slightly important.
i. International considerations regarding the use of the Salmonella Syst-OMICS subtyping method

Considering the trade in North America and the import and export flows of fresh produce respondents raised several international considerations regarding the use of the Salmonella Syst-OMICS subtyping method. Notably, there was a 94% consensus among third-round survey respondents who consider data sharing harmonization across countries such that international efforts addressing foodborne illnesses risks are more efficient to be very important. This is a dramatic difference with round two, where responses were more mixed with 53% of respondents considering it to be very important; 42% considering it to be moderately important; and 5% considering it to be only slightly important. No respondents considered it not to be unimportant.

There is also a consensus, albeit a lesser one at 81%, among third-round survey respondents who believe it to be very important that expertise, best practices, and lessons learned from other countries should be taken into consideration. The remainder of third-round respondents (19%) consider it to be moderately important. This is in slight contrast with second-round survey responses which were more mixed with 63% of participants considering transnational knowledge sharing to be very important; 32% considering it to be moderately important; and 5% considering it to be only slightly important. However, no respondents in any round considered it not to be important.
In comparison to the considerations mentioned above the need to assess the impact of the adoption of the Syst-OMICS subtyping method in Canada on international trade and importation/exportation businesses generated more mixed results. Indeed, 47% of round two respondents agreed that it was very important; 21% estimated that it was moderately important; and 32% believed it to be only slightly important. The results are even more mixed when it comes to round three where the number of participants who believe that assessing the impact of the adoption of the subtyping method in on international trade is very important goes from 47% to 38%. Meanwhile, the percentage of those who think it is moderately important goes up from 21% in round two to 38% in round three, while the percentage of participants who believe it to be slightly important goes down from 32% to 25% between round two and round three.

The fact that potential adoption of the subtyping method may raise concerns among Canadian trade partners about the possibility of importing and exporting fresh produce containing non-pathogenic or low-virulence Salmonella was raised by the respondents to Round 2. Opinions of Round 3 respondents about this issue were divided with 38% considering it to be very important, 38% believing it is moderately important, and 25% estimating that this issue is slightly important. Interestingly, despite the divided answers, no Round 3 respondents believed that trade partners’ concerns were unimportant.
The potential adoption of the *Salmonella* Syst-OMICS subtyping method may raise concerns among trade partners about the possibility of importing or exporting food containing non-pathogenic *Salmonella*.

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<th>Importance</th>
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<td>Very important</td>
<td>38%</td>
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### 2.2.3 The *Salmonella* Syst-OMICS biocontrol method

Bacteriophages are viruses that infect and replicate in bacterial cells. As such, these bacteria-killing viruses can reduce or eliminate the pathogenic bacterial load of ready-to-eat foods, including fresh produce. They usually infect only one bacterial species or even specific strains within a species. Since bacteriophages are strain-specific, easy to isolate, and effective, they can be used as biocontrol agents in pre- and post-harvest processes, alone or in combination with antimicrobial agents, to control pathogenic bacteria such as *Salmonella*. *Salmonella enterica* (S. enterica) is at the root of many outbreaks of foodborne illness associated with fresh produce. Current industrial antimicrobial interventions have been shown to reduce microbial populations by <90%. Consequently, Bacteriophages have been suggested as an alternative to chemical sanitizers. We therefore wanted to know the experts’ opinion on the perceived risks and benefits, barriers and facilitators to the adoption of using bacteriophages as a biocontrol method.

#### a. Potential benefits of using bacteriophages as a biocontrol method

Respondents identified several potential benefits that could stem from using bacteriophages as a biocontrol method. Among those benefits, the reduction of food recalls and associated food waste was mentioned. However, the opinions of survey respondents were mixed regarding the importance of this particular benefit. Indeed, 38% of round-three participants considered it to be very important, while 44% deemed it to be moderately important, and 19% estimated that it was slightly important. These mixed results are not significantly different from the responses obtained in the second round, although there is a reversal of trends between the very important and moderately important categories. Indeed, 47% of second round participant considered the reduction of recalls and food waste to be very important, 32% deemed it of moderate importance, 16% estimated that it was slightly important, and 5% consider that it was not at all important.

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17 https://www.ncbi.nlm.nih.gov/books/NBK493185/
Survey responses are a little more decisive with regard to using bacteriophages to help reduce the number of foodborne outbreaks and improve public health outcomes. Indeed, 63% of round three participant considered it to be a very important benefit, while 31% believed it was moderately important, and 6% considered it to be slightly important. These results are slightly different from round two responses where 68% or participants considered the reduction of foodborne outbreaks to be very important. The most significant change between the two rounds is the number of people considering this benefit as moderately important which increase from 16% in round two to 31% in round three. Additionally, we notice a decrease in the percentage of respondents who consider this benefit to be only slightly important going from 16% in the second round to 6% in the third round.

Another potential benefit of using bacteriophages to eliminate *Salmonella* on fresh produce is that they are less likely than other options (e.g., chemical agents) to affect the taste, smell, and appearance of produce. Overall, 56% of third-round participants consider it to be a very important benefit, 25% consider it to be moderately important and 19% consider it to be slightly important. Interestingly, these results are quasi-identical to the second-round results if we account for the weighting associated with inter-round drop-out of participants. Indeed, 53% of these participants consider the advantages of using bacteriophages over chemical agents to be a very important benefit, 26% consider it to be moderately important and 21% consider it to be slightly important.
There is also little change between rounds with regards to bacteriophages being considered a more “natural” method of control than using chemical agents. However, regarding this potential benefit, the bulk of the respondents in round two (53%) and three (50%) agrees that it is moderately important. Few seem to consider it to be very important: 21% of the second-round and 19% of the third-round participants. The number of respondents who consider this benefit to be only slightly important goes from 26% in the second round to 31% in the third round. No respondents consider that this benefit is not at all important.

b. Issues and evidentiary considerations regarding the adoption and implementation of bacteriophages as a biocontrol method

Before reaping the potential benefits of using bacteriophages, many issues and evidentiary considerations must be taken into account regarding the adoption and implementation of this biocontrol method. First, there is a consensus among 88% of third-round survey respondents about the need for more scientific proof of the efficacy of bacteriophages to control Salmonella on a variety of fruits and vegetables being a high priority, and the remaining 13% agreeing that this is a moderate priority. Round two responses were also divided between those who thought it was a high priority (63%) and those who believed it was a moderate priority (37%). Importantly, no respondent at any round indicated that it was a low priority or not a priority.
There is a need for more scientific proofs on the efficacy of bacteriophages as a biocontrol method for *Salmonella* on a variety of fresh fruits and vegetables.

Results were similar regarding the need to assess the ability of bacteriophages to target the range of *Salmonella* strains in that all respondents believe that it is either a high or a moderate priority. However, we notice a slight decrease in the percentage of respondents who consider it to be a high priority between round two (79%) and round three (75%). Concomitantly, there is a slight increase in the number of respondents who deem it to be of moderate priority between the second (21%) and third round (25%).

Interestingly, when asked about the need for more scientific proofs on the lack of adverse effects of bacteriophages on human health, the responses are more mixed. Indeed, 56% of round-three participants consider this to be a high priority, 25% believe it is a moderate priority, and 19% estimate that it is a low priority. There is an upward trend between the second and third round for those who consider it a high priority, from 47% to 56%. The same trend can be observed for those who consider it to be a moderate priority, going from 21% to 25%. On the other hand, there is a downward trend among those who consider this to be a low priority, going from 26% to 19%, as well as among those who consider it not to be a priority at all, going from 5% to 0% between rounds.
A total of 81% participants to the third round considered the need to assess the potential environmental risks of using bacteriophages to be either highly important (56%) or moderately important (25%). Meanwhile, 19% of third-round survey respondents estimate that this is a low priority. Such results differ slightly, but not significantly from round two results where 53% estimated potential environmental risks to be a high priority, 21% deemed it to be a moderate priority and 26% considered it to be a low priority. No participant at any round considered that it was not a priority.

When combining the number of third round respondents who consider it to be a high priority (56%) and those who consider it to be a moderate priority (38%), a total of 94% of third round participants believe that the need to study the possibility that bacteriophages may lead to the emergence of phage-resistant bacterial variants should be considered a priority. Only 6% of third round respondents consider it to be a low priority. Second round results are slightly more mixed with 42% of respondents who deemed it to be a high priority and 42% who estimate that it is a moderate priority. This means that a total of 84% of second round respondents believe that examining the possibility that phage-resistant bacterial variants could emerge, should be considered a priority. However, in the second round 11% of participants deemed it to be a low priority and 5% believed it was not a priority.
The opinion of survey respondents about the need for oversight mechanisms to ensure regulatory compliance are more mixed with 31% of participants considering it to be a high priority, 50% estimate that it is a moderate priority, and 19% believed it to be a low priority. Overall, 81% of third round respondents consider oversight mechanisms to be somewhat of a priority. Furthermore, 37% of the respondents in the second round agree that it is a high priority, 32% believe it is a moderate priority, 32% estimate that it is a low priority. None of the respondents in any of the rounds, however, rated this as not a priority.

The need to evaluate the efficacy of the bacteriophages biocontrol method when applied in the field or along fresh produce supply-chain in addition to laboratory evaluation was raised by respondents to the second round. All respondents to the third round agreed that it was either a high priority (63%) or a moderate priority (38%).
Second round respondents also brought up the need for longitudinal evidence of the environmental risk of the safety of using bacteriophages as a biocontrol method on fresh produce, especially as it applies to possible consequences on the microbial biology. Third round participants responses were somewhat mixed regarding this specific evidentiary consideration with 25% considering it a high priority, 75% deemed it to be a moderate priority and 25% estimating that it is a low priority. However, no respondents believed it was not a priority.

Respondents were asked to rank the five following statements in order of priority: a) demonstrating the ability of bacteriophages to successfully target *Salmonella* on fresh produce; b) confirming the lack of adverse effect on human health related to the consumption of produce treated with bacteriophages; c) requiring the monitoring of the potential emergence of phage-resistant bacterial variants; d) evaluation the potential environmental impact(s) of the use of bacteriophages as a biocontrol method; e) requiring mechanisms to ensure that the use of bacteriophages remains within regulatory compliance.

Reminiscent of the answers obtained for the ranking question on the subtyping method, the order of priority given to the statements only changes slightly between the second and third rounds. The statements about “demonstrating the ability of bacteriophages to target *Salmonella*” and “confirming the lack of adverse effect on human health” are the two statements which ranked higher for both rounds. However, of these two statements, only the first one scored higher than 4.3, with
a near perfect score of 4.88 out of 5 in the third round. Interestingly, implementation of mechanisms to ensure compliance of bacteriophage use with existing regulations received the lowest score in both rounds – a score that goes down to 1.63 in round three.

c. Potential drivers to using bacteriophages as a biocontrol method

In addition to the many issues and evidentiary considerations that must be accounted for, there are also potential drivers that could help the adoption and implementation of bacteriophages as a biocontrol method. Third round participant opinions regarding the growing consumer demand for natural biocontrol options were mixed, with 6% considering it to be very relevant, 56% believing it to be moderately relevant, 31% deemed it to be slightly relevant, and 6% considering it not at all relevant. Second round results were even more mixed with 28% estimating is was very relevant, 33% believing it to be moderately relevant, 33% deeming it slightly relevant, and 6% considering it not at all relevant.

When asked about ongoing ‘farm to fork’ collaborative efforts to reduce the risk of outbreaks and illness, the opinions of respondents were also mixed. In the third round of the survey,
38% answered that it was a very relevant, while 44% responded that it was moderately relevant, and 19% considered it to be slightly relevant. These numbers differ slightly from round two results where 50% of participants considered ‘farm to fork’ collaborative efforts as highly relevant, 12% higher than the round three percentage. Additionally, 39% of round two respondents considered it to be moderately relevant and 11% answered that it was slightly important. These numbers are lower than round three responses by 5% and 8% respectively.

**Ongoing farm to fork collaborative efforts to reduce the risk of outbreaks and illness.**

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<th>Round 2</th>
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<td>Very relevant</td>
<td>38%</td>
<td>50%</td>
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<tr>
<td>Moderately relevant</td>
<td>39%</td>
<td>44%</td>
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**d. Potential drivers that may influence the uptake of bacteriophages as a biocontrol method by industry stakeholders**

As with the subtyping method, uptake by industry stakeholders is a favorable condition for the adoption and implementation of bacteriophages as a prevention strategy for *Salmonella*. A majority (75%) of third round respondents agreed that demonstrating the cost-effectiveness of this approach is a very relevant factor that may influence the uptake of bacteriophages by industry stakeholders. The remaining 25% of third round responses were divided between those of who answered it was moderately relevant (19%) and those who deemed it to be only slightly relevant (6%). We noticed a significant increase in those who consider it to be very relevant between round two (44%) and round three (75%). Concomitantly, the percentage of respondents who selected ‘moderately important’ decreased appreciably between round two (39%) and round three (19%). A similar, but less marked trend was observed for those who responded that it was slightly relevant with a drop from 17% in the second round to 6% in the third round.
Concerns of industry stakeholders about liability could also influence their uptake of bacteriophages as a biocontrol method either by promoting it for those who fear being held responsible for a *Salmonella* outbreak or, on the contrary, by slowing it down for those who are more hesitant about the use of bacteriophages. The bulk of third round survey participants (56%) consider that these concerns are moderately relevant, while 19% consider it to be very relevant and 25% deem it to be slightly relevant. Results were even more mixed for second round respondents with 22% agreeing it is a very relevant consideration, 39% considering it to be moderately relevant, 33% believed it to be slightly relevant, and 6% considered it was not at all relevant.

When it comes to the practicality and ease of using bacteriophages, the majority (94%) of third round respondents considered it to be either a very relevant (56%) or moderately relevant (38%) factor. Only 6% of third round participants considered practicality and ease of use as slightly relevant to the uptake of this biocontrol method by industry stakeholders. Responses to the second round were slightly more mixed, being split between those who deemed practicality and ease of use to be very relevant (39%), those who thought it was moderately relevant (44%), and those who consider it to be slightly relevant (17%).
e. Potential financial barriers that may hinder the adoption of bacteriophages as a biocontrol method

Some resource-related barriers could also hinder the adoption of bacteriophages as a biocontrol method. However, most respondents consider these barriers to be only moderately important. Indeed, when asked about the potential impact on fresh produce desirability to consumers, especially if prices are increased by using bacteriophages, 75% of third round participants consider this barrier to be moderately important. In comparison, 19% of third round respondents answered it was very important to them, while 6% thought it was slightly important. The percentages of respondents who believe and increase in price could be a very important barrier are similar between round two (17%) and round three (19%), while we notice a slight decrease in the number of people who consider it to be moderately important going from 83% in the second round to 75% in the third round. Interestingly, the number of participants who consider this potential barrier to be only slightly important goes up from 0% in the second round to 6% in the third and last round.

When asked about the need to determine how the costs of using bacteriophages will be allocated along the supply-chain, a slight majority (56%) of respondents estimate that this issue is moderately important. This percentage remains unchanged between round two and round three.
The percentage of respondents who answered that the allocation of costs along the supply-chain was very important increased slightly between rounds, going from 11% in the second round to 13% in the third round. Respondents who considered that this is a slightly important consideration goes up from 28% in the second round to 31% in the third round, while the percentage of respondents who consider this unimportant goes down from 6% in round two to 0% in the last round.

f. Selected results regarding potential policy and regulatory barriers that may hinder the adoption of bacteriophages as a biocontrol method

As we have seen throughout this report, the policy and legal dimensions are crucial and may act as either barriers or facilitating factors in the adoption of the Syst-OMICS methods. This is reflected in how round three respondents evaluate the importance of regulatory misalignments across the food industry or between international trade partners on the uptake of bacteriophages as a biocontrol method. Indeed, A total of 81% of respondents estimated that it was either very important (50%) or moderately important (31%). About one-fifth (19%) of respondents considered regulatory misalignments to be only slightly important as a barrier that could prevent the adoption of bacteriophages. It is worth noting that no respondents considered regulatory misalignments not at all important.
g. Selected results about the acceptability of potentially adopting bacteriophages as a biocontrol method from the point of view of the public

Public acceptance can have a significant effect on the potential adoption of novel technologies. We therefore focused on surveying the participants on the different factors associated with public opinion that could hinder or facilitate the potential adoption of bacteriophages as a biocontrol method. One such detrimental factor was the possibility that bacteriophages will impact the quality of the food. A majority (75%) of third-round respondents considered that this was only slightly important, while 19% estimated that it was moderately important, and only 6% answered that it was very important. In comparison, respondents to the round two survey placed slightly more importance on this issue with 17% estimating it was very important, 17% considering it to be moderately important, 61% believing it was slightly important and 6% is not important at all. One notable difference between round two and three is the decrease in respondents who consider possible impact on food quality as very important, going from 17% to 6%. However, the most notable difference is the increase, by 14%, of respondents who think this issue is slightly important going from 61% to 75%.

The possibility that bacteriophages will impact the quality of food.

There is a consensus around the relevance of a transparent risk communication strategy supported by scientific evidence. Such a strategy could facilitate the adoption of bacteriophages as a biocontrol method. In fact, 100% of round three respondents considered it to be either very relevant (75%) or moderately relevant (25%). For round two, 67% estimated that a transparent, evidence-based, communication strategy was very relevant, 28% considered it to be moderately relevant, and 6% believed it was slightly important.
A risk communication strategy is even more important as a low level of scientific knowledge could negatively influence the public perception of bacteriophages and hinder their adoption as a biocontrol method. This potential barrier was considered very important by 69% of the round three respondents, while 19% and 13% believed it was moderately important or slightly important, respectively. The percentage of respondents who consider that a low level of scientific knowledge in the public was a very important issue went from 56% in round two to 69% in round three. Meanwhile, the number of respondents who estimated that it was moderately important decreased, going from 39% in the second round to 19% in round three. Interestingly, the percentage of respondents who considered this issue to be only slightly important went up from 6% in round two to 13% in the third round.

In addition to negative perceptions due to lack of scientific knowledge on the subject, the public may also have health concerns related to eating fresh produce treated with bacteriophages. A slight majority of round two (61%) and round three (63%) respondents considered that this was a very important issue. Interestingly, the percentage of respondents who believe that this issue was moderately important went from 39% in the second round to 25% in the third round, while the percentage of those who thought it was slightly important went from 0% to 13% from round two to round three.
Despite the potential barriers related to public perceptions and knowledge gaps, the majority (69%) of round three respondents felt that a broad engagement process to educate the public about bacteriophages was only moderately relevant, while 13% estimated that it was slightly relevant. Only 19% of round three respondents believed that such an engagement process would be very relevant. Second round responses were more balanced with 39% of respondents considering it to be very relevant, 44% believing it to be moderately relevant, 11% estimating that it was slightly relevant, and 6% considering it not relevant at all. The most notable difference between round two and round three is the shift in the number of people who consider a broad public engagement process to be a moderately relevant approach going from 44% in the second round up to 69% in the third round. Another notable difference is the shift in the number of people who felt it was a very relevant strategy going down from 39% to 19%.

Opinions were also divided about the statement “the public should be informed of the potential benefits and risks of using bacteriophages on fresh produce” with 38% of round three respondents considering it to be very relevant and 63% estimating that it was moderately relevant. Although there is no consensus and a small majority (63%) consider it to be moderately relevant, it is interesting to note that none of the round three participants responded that informing the public about the potential risks and benefits of using bacteriophages was either slightly relevant or not at all relevant. In comparison round two responses were distributed between those who thought it was very relevant (39%), those who thought it was moderately relevant (50%) and those who thought
it was only slightly relevant (11%). The most significant inter-round difference is between those who believed informing the public about potential risks and benefits of bacteriophages was moderately relevant going from 50% in round two to 63% in round three. It is also noteworthy that those who answered that it was slightly relevant went from 11% in round two to 0% in round three.

When asked about what type of stakeholders should be involved in the implementation of subtyping and biocontrol methods, the categories that have received a strong consensus at above 80% are as follow: producers (94%), scientists (88%), regulators (88%), and public health experts/epidemiologists (81%). Additionally, the two following categories of stakeholders that were agreed upon by 75% of the respondents were farmers and decision-makers. Involvement of food processors was agreed upon by about half (56%) of the respondents, while only 38% of respondents thought consumers from the public should be involved, 19% thought retailers should be involved and only 6% saw relevance in involving the pharmaceutical industry. It is noteworthy that 0% of the experts surveyed thought relevant to involve civil society organizations.

2.2.4 Need and readiness to shift to Syst-OMICS methods

All the graphs presented above correspond to statements made by the respondents of the Delphi survey, which sought to collect qualitative data through open-ended questions. However,
four statements to be evaluated on a Likert scale were included in the first round, mostly qualitative, survey. All four statements aimed at assessing expert survey participants perception of the need and readiness to shift from current approaches to the risk assessment and management of *Salmonella* to Syst-OMICS methods.

A majority of respondent agree that there is a need to shift current risk assessment and management of *Salmonella* on food towards an approach integrating the level of virulence of the serotype (i.e., the Syst-OMICS subtyping method). Although there are small variations between the percentage of respondents who answered “agree” in the first round (72%), the second round (67%), and the third round (69%), the overall trend does not change significantly between rounds. It is interesting and important to note that only a few respondents strongly agreed that there is a need to shift to *Salmonella* management approaches integrating subtyping methods. Indeed, the percentage of those who chose “strongly agree” went from 8% in the first round to 17% in the second round, and then went down to 6% in the third round. Also noteworthy is the increase of respondents who answered “neither agree nor disagree” between the first (16%), second (11%) and third (25%) round. There is only a small proportion of experts who disagree that there is a need to integrate subtyping methods into risk assessment and management of *Salmonella* with 4% of first-round and 6% of second round survey participant indicating that they disagree with the statement. Finally, no participant at any round strongly disagreed with the statement.

![Graph showing the percentage of respondents agreeing with the statement across three rounds.](image)

There is a need to shift current risk assessment and management of *Salmonella* on foods towards an approach integrating the level of virulence of the serotype.

However, there is a difference between needing a change and being ready for it and the following results demonstrate this. Indeed, 63% of round three respondents disagreed with the statement “we are ready to shift current risk assessment and management of *Salmonella* towards an approach integrating the level of virulence of each serotype”. Very few respondents strongly agreed with this statement on the readiness to shift towards an approach that would integrate subtyping methods. Indeed, this answer choice was not selected by any of either the round one (0%) or three (0%) respondents, while only 6% of round two respondents selected it. And, while 29% of the first round respondents agreed that we are ready to shift the current risk assessment and management of *Salmonella* towards an approach that would rely on subtyping, this percentage is of 11% in the second round, and only 6% in the third and final round. Most of the responses are divided between the “neither agree nor disagree” and “disagree” categories. Indeed, 29% of first-round respondents, 33% of second round respondents, and 25% of third round respondents indicated that they neither agreed nor disagreed with the statement on the readiness to shift towards an approach that would integrate subtyping methods. Meanwhile, the percentage of those who disagree with this statement is increasing from one round to the next with 29% in round one, 39% in round two, and up to 63% in round three. Finally, the category “strongly disagree” gathered 13%
of responses in round one, 11% in round two, and 6% in round three, slightly decreasing as the rounds progresses.

We are ready to shift current risk assessment and management of *Salmonella* towards an approach integrating the level of virulence of each serotype.

![Graph showing responses](image)

Even if a majority of respondents agreed that there is a need to shift towards an approach integrating the level of virulence of the serotype, respondents are rather neutral with regards to the need to shift to using bacteriophages as a biocontrol method to reduce the presence of *Salmonella* on fresh produce. Indeed, in each round the majority of the respondents answered that they neither agreed nor disagreed. In addition, the percentage of respondents selecting this answer choice increases consistently from one round to the next with 44% respondents in round one, 56% in round two, up to 63% in round three. The remainder of the respondents were split between those who answered “agree” and those who answered “disagree”, with virtually no responses for the “strongly agree” and “strongly disagree” categories. Interestingly, the percentage of respondents who answered that they agreed that there is a need to shift to using bacteriophages as a biocontrol method decreased steadily between rounds going from 40% in round one, to 28% in round two, to 19% in round three. Meanwhile, the percentage of respondents who disagree went from 16% in the first-round, to 11% in the second round, and up to 19% in the third round. No respondents answered that they strongly disagreed at any of the three rounds.

There is a need to shift current risk management approaches to use bacteriophages as a biocontrol method to reduce the presence of *Salmonella* on fresh produce.

![Graph showing responses](image)

Not surprisingly, given the above, the bulk of responses concerning the statement “we are ready to shift our current risk management approach towards the use of bacteriophages…” tend
towards measures of disagreement. Indeed, about half of the responses are consistently in the “disagree” category, with 50% of round one respondents, 50% of round two respondents, and 56% of round three respondents giving this answer. A proportion of respondents strongly disagreed with the statement in each round of the survey with 19% choosing this answer at round one, 11% and 13% choosing this answer at round two and three respectively. A non-negligible proportion of respondents were rather indifferent to the statement. Indeed, 19% of first-round respondents neither agreed nor disagreed with the readiness to shift current risk management approach towards the use of bacteriophages, this percentage increase to 28% in the second round, and 31% in the third and last round. Few people strongly agreed or agreed with the statement, and it should be noted that none of the respondents in the third round selected these answer choices.

![Graph showing the percentage of responses across rounds](image)

2.3 Workshop discussion around Delphi survey results

Several questions were raised surrounding the cost of the technology. These included questions about whether private labs would have access to the testing method; this was of particular importance, as some private companies conduct their own testing and may want to align their testing to that available to the government. Even though the testing method will be used as a confirmatory test conducted by the governmental agencies and not the industry, access to the methodology and data is presently sought by industry partners. Other questions around costs included the note that affordable cost may be a driver for uptake, and that cost analyses will need to account for small producers and how they will adapt to the technology. While the production of phages is expensive and the cost is currently high on the market due to the lack of competition, investment in research and development is anticipated to lower the costs in the future. Notably, whole genome sequencing in general is becoming more affordable, and bacteriophages may be used in combination with other methods. Drivers for subtyping and whole genome sequencing will be the cost of the tests and availability of these tests in private laboratories. The main barrier in the use of bacteriophages will be their debated efficacy.

Several scientific and technical questions were raised by the Delphi results. Participants noted that adoption of bacteriophage may require a new way of approaching decontamination: not seeing phages as an additional add-on but framing the decontamination process around the phage

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20 Pascal, Scott, Larry

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approach. Others remarked that sampling may have a significant impact on results and should be accounted for: where and how sampling is done can have an impact on contamination being detected. Even if the detection method is used as a confirmatory test, sampling remains key in detecting contamination at the first place, before seeking a confirmation. In addition to sampling, determining the source of the contamination is crucial. The cucumber outbreaks\textsuperscript{22} have underlined the challenges in determining where sampling should be conducted, the difficulty in microbial source tracking and identifying the source of contamination. Detection procedures may need to be updated and improved to address this. One participant noted that the analytical unit sizes are getting smaller, and the number of samples taken is small, both of which affect the validity of results.

Participants also noted that practicality and ease of use of methods are important for industry. It was also mentioned that phages enable a log reduction. However, a drawback of the phage approach is that application occurs after contamination, while the key is to prevent contamination in the first place. It is also difficult to know what to sample (e.g., soil, water, etc.) when there is an outbreak; where along the chain should the sampling happen?

3. Stakeholder Interviews

To facilitate the success of putting Syst-OMICS methods into practice, early engagement of stakeholders is necessary. To this end, we designed a qualitative study aimed at assessing stakeholders’ perceptions toward the Syst-OMICS subtyping and biocontrol approaches through qualitative interviews with relevant stakeholders. The main objective of this sub-study was an in-depth exploration of the perspectives of representatives from consumer associations and groups interested in health and food safety; environmental agri-food practices (e.g., organic farming); and the Canadian agri-food industry across Canada on the Syst-OMICS subtyping and biocontrol approaches. Our goal was to obtain a representative sample of key players, both at the provincial and national levels. Interviews were targeted more towards civil society organizations, NGOs and industry members since experts and government officials were already involved in other empirical sub-studies, i.e., the Delphi survey. A deeper understanding of the perspectives of these key players may facilitate the translation of Syst-OMICS subtyping and biocontrol research into practice. This is especially important, as Syst-OMICS subtyping and biocontrol approaches for Salmonella could potentially have both social and economic benefits for Canadians.

3.1 Methodology

Between February and June 2019, we conducted qualitative interviews with 19 representatives from consumer associations and groups interested in food safety, organic farming as well as representatives from the Canadian agri-food industry. As much as possible we sought to have a fair representation at the federal level as well as the different Canadian provinces. To ensure high-quality data, we purposely sampled interviewees with diverse characteristics such as subject knowledge and representativeness\textsuperscript{23}. Because of these differences, we asked targeted questions to each subgroup in addition to the major cross-cutting questions which we asked to all stakeholders on the following topics: a) their organization and its mission, and their specific roles in it; b) their experience, issues, and concerns with Salmonella outbreaks; c) their attitudes and expectations for


\textsuperscript{23} https://journals.sagepub.com/doi/abs/10.1177/1049732315588501
the development of subtyping methods; d) their attitudes and expectations for the development of biocontrol methods.

Potential participants were identified from publicly available information on the Internet. An invitation email was then sent to potential respondents. Those who responded positively to the invitation then received a copy of the Information and Consent Form. Interviews were conducted in-person and by telephone or Skype (audio only) when distance or other practical considerations did not allow a face-to-face interview. Recruitment and interviews continued until saturation of data was obtained. The content of the interviews was audio recorded and outsourced to a professional transcription service for speech-to-text conversion with the consent of the interviewees. Content from the discussions was then extracted from transcripts and analyzed using NVivo software. We performed a thematic analysis using an iterative process.

First, a coding tree was developed based on our knowledge of the subject and the questions asked in the interviews. The qualitative data set was coded using the themes and subthemes identified in this coding tree. The coding tree was then revised and refined as the coding progressed and the coders debated the categories. Some themes "emerged" from the data and were added to the original categories. Other themes and sub-themes were replaced, merged, or, conversely, subdivided into sub-themes. This qualitative analysis process was underway at the time the stakeholder workshop took place. Thus, this report reflects mainly the preliminary results that were presented at the workshop. However, additional citations and a slightly more in-depth analysis are presented.

3.2 Summary of Results

3.2.1 Socio-demographics information

A total of 19 relevant stakeholders were interviewed before we reached saturation – the point at which the responses of new participants do not add new information to what has already been obtained. This is consistent with the literature stating that saturation can be reached with a sample of 20-25 participants. We achieved a balanced representation of sectors with 48% of respondents from the agri-food industry and 52% of respondents from either organic farming (26%)

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or organizations dedicated to health or consumer protection (26%). Gender balance was also represented with 47% of male and 53% of female interviewees.

Stakeholders across Canada agreed to be interviewed, making our sample pan-Canadian with 3 respondents in British Columbia, 3 in the Prairies, 3 in Quebec, and 10 in Ontario. Ontario over-representation can be explained partly because we interviewed some representatives of national organizations based in Ottawa. Although we solicited individuals in the Maritime provinces, none agreed to our request for an interview. Interviewees discussed the factors they believe contribute to Salmonella outbreaks.

3.2.1 Summary of the thematic analysis results

a. Causes of Salmonella outbreaks

The actual and perceived causes of Salmonella outbreaks was one of the general themes identified. Interviewees mentioned a variety of causes ranging from improper preparation of chicken products by consumers to possible contamination of irrigation water to deficiencies in food handling and processing. Subpar hygiene measures and the presence of vermin and birds were also pointed out as contributing factors at the farm level. Although responses were varied, most respondents agreed that contamination can occur at any stage of the supply chain and finding the source can be challenging as illustrated by the following excerpts:

“Salmonella starts at the farm. It is enhanced through supply chains with poor handling or poor temperature management and transportation methods.” – Industry 9

Interestingly, many did not perceive the risk of contamination on fresh fruits and vegetables to be a primary concern.

b. Current regulations and prevention practices
Most of the interviewees seemed satisfied with the current practices for preventing Salmonella outbreaks. Traceability was cited, but physical prevention, especially on the farm site, was emphasized, as this industry representative testified.

“Traceability. otherwise, prevention on the farm and physical prevention in general to prevent contamination” - Industry 6

Some mentioned the need for more testing or washing of fresh produce and the need to address the human factor through education and training. Nonetheless, the implementation of Good Agricultural Practices (GAPs) seemed to elicit the most trust from stakeholders, as summarized in the following quote from an organic farming representative.

“If we know that people follow a GAP program, they shouldn’t have contamination problems” - Organic farming 2

The implementation of the Safe Food for Canadian Act and its Regulations has been mentioned by many as a good practice to the extent that it is enforced. In this regard, the human factor was pointed out by interviewees as one of the main weaknesses of current regulatory practices.

“You can introduce all the laws and regulations you want, but if the person handling it does not follow that, regulations mean nothing.” - Organic 1

Indeed, some of them stressed the importance of enforcing existing regulations. The other weak point, mentioned by many of the interviewees, in both the agri-food industry and organic sector, was the importance of border control and inspection.

“Because I know even with the Safe Food for Canadians Regulation, [we are] also offloading a lot of different controls for the produce sector in the US” – Organic farming

"There are a lot of things we should be checking on the way into the country that we're not doing."
- Industry 3

c. Stakeholders’ engagement

Several food industry representatives stressed the importance for decision-makers to consult stakeholders when developing regulatory frameworks. Consultation is generally appreciated and can be understood as a factor in facilitating the adoption of new practices or, on the contrary, the absence of consultation, could be a barrier to implementation.

“We’ve seen it a number of times where a regulation has been set but it’s almost like no consultation has been made with the users.” - Industry 5

The government’s consultation work around the development of the Safe Food for Canadians Act and its regulations was commended by one industry representative as an example of good consultation practices.

“I'll go back to the Safe Food for Canadians Regulations again: the government did an excellent job in consulting with industry.” – Industry 8
Opinions differ somewhat, however, as to which types of stakeholders should be involved, with some mentioning government, industry, producers, experts, academics and scientists, or organic producers, while opinions are more divided as to the role of consumers and the organizations that represent them. For all the interviewees, however, stakeholder consultation is vital and nowadays decision making can no longer be confined to government experts, as the following excerpt illustrates:

“The people that regulate this should be people that live and breathe this, that actually work with it day in and day out. Not government experts” - Organic 1

d. Drivers supporting the implementation of Syst-OMICS approaches

In terms of factors that would support the implementation of Syst-OMICS approaches, interviewees mentioned several factors that can be grouped under the broad themes of more accountability and an increased knowledge. For some, the proposed Syst-OMICS approaches would allow better traceability and higher accountability, in a context where there is a perceived moral obligation to ensure the safety of food products.

“For because we are for safety culture, anything that helps us ensure that our product is safe, then we would be up for it.” – Industry 10

For others, Syst-OMICS approaches are seen as fostering innovation, which would generate new information in support of best practices. This could, in turn, help compensate for the lack of education of both workers and consumers regarding best handling practices to ensure food safety. Thus, Syst-OMICS approaches are perceived as an additional layer of protection against the consequences of outbreaks such as economic losses due to recalls and food safety issues, but also against lawsuits and reputation loss or damage for the companies in the supply chain.

e. Barriers to the adoption of the Syst-OMICS approaches into practice

Over the course of the interviews, interviewees identified several elements that should be taken into consideration prior to the adoption of the Syst-OMICS approaches into practice. These concerns included, but were not limited to, the following themes: 1) real or perceived additional burden on the agri-food industry; 2) scientific concerns about validity, reliability, and potential unintended effects. These concerns applied to both subtyping and the use of bacteriophages to eliminate Salmonella strains, but they were framed slightly differently for each approach, with more concerns about the scientific validity of the subtyping method and more concerns about possible unintended effects of bacteriophage use.

“We would need more information, more data to be able to understand how the technology works and how it’s going to be applied within the industry, which commodities it’s applicable for, how widely available it is, and what are the costs involved, before we’d be supportive.” - Industry 2

The predominant concerns were generally related to elements being perceived, rightly or wrongly, as additional burdens for the agri-food industry. Thus, the issue of any additional costs that could be associated with the use of either one of the Syst-OMICS methods (i.e., subtyping and bacteriophages) was the primary concern. Closely associated with the question of cost, some respondents expressed concern about competition and inequities that could emerge between larger and smaller producers. In addition to the potential financial burden, respondents were concerned about any additional demands put on their business, from administrative and regulatory
incumbrances to additional responsibilities in training employees. All these concerns could act as barriers to the eventual adoption of Syst-OMICS methods.

Some interviewees also mentioned that aspects related to subtyping tests could be additional burdens. The ease of use of the subtyping method, the conditions of conservation and handling of the samples, the need for easy access to a laboratory, issues associated with incidental findings, and questions about how the data would be used were raised by the interviewees. Ease of use was also mentioned by interviewees as a potential barrier hindering the adoption of bacteriophages into practice. All those concerns would need to be addressed to facilitate adoption of the Syst-OMICS methods by industry stakeholders.

“I think what will come into play is what are the implications of the method? How difficult is it to employ the method?” - Consumer Association 1

Interviewees also raised several scientific concerns about the subtyping method. Many interviewees were concerned about the scientific validity, accuracy, and effectiveness of this little-known method, which was still under development at the time of the interviews. In addition, some interviewees were concerned about the health effects on consumers. Other interviewees questioned the ability of this method to consider possible bacterial changes. Similar concerns were raised regarding the scientific validity of bacteriophages as a means to eliminate Salmonella on fresh produce. Some interviewees raised questions about the accuracy and efficacy of this method. Other interviewees were concerned about possible unintended consequences, including possible changes in the bacterial strains and the possibility that they might become somehow resistant to the bacteriophages.

“It’s the long-term effects that we don’t understand, and we don’t know.” - Organic 1

In addition, with respect to the use of bacteriophages, interviewees mentioned several concerns regarding potential impacts on the environment. Indeed, some interviewees stated that they were concerned about the potential effects of bacteriophages on biodiversity, particularly if their use is not done in a controlled environment. While some interviewees viewed bacteriophages as an environmentally friendly approach, others expressed concern about the lack of knowledge, real or perceived, about the long-term effects of using such a method.

f. Syst-OMICS approaches along the supply chain

When asked about the best moment, along the supply chain, when Syst-OMICS methods should be used, the interviewees provided quite diverse responses. While for some it seemed preferable to use Syst-OMICS methods downstream (e.g., at the farm), for others it made more sense to use Syst-OMICS methods upstream (e.g., retail) since fresh produce runs the risk of being re-contaminated during transport and handling. For other interviewees the safest approach would be to use Syst-OMICS methods at different stages along the supply chain. Finally, some interviewees mentioned that, in their opinion, Salmonella detection and prevention efforts should focus on imports with the use of the Syst-OMICS methods at the borders.

“If we've got the knife, a surgical knife, to remove the pathogen, I think it needs to be as close to final consumption as we can get it.” – Industry 7

However, there are some differences between the two methods. The interviewees favor the use of the Syst-OMICS subtyping detection method either at the time of production or in real time along the supply chain. Regarding the use of bacteriophages to treat fresh produce against some
strains of *Salmonella* bacteria, the interviewees mentioned the stages of production, processing, distribution, retail and some even envisioned their use by consumers.

g. Considerations about communication to the public/consumers

Interviewees were also asked for their opinions regarding the potential consumer perception of Syst-OMICS methods and the communication strategies that they would recommend, if any. Several interviewees mentioned that the limitations in the public understanding of science and agri-food could have a negative impact on the adoption of Syst-OMICS methods. Interviewees gave as examples, the debates surrounding GMOs, the limited understanding of food irradiation, the perception that once a product is contaminated it is necessarily unfit for consumption, and the sometime inaccurate perceptions of what is natural and what is not (e.g., bacteriophages).

“Part of the problem is that people who don’t understand how farming works, don’t understand how food manufacturing works, and then don’t understand how those technologies are utilized and the reason why they’re utilized. They just don’t understand.” - Organic 2

With respect to consumer acceptance of the new Syst-OMICS methods, interviewees emphasized the diversity of consumer behaviors and values as well as the fact that our social relationship to food is in constant evolution. Ultimately, according to the interviewees, what will make a difference in consumer acceptance of Syst-OMICS methods is the degree of trust the public puts in governments and how the approaches are communicated. In this regard, we asked interviewees about the appropriateness (or not) of labeling products that have been treated with the Syst-OMICS methods, namely bacteriophages. The opinions on this subject were divided. While for some, labeling is a moral duty, or even a marketing argument, for others, labeling is perceived as unnecessary and could even lead to consumer pushback.

“Our organization supports transparency and accurate labelling. [...] As long as there was enough information provided to the public to be able to understand what the technology is and how it works and what the benefits are. - Industry 2

“I think the less that they know sometimes the better, especially when they don’t understand how a lot of it works.” – Organic 2

3.3 Workshop discussion around in-depth interviews results

Discussion on the results of the stakeholder’s interviews fell into two large categories: concerns around communication, and concerns around science. Regarding communication, trust appears to be one of the primary issues that needs to be addressed. As the stakeholders emphasized, there is often a disconnect between the industry and the government, which may relate to a need for more appropriate exchange and communication of information. Labeling of fresh produce treated with bacteriophages could be a selling point, but a potential opt-out option may also be needed. One participant noted that the lack of knowledge/awareness about the source of contamination could be a driver for addressing the sources of the problem and using bacteriophages to correct it. Communication would need to balance explaining the risks and the benefits; it was remarked that some lessons might be taken from past experiences in communicating about GMOs. Finally, communication strategies would need to consider the current informational context, whereby people have access to alternative sources of information and use different media than the traditional ones to access and share food safety or health information.
Regarding scientific concerns emerging from the national stakeholders’ interviews, there was a note that incidental findings will need to be addressed. There have been cases where the detection of a *Salmonella* isolates usually associated with chicken (*Salmonella Typhimurium*), are also linked to ground beef, pork and other poultry products\(^2^5\), which can prejudicially impact associated products e.g.: Kosher foods. Such unanticipated offshoots of communication strategies will need to be considered.

4. National Survey

4.1 Methodology

The Delphi survey allowed us to take the pulse of experts in the field and the semi-structured interviews allowed us to better understand the concerns of organizations involved with food safety and consumer protection, the organic farming community, and the actors along the supply-chain of the agri-food industry. It is also important to explore the perceptions of Canadian consumers. Exploring the perspective of consumers across Canada on the Syst-OMICS subtyping and biocontrol approaches makes it possible to anticipate possible bottlenecks concerning, for example, the public understanding or the social acceptability of the new methods under development. This in turn, allows for a better integration of stakeholders’ attitudes and concerns towards food safety in future policies, programs and applications.

Our primary objective was to determine if the presence of scientific information had a significant influence on the willingness to eat OMICS-treated fresh produce. In addition, we wanted to explore what other variables could influence the formation of opinion regarding the willingness to eat, from socio-demographics to people’s personal values and people’s trust in legislators.

To this end, we used a split-sample of 1000 participant representatives from the general Canadian population, randomly selected from the Ipsos eNation Canada Omnibus online panel of over 200,000 members. Data was be weighted by Ipsos to ensure the sample’s age and gender composition reflects that of the actual adult Canadian population, according to census data. Roughly 20-25% of Ipsos online panel respondents come from Quebec, and among those about 80% are francophone. Immigrant and minority groups were slightly under-represented in the sample, as is the case for most opt-in research, including online panels. The margin of error on a sample size of 1,000 adult Canadians is ±3.1%, 19 times out of 20, of what they would have been had the entire population been polled, which exceeds current practices for opinion polls, where a margin of error of ±5% is usually considered good practice.

The survey consisted of sociodemographic questions, followed by nine questions concerning the participant’s opinion on omics innovations. The questions related to the following themes: (Q1) trust in science; (Q2) trust in the agri-food industry; (Q3) trust in legislators; (Q4) prioritization of economic, environmental, or social values, (Q5-Q6) willingness to eat fresh produce treated with Syst-OMICS methods; (Q7) opinion regarding health applications of the subtyping method; (Q8) information needs; and (Q9) feelings about the potential of genomics to improve *Salmonella* detection and control. The two questions aimed at assessing the willingness of respondents to consume produce treated with Syst-OMICS methods were as follows: (Q5) “If a genomic (genetic) method could identify the subtypes of *Salmonella* that does not present a risk to

human health, how likely would you be to eat fresh produce that carries such subtype of *Salmonella*?" and (Q6) "If a process using bacteriophages (bacteria-eating viruses) was successful in eliminating *Salmonella* on fresh produce, how likely would you be to eat fresh produce treated with bacteriophages (bacteria-eating viruses)?"

The second half of the sample received additional scientific information about the Syst-OMICS subtyping method and bacteriophages in layperson’s terms preceding the questions about willingness to eat food treated with these Syst-OMICS approaches. The objective of this methodological choice was to better understand the effect (or lack thereof) that preliminary scientific information may have on the formation of consumers’ opinions.

Data output was analyzed quantitatively, first by producing basic descriptive statistics and then by performing regression analyzes. We analyzed the correlation between independent variables such as “level of trust in science” (Q1), “level of trust in agri-food business leaders” (Q2), “level of trust in legislators and policy-makers” (Q3), and “relative importance of economic, environmental and social values” (Q4) on responses regarding the willingness to eat produce treated with Syst-OMICS approaches. Willingness to eat was operationalized into two different questions (Q5 and Q6) in the survey.

### 4.2 Summary of Results from the national survey

This section presents a summary of the survey results. It will be divided into three parts. The first part will address the socio-demographic characteristics of the panel of respondents. The second part will present descriptive statistic results highlighting major trends in the responses of survey participants. A third section presents selected results from logistic regression performed on the survey data. This last section aims to explain the relationship between a dependent binary variable – here the willingness to eat (or not) food carrying a low-virulence *Salmonella* sub-type and the food treated with bacteriophages –, and several independent variables, namely, gender; education; assigned group (i.e., provision of additional information); trust in legislators; and personal values.

#### 4.2.1 Socio-demographics information

Our panel participants were evenly split between 47% men and 53% women in proportions representative of what can be found in the general population. The representation of the different Canadian provinces was also somewhat proportional with 14% of respondents from British Columbia, 11% from Alberta, 6% from Saskatchewan and Manitoba combined, 38% from Ontario, 24% from Quebec and 7% from the Atlantic. The age distribution was fairly balanced with 27% of respondents being 18-34 years of age, 34% being 35-54 years of age, 21% being 55-64 years of age, and 18% being 65 years of age or older. However, the level of education of the participants was higher than that of the general population, which is not unusual for opt-in online panels. More specifically, 43% of respondents had a post-secondary education, 32% were university graduates, 19% had a high school diploma, and 6% had not completed high school. Regarding marital status, 30% of respondents were single, 13% were living with a partner, 43% were married, 4% were widowed, and 10% were divorced. Most respondents were employed full-time 40% or retired 24%, while 11% of respondents worked part-time, 6% were self-employed, 4% were unemployed, but looking, 5% were not employed and not looking, some because of illness or disability, 5% were full-time homemakers, 4% were students, and 2% preferred not to answer. Regarding their household income, 18% of respondents had an income of 25k or less, 27% had an income of 25k-55k, 31% had an income of 55k-100k, 9% had an income of 100k-150k, and 4% had an income of
150k or more, which reflect the general trends of the population at large. When asked "How much of your household's grocery shopping do you, yourself, do?", 52% responded "all of it", 20% responded "almost all of it", 19% responded "about half of it", only 7% responded "less than half of it" and 2% responded "none of it".

4.2.2 Descriptive results

In this section, we present the descriptive results for the responses given by the two groups of respondents combined. In doing so we describe the basic features and general trends of the survey data, providing simple summaries and graphic representations. These descriptive results allow us to identify the main trends that emerge from the survey participants’ responses with respect to their opinion on science; their level of trust in the business leaders of the agri-food industry and its decision-makers and regulators. We also see how respondents’ personal values are distributed with respect to the agri-food industry’s responsibilities for food safety, protecting the environment, reducing food waste, and generating profits. The results also show the main trends in the willingness to eat fresh products carrying a low-virulence strain of Salmonella as well as fresh products treated with bacteriophages. It also describes the perceptions of survey respondents regarding health care and public health applications of the sub-typing method. Respondents’ needs in terms of information and public communication as well as their general opinion about the potential of genomics to improve the detection and prevention of Salmonella in fresh produce are also discussed in this section.

The question of public trust in science is a major issue for genetics and genomics, not least because of the prominence and widespread use of these methods in the fields of public health and agri-food26. So, the first question we asked our survey respondents was aimed to gauge their perceptions about science in general. We asked them to choose between the statement “scientific and technical innovations enable society to progress continuously” and the statement “scientific and technical innovations create more problems than they solve”. Even if the statement measuring mistrust of science was deliberately mild, a majority (80%) of respondents selected the statement reflecting trust in the science, while only 16% of respondents selected the statement showing a level of mistrust. This shows that survey respondents, and by extrapolation the Canadian population, generally have a favourable opinion of science.

Question 1 : Select the sentence that most accurately describes your opinion about science.

| Scientific and technical innovations enable society to progress continuously | 80% |
| Scientific and technical innovations create more problems than they solve | 16% |

26 https://www.karger.com/Article/Abstract/92659
Consumer trust (or lack thereof) in the conventional food sector has become a major concern in the food policy debate in recent years\textsuperscript{27,28}. Over the past few decades, several studies\textsuperscript{29,30,31} have examined public perceptions of the use of biotechnology in the food sector. The debates associated with the GMO at the turn of the decade 2000 also come to mind\textsuperscript{32-34}. Although the proposed Syst-OMICS approaches do not involve genetically modifying foods, we wanted to measure the public’s trust in the ability and willingness of the food industry to manage the potential risks of the biotechnology processes that they use. Opinions were divided, but a small majority of respondents (57%) either agreed (45%) or strongly agreed (12%) with the statement “I trust business leaders within the food industry to minimize potential risks of the biotechnology processes that they use”. In contrast, 43% of respondents appear to be more distrustful with 35% disagreeing with the statement. It is noteworthy that only 8% of survey respondents strongly disagreed with the statement.

![Image of a bar chart showing the distribution of responses to the statement: 12% strongly agree, 45% agree, 35% disagree, and 8% strongly disagree.]

Question 2: I trust business leaders within the food industry to minimize potential risks of the biotechnology processes that they use.

Trust in legislators and policymakers is another important element regarding the issue of consumer trust in food safety. For this reason, we designed a question aimed to assess, in a broad sense, the public trust in legislators and policymakers to regulate the use of biotechnology in the food sector. Interestingly, the trends were very similar to the results obtained for the question assessing trust in agri-food business leaders with a small majority (56%) of respondents agreeing (47%) or agreeing strongly (9%) with the statement “I trust legislators and policy makers to adequately regulate biotechnology processes in the agri-food sector”. In comparison, 45% of respondents appear to be more distrustful with 35% disagreeing and 10% disagreeing strongly with the statement.

\textsuperscript{27} https://www.sciencedirect.com/science/article/pii/S0306919214001961
\textsuperscript{28} https://link.springer.com/article/10.1007/s41055-017-0021-5
\textsuperscript{29} https://ageconsearch.umn.edu/record/27944/
\textsuperscript{30} https://www.mdpi.com/2071-1050/7/6/7512
\textsuperscript{31} https://www.annualreviews.org/doi/abs/10.1146/annurev-resource-100913-012630
\textsuperscript{32} https://ageconsearch.umn.edu/record/18174/
\textsuperscript{33} https://www.sciencedirect.com/science/article/abs/pii/S1053535708000577
\textsuperscript{34} https://www.sciencedirect.com/science/article/abs/pii/S0959652617302469
Positing that some personal values and preferences may influence consumers perceptions of the Syst-OMICS methods, we designed a question to measure the relative importance of these values. We asked respondents to rank by order of importance four priorities for the agri-food industry, namely: increasing food safety; using environmentally friendly methods; reducing the waste of fresh produce; and reducing its financial loss. Each of these priorities were associated with a consumer value or concern: health and safety promotion; environmental protection; food waste reduction; and economic expansion. The table below shows the percentage of respondents who ranked each statement as what should be, in their opinion, the agri-food industry’s number one priority. Particularly relevant to the objective of the Syst-OMICS approaches is the fact that a majority of respondent (59%) identified “the safety of fresh produce for consumption and public health” as the number one priority for the agri-food industry. In comparison, 19% of survey respondents chose the use of environmentally friendly methods as the industry’s most important priority in their opinion and 16% selected reducing the waste of fresh produce as what they see as the industry’s top priority. Concerns about economic development were prioritized only by the 7% of respondents who chose the reduction of financial losses as the most important priority they envisioned for the food industry.
The objectives of the next two questions were to identify the willingness of survey respondents to eat fresh produce carrying a low-virulence sub-type of *Salmonella* and their willingness to eat produce treated with bacteriophages. Willingness to consume and willingness to pay have both been used extensively as a measure of consumers attitude and, to some extent, a predictor of consumers behaviors in food studies\textsuperscript{35,36,37}. We chose willingness to consume over willingness to pay because we anticipated a possible reluctance of Canadian consumers towards consumption of fresh produce treated with the Syst-OMICS methods. Before knowing if Canadian consumers would be willing to pay for food processed with Syst-OMICS methods, it was important to first know if they were willing to consume it. Although these methods could, in the long term, present an added value for both consumers and producers, we wanted first and foremost to measure the degree of resistance to consumption of fresh produce treated with Syst-OMICS approaches.

The data confirmed our intuition since a total of 59% of all respondents in both groups were reluctant to consume fresh produce that had been identified as carrying *Salmonella*, even if that specific sub-type did not pose a risk to human health. In fact, 40% of the respondents stated that they would not be likely to eat such produce, while 19% stated that they would not consider eating such produce at all. In comparison, one-third of the survey respondents from both groups (31%) reported that they would be likely to eat fresh produce carrying *Salmonella* if a genomic method could identify that this sub-type of *Salmonella* did not present a risk to human health. A minority of respondents (10%) indicated that they would be very likely to eat produce carrying a low-virulence sub-type of *Salmonella*.

![Bar chart showing responses to Question 5](image)

Question 5: If a genomic (genetic) method could identify the subtypes of *Salmonella* that does not present a risk to human health, how likely would you be to eat fresh produce that carries such subtype of *Salmonella*?

- Very likely: 10%
- Likely: 31%
- Not likely: 40%
- Would not eat: 19%

Interestingly, answers from survey respondent’s willingness to eat food treated with bacteriophages was equally divided between those who indicated that they were inclined to eat such products (50%) and those who were not (51%). More precisely, 12% of respondents stated that they would be very likely to eat fresh produce treated with bacteriophages and 38% indicated that they would be likely to do so, while 37% of respondents reported that they would not be likely to eat such produce. Finally, 14% of respondents stated that they would not eat fresh produce treated with bacteriophages for eliminating *Salmonella*.

\textsuperscript{36} https://www.sciencedirect.com/science/article/abs/pii/S0956713517305364
\textsuperscript{37} https://ageconsearch.umn.edu/record/6876/
The following figures combine respondents from both groups, i.e., group A respondents who received only the questions and group B respondents who were presented with vignettes of additional information on Syst-OMICS methods. The reader should consider the possible effect of the additional information provided to Group B respondents in interpreting the results. However, we can see that opinions are almost equally divided between those who have a positive opinion (46%) of health care and public health applications of a new genomic-based testing method and those who say they have a neutral opinion (48%), but only 6% of respondents answered with a negative opinion. Although response biases (e.g., demand characteristics, social desirability) may have influenced the responses of some respondents and the additional information provided to group B respondents may have influenced the number of positive opinions, these results seem encouraging for the adoption of the Syst-OMICS subtyping method for public health purposes.

The results also show a tendency for respondents to want to be informed if Syst-OMICS methods (e.g., subtyping and bacteriophages) were to be approved for use in Canada. Indeed, only about one in five respondents (19%) said that assuming these methods have been approved, they would not need to be informed further. The percentages of respondents who would like to be
informed if fresh produce treated with the Syst-OMICS methods were made available for consumption were similar for the use of bacteriophages (60%) and for the use of the subtyping method (57%). It is not surprising considering the overall education level of respondents that slightly more than half (53%) indicated an interest in the scientific basis of the Syst-OMICS approaches. Again, the results must be interpreted with caution, considering the possibility of response bias (e.g., demand characteristics) and the fact that the additional information provided to group B respondents may have influenced the opinions of respondents in this group.

Question 8: Should a genomic (genetic) method to detect the subtypes of *Salmonella* and the use of bacteriophages be approved for use in Canada, what would be your information needs?

<table>
<thead>
<tr>
<th>Information Needs</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assuming these methods have been approved, I would not need to be further informed</td>
<td>19%</td>
</tr>
<tr>
<td>I would like to receive more information on the scientific basis of the Syst-OMICS approaches</td>
<td>53%</td>
</tr>
<tr>
<td>I would like to be informed if fresh produce treated with bacteriophages was made available for consumption</td>
<td>60%</td>
</tr>
<tr>
<td>I would like to be informed if fresh produce carrying low-virulence <em>Salmonella</em> was made available for consumption</td>
<td>57%</td>
</tr>
</tbody>
</table>

Like the opinions of respondents on health care and public health applications of a new genomic-based testing method, opinions on the potential of genomics to improve the detection of *Salmonella* and control its presence on fresh produce were almost evenly divided between those who were hopeful (43%) and those who were neutral (41%). However, slightly more respondents (16%) indicated they felt worried about the potential of genomics to improve detection and control of *Salmonella* compared to the 6% who had a negative opinion about the health applications of the subtyping method. Again, these results should be interpreted with caution, but overall, there seem to be a more positive than negative trend in respondents’ views of the Syst-OMICS methods.

Question 9: How do you feel about the potential of genomics (genetics) to improve *Salmonella* detection and control the presence of *Salmonella* on fresh produce?

<table>
<thead>
<tr>
<th>Opinion</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hopeful</td>
<td>43%</td>
</tr>
<tr>
<td>Neutral</td>
<td>41%</td>
</tr>
<tr>
<td>Worried</td>
<td>16%</td>
</tr>
</tbody>
</table>
4.2.3 Logistic regression

A preliminary analysis was conducted to select variables to consider in our main analysis. Considering the categorial nature of our data, we chose to analyze the data using logistic regressions. We considered two dependent variables: (1) willingness to eat fresh produce that carry non-pathogenic Salmonella and (2) willingness to eat fresh produce that was treated with bacteriophage technology. Every independent variable (e.g., sociodemographic variables, trust in legislators, personal values) was tested individually with a binomial logistic regression with both dependent variables. Only the variables that had a significant effect will be presented in this document.

Considering willingness to eat non-pathogenic Salmonella carrying produce, the regression model was a good fit \((p = 0.108)\) and was significant \((p < 0.0005)\). Five independent variables were found to have a significant effect on respondents’ willingness to eat non-pathogenic Salmonella carrying produce: namely, gender \((p < 0.0005)\); education \((p = 0.026)\); assigned group \((p < 0.0005)\); trust in legislators \((p < 0.0005)\), and personal values \((p < 0.0005)\).

Males were more likely \((\text{OR} = 1.81, \text{CI: 1.385 – 2.365})\) to eat produce carrying a non-pathogenic Salmonella strain than females. Having a degree – any degree – seemed to influence positively \((\text{OR} = 1.397, \text{CI: 1.040 – 1.875})\) respondents’ willingness to eat such produce, regardless of their level of education. Respondents belonging to the experimental group that was provided with additional information vignettes were more likely \((\text{OR} = 1.79, \text{CI: 1.37 – 2.339})\) to be willing to eat produce carrying non-pathogenic Salmonella than the control group. This points to the possibility of a framing effect\(^{38}\) where opinions specifically relevant to science and technology may be influenced by how the issue is framed. One of our most interesting results, however, is the fact that respondents that trust legislators were more than twice \((\text{OR} = 2.191, \text{CI: 1.665 – 2.884})\) as likely to eat produce carrying non-pathogenic Salmonella.

As mentioned earlier, personal values were measured using a question that asked the respondent to indicate which of the following four choices they thought should be the top priority for the agri-food industry: (1) reduce its financial losses; (2) reduce the waste of fresh produce; (3) increase the safety of fresh produce for consumption and public health, and (4) uses environmentally friendly methods. Each of the “personal values” variables were compared to the “reduce food waste” category. “Environment” and “food safety” were significant when compared to “reduce food waste” \((p = 0.045 \text{ and } p < 0.0005 \text{ respectively})\). This meant that people who chose “environment” as a first priority would generally be less inclined to eat non-pathogenic Salmonella carrying produce than people who chose “reducing food waste” as a priority. Unsurprisingly, people who chose “food safety” as a first priority were also less likely \((\text{OR} = 0.451, \text{CI: 0.310 – 0.658})\) than people who chose “reducing food waste” to eat non-pathogenic Salmonella carrying food.

Considering willingness to eat bacteriophage treated produce, the regression model was a good fit \((p = 0.688)\) and was significant \((p < 0.0005)\). Five independent variables were found to have a significant effect on respondents’ willingness to eat produce treated with bacteriophages: namely, gender \((p = 0.001)\); education \((p = 0.025)\); assigned group \((p = 0.011)\); trust in legislators \((p < 0.0005)\) and age \((p = 0.001)\). Interestingly, unlike the results for willingness to eat fresh produce

\(^{38}\) https://journals.sagepub.com/doi/abs/10.1177/1075547005281473
carrying a non-pathogenic *Salmonella* strain, the personal values were not significant (*p* = 0.265) when it came to willingness to consume produce treated with bacteriophages.

Like the results obtained for the other independent variable concerning “willingness to eat”, males were more (*p* = 0.021, OR = 1.424, CI: 1.098 – 1.846) likely than females to be willing to eat bacteriophage treated fresh produce. Education also influenced the willingness to eat fresh produce treated with bacteriophages, with university degree holders being more likely than non-graduates to be willing to consume such produce (*p* = 0.021, OR = 1.402, CI: 1.052 – 1.870). Not surprisingly, respondents in the experimental group that received additional information vignettes were more likely (*p* = 0.013, OR = 1.386, CI: 1.071 - 1.794) to be willing to consume bacteriophage-treated products than respondents in the control group, which tend to confirm the presence of a framing effect.

Echoing the results obtained for “willingness to eat produce carrying non-pathogenic *Salmonella*”, people who are trusting of legislators were more likely to eat bacteriophage treated food (*p* < 0.0005, OR = 2.252, CI: 1.729 – 2.933) than people who are not trusting. Finally, although this variable had no effect on willingness to eat *Salmonella* carrying produce, age was a significant factor affecting willingness to eat fresh produce treated with bacteriophages. (*p* = 0.021). With an odds ratio decrease of 0.991 (CI: 0.983 – 0.999) every year, meaning that for every passing decade, (0.991<sup>10</sup> = 0.914) people are 0.914 as likely to be willing to eat produce treated with bacteriophages, meaning that the older the people are, the less likely they will be to eat bacteriophage treated food.

### 4.3 Workshop discussion on the National Survey

Regarding the drafting of the survey questions, it was noted that the formulation of the questions and the references to non-pathogenic *Salmonella* could have yielded a different response if framed as low-virulence *Salmonella* (low risk to human health as opposed to no risk). One way of framing the low virulence that was suggested could be to state “that does not cause disease” (or is not known to cause diseases) rather than no risk. Another way of framing would be to compare the risk to something similar, e.g.: “present the same risk as…” or “does not present a greater risk than…”

In general, there were no major surprises in the context of risk factors, as men tend to eat more risky foods<sup>39</sup>. It was noted as well that it may be important to review the correlation between panel and income of respondents. Since many respondents had at least a university degree, this may tie them to higher level of income and influence their answers. However, as most online panels have higher educated participants it is difficult to curb this, so it may need to instead be stated as a limitation.

One important consideration discussed was the question of which information should be communicated to the public, and the most efficient methods for this communication. For example, the public may not be aware that bacteriophages are already approved for certain uses in Canada and other countries. Pet foods, for instance, are already being marketed as treated with bacteriophages. It may be useful to see a ranking in the values and to assess how this impacts the willingness to eat these foods. For consumers’ education packaging and labeling, this may be important.

Finally, regulatory questions will also need to be answered surrounding not only technology implementation, but product labelling. Agriculture and Agri-Food Canada (AAFC) has

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already approved the use of bacteriophages as a processing aid. However, the marketing of products that undergo this processing may be strictly regulated, as, for example, in the case of the Canadian Food Inspection Agency initiative on non-misleading packaging information. The question of whether a label may be required or not was raised as not all decontamination treatments are labeled, for example, not all foods treated with chlorine are identified as such.

5. Working Sessions

5.1 Points to Consider for Policymakers and Scientists

Among the points most discussed during the working session were concerns about risk management, including the need to incorporate into policy strategies a plan for protecting vulnerable populations. Participants noted the importance of a multi-layered approach to risk calculations as a “one size does not fit all” approach, in recognition that food contamination may create different risk levels for different individuals and populations. There was also a call for equity in the distribution of risks and benefits among the consumers, industry, and government as well as equity between smaller and larger producers in managing and shouldering these risks. Participants discussed the need to consider the worst outcomes and to build contingency plans accounting for these possibilities at every step of the supply chain. One participant noted that this technology could be used to improve risk-management and avoid recalls by enabling the industry to police itself through pre-emptive withdrawals.

Related to the question of risk management was a call for clear criteria and threshold metrics for virulence in making policy assessments around the technology. In particular, participants noted the need to assess the difference in hazard considerations between different levels of virulence. It was noted that there is an existing model (e.g., E Coli) of virulence characteristic approach that could be leveraged for Salmonella subtyping. Participants also noted the need to consider that high virulence strains may be less known and erroneously presumed to be of less incidence; but there is no zero risk in this context. The need to give the industry access to validated data was discussed, including the need for more health studies on the product’s impact on the microbiome. Finally, it was noted that direct to consumer bacteriophages may be found to carry an unacceptable level of risk.

A third point of discussion was that of cost-analyses and other challenges to industry acceptance. Cost effectiveness analyses were seen as a crucial component for industry uptake. This would include a multi-layer analysis of who would be implementing various parts of the technology and at what levels of industry to determine the costs for different parties. It was noted that field-spraying could result in a lot of costs for farmers. Regarding fostering acceptance and uptake of the product amongst regulators, it was noted that one challenge would be the current lack of evidence surrounding Salmonella. To get industry acceptance, the regulatory approach would need to be transparent, evidence-based, and validated beyond statistical models.

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40 https://www.inspection.gc.ca/food-label-requirements/labelling/industry/general-principles/eng/1392324632253/1392324755688?chap=0
41 Loraine, Alex, Dele, Jeff, Scott
42 Marie, Scott, Vincent, Aaron
43 Loraine, Dele, Vincent
44 Alex, Jeff
Finally, participants contemplated several other regulatory considerations for policymakers. A few questions were raised around implementation that would need to be addressed from an industry perspective, including what regulatory bodies would be involved, and how they would be enforced. It was noted that policymakers might not want to delegate the responsibility to industry stakeholders. Planning, public-private partnerships, and proof of principles were named as factors that would help with implementation, as well as the need to tailor the message to policymakers, who may not have a science background. One participant noted the need for the organic regulatory framework around bacteriophages specifically to be addressed.

5.2 Considerations for Public Engagement and Communication Strategy

In discussing public engagement and communication strategies, participants raised three main points: who should communicate, who is the audience, and what should be the content. With regard to the question of who should communicate, a number of individuals raised the importance of using social media and other non-mainstream media to reach consumers across different populations, as it has been shown that mainstream media alone is not sufficient to inform Canadians about food safety. A need was also noted for government resources to take a clearer role in educating the population so that this information can come from validated sources. Participants raised a few potential third-party options for communication strategies, including knowledge brokers, extension professionals, and communication strategists, as well as the importance of testing these strategies with focus groups. Participants also noted a need for engagement with industry partnerships and a multi-faceted approach that is broad enough to incorporate a One Health Approach.

Considering the audience for these communications, participants noted the importance of clarifying exactly what audience is being targeted, including consumers, retailers, and producers, so that the message can be tailored accordingly. One participant noted the timing on these communications may be good considering the new food guide and Canadians adopting more plant-based diets. It was noted that communications would need to take into consideration the lack of statistical sophistication in the public and the need to be both transparent and to communicate in lay terms.

One major area under discussion for communication was that of risk communication strategies. In particular, these is a need for an effective risk communication strategy that relies on the best risk communication professionals, again with a focus on effective communication with parties who do not have an extensive scientific education. It was noted that advertising and marketing should not make scientific claims and workshop participants recommended that communication strategies used in the health sector to frame communication around bacteriophages be mirrored in this context. Other consumer communication deliberations included the lack of awareness of consumers as to where contamination originates and consumer considerations of

45 Bob, Marie, Stephen, Vincent, Aaron
46 Larry, Ian
47 https://www.dal.ca/faculty/management/news/events/news/2018/04/05/release__canadians_are_confused_about_food_recalls.html
48 Loraine
49 Sarah, Loraine
50 Sarah
51 Pascal
52 Ian
where the food is coming from with regard to local, transported long distance, or imported. Not all consumers have the same food behavior and expectations.

5.3 Integration of Canadian-Specific and International Considerations

In the final segment of the workshop, participants discussed the importance of understanding the regulatory frameworks and scientific research taking place internationally, with a particular focus on the United States and Europe. This international perspective would need to account for considerations around data harmonization with importing and exporting countries and the need to integrate Canadian regulations with international standards including those involving transparency, evidentiary concerns, and a clear numerical definition of threshold. This would need to incorporate discussions that are taking place elsewhere about other uses of bacteriophages, including those regarding other bacteria such as *Listeria*. It was noted that it would be good to know how long bacteriophages have been used in other countries; such research and lessons would be useful here. Phages have been used as a pesticide for a long time in other countries, and there are two major companies that are currently expanding their activities; one company is based on the US, and the other in the Netherlands. There may also be lessons from other commodities that have been treated with phages; look at high priced commodities such as cheese and meats (ex. Smoked salmon) from Europe or South America. It would be helpful to review the report from European Food Safety Authority on bacteriophages (making the use of bacteriophage permissible in the EU).

In the context of how Canada fits in to these international concerns, it was noted that if accomplished, these new regulatory approaches could help Canada to become a leader in integrating genomics for all products. Participants noted that Canada has traditionally been conservative on this front, leading to a need to assess what has been done elsewhere and to consider the pros and cons of implementing existing approaches in Canada. Participants also addressed that though Canada has historically been resistant to these changes, in this case there is an opportunity for the country to take more of a leadership role. One participant noted that public opinion may vary across Canada, and that focus groups could be utilized across different parts of the country in order to assess public perception in different contexts. At was also noted that at the regulatory level, having the bacteriophage approved by the US FDA could facilitate its adoption in Canada.

Finally, a number of external organizations, bodies, and documents were noted during the session whose participation or consultation would be beneficial for integration both across Canada and at the international level. These included the FAO Codex Committee on Food Hygiene (CCFH); the Federal/Provincial/Territorial Food Safety Committee (FPTFSC); the Quadrilateral Food Safety Group should also be involved’ the World Health Organization; Jenny Scott, Senior Advisor in the Office of Food Safety with the U.S. Food and Drug Administration’s Center for Food Safety and Applied Nutrition; and the International Association for Food Protection (IAFP).

Concluding Remarks

To conclude our studies on GE3LS (genomics and its ethical, environmental, economic, legal, and social aspects) and the acceptance of Syst-OMICS methods, we held a stakeholder workshop. The objective was to validate the research results of the GE3LS studies on the technological acceptance.

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53 Jeff, Sarah, Aaron, Alex, Larry, Vincent
54 Dele, Stephen
55 Jeff, Bob
of the approaches developed by the Salmonella Syst-OMICS project through its methods of (1) subtyping and virulence classification and (2) biocontrol using bacteriophages. Participants at the stakeholder workshop were able to discuss the results of three empirical sub-studies, namely: (1) a Delphi survey of experts in the field of food safety, mostly government employees; (2) qualitative interviews with representatives of consumer associations or institutions interested in food safety, representatives of organic agriculture and the Canadian agri-food industry; and (3) a national survey of 1000 Canadian consumers.

While these empirical activities generated a wealth of data and information specific to each type of stakeholder studied and their specific issues, three broad categories of cross-cutting issues emerged: (1) policy, regulatory, and evidentiary considerations; (2) consumer and end-user communication strategy considerations for Syst-OMICS methods; and (3) integration of Canadian and international considerations. Points for consideration were raised under each of these categories of issues.

(1) **Policy, regulatory and evidentiary considerations**

- Need for a risk management strategy, including the need to incorporate a plan to protect vulnerable populations into policy strategies.
- Need to establish clear criteria and virulence thresholds for policy evaluation of this technology.
- Need to conduct cost-effectiveness analyses to mitigate barriers to industry acceptance.
- Need to address regulatory considerations for policy makers.

(2) **Consumer and end-user communication strategy considerations for Syst-OMICS methods**

- Need to use social media to reach consumers from all walks of life and reach different populations.
- Need to clarify exactly who the target audience is, including consumers, retailers, and producers, so that the message can be tailored accordingly.
- Need to develop an effective risk communication strategy with an emphasis on effective communication with parties who are not highly trained in science.

(3) **Integration of Canadian and international considerations. Points for consideration were raised under each of these categories of issues.**

- Need to understand the regulatory frameworks and scientific research taking place internationally, particularly in the United States and Europe.
Annex I: Meeting Agenda

MEETING AGENDA
08:30-9:00 Breakfast
09:00-09:10 Welcome and Introductions
- Introducing the CGP team, and the Chairs
- Participants round table introductions
- Presenting the methodology and aims of the workshop

09:10-09:30 Overview of the Salmonella Syst-OMICS Project (Lawrence Goodridge)
- Brief presentations of Salmonella Syst-OMICS Project:
  • the Syst-OMICS sub-typing method and virulence classification
  • the bacteriophage-based biocontrol approach

FINDINGS FROM THE SALMONELLA S-OMICS GE3LS RESEARCH
09:30-10:45 Delphi Survey
- Presentation of the objectives and methodology of the study
- Presentation of the research findings from the Delphi Survey

10:45-11:00 Break for coffee/tea

11:00-11:30 Discussion on the Delphi Results
- Discussions on the findings

11:30-12:00 Stakeholders’ Interviews
- Overview of the study and presentation of the research findings

12:00-13:00 Break for lunch

13:00-13:15 Discussions on the Stakeholders’ Interviews
- Discussions on the findings

13:15-14:45 Discussion of the National Opinion Survey
- Overview of the study and presentation of the findings
- Discussion of the findings

14:45-15:00 Break for coffee/tea

WORKING SESSION ON THE DRAFT REPORT
15:00-15:30 Working Session on the Points to Consider for Policymakers
- Defining and formulating key considerations for policymakers

15:30-16:00 Working Session on the Considerations for Implementation
- Defining and formulating key considerations for technology implementation

16:00-16:30 Working Session on the Considerations for Public Engagement and Communication Strategy
- Defining and formulating key considerations for technology implementation
16:30-16:45  **Integration of International Considerations**  
- Discussion and integration of international perspectives and approaches to assess additional considerations

16:45-17:00  **Final Remarks** (Yann Joly)  
- Timeline for finalizing the Draft Report, administrative reminders and thank you.

This workshop is funded by Genome Canada, provincial genome centers Genome Québec and Genome BC, and the Ontario Ministry of Research and Innovation.
Annex II: Members of the working group

Members of the Working Group

Meeting Chairs:
1. Chair: Yann Joly, Research Director and Associate Professor, Centre of Genomics and Policy (CGP), McGill University – Lead of the GE3LS Activity 5 (economic, social and policy research)
2. Co-Chair: Lawrence Goodridge, Leung Family Professorship in Food Safety, University of Guelph – Lead investigator of the project and lead of Activity 3 (Rapid diagnostics for Salmonella)
3. Co-Chair: Roger Levesque, Director of the Institute for Integrative Systems Biology (IBIS), University of Laval - Co-lead investigator of the project and lead of activity 1 (Salmonella virulence classification)
4. Co-Chair: Jeff Farber, Director, Canadian Research Institute for Food Safety (CRIFS), University of Guelph - Collaborator on the GE3LS Activity 5
5. Vice Co-Chair – Law and Policy: Ida Ngueng Feze, Academic Associate, CGP, McGill University – GE3IS Coordinator - Activity 5
6. Vice Co-Chair – Mixed-methods Research: Julie Hagan, Academic Associate, CGP, McGill University – Activity 5
7. Rapporteur: Samuel Alarie, Research Assistant, Mixed-Methods Research, CGP, McGill University - Activity 5

Members actively involved in the Salmonella Syst-OMICS project:
8. Sadjia Bekal, Head - Enteric pathogens and bioterrorism, Laboratoire de santé public du Québec lead of Activity 4 (development of strain typing tools)
9. Pascal Delaquis, Research Scientist – Food safety and Quality, Agriculture and Agri-Food Canada (AAFC) – Lead of Activity 2 (development of a biocontrol method)
10. Alex Gill, Research Scientist, Health Canada – Research in Activity 3 and Activity 5
11. Dele Ogunremi, Research Scientist, Canadian Food Inspection Agency (CFIA), Researcher Activity 4

Members who have participated in one or more Syst-OMICS GE3LS studies:
12. Burton Blais**, Section head. Canadian Food Inspection Agency (CFIA)
14. Elisabeth Fortier**, Project Agent, Association des producteurs maraîchers du Québec
15. Eleni Galanis**, Physician Epidemiologist, BC Centre for Disease Control
16. Mel Krajden**, Medical Director, BC Centre for Disease Control
17. Pascale-Valérie Lett**, Corporate Alliance and Food Safety Director, VegPro International Inc
18. Loraine McIntyre, Food Safety Specialist, BC Centre for Disease Control
19. Alison Orr**, National Manager – Policy and Programs Branch, CFIA
20. Vincent Strickland, Compliance Coordinator, Pfenning’s Organic Vegetables
21. Scott Wright, Senior Vice President, Star Produce – The Star Group, Saskatoon

Members who have not been involved in the Syst-OMICS research activities:
22. Vanessa Allen**, Chief - Medical Microbiology, Public Health Ontario Laboratory
23. Sarah Berger Richardson, Assistant Professor, Faculty of Law – Civil law section, University of Ottawa
24. Marie Breton, Section Head, Health Canada
25. Robert Buchanan, professor (retired) and Director (former), Center for Food Safety and Security Systems, University of Maryland, USA.
26. Stephen Parker, Manager, Center for foodborne environmental and zoonotic infectious diseases – Public Health Agency of Canada (PHAC)
27. Natalie Prystajecky**, Environmental Microbiologist, BC Centre for Disease Control
28. Carol A. Wallace**, Professor of Food Safety Management Systems, Co-director of the Institute of Nutritional Sciences and Applied Food Safety Studies, University of Lancashire, UK

29. Aaron White, Research Scientist, Vaccine and Infectious Disease Organization – International Vaccine Centre, and University of Saskatchewan

30. Ian Young, Assistant Professor, Ryerson University

**Member with Observer Status (not involved in the Syst-OMICS project)** (1):
The United States Center for Disease Control and Prevention (US CDC), represented by:

29. Dr. Patricia Fields**, Enteric Diseases Laboratory Branch, Associate Director for Laboratory Science, Division of Foodborne, Waterborne, and Environmental Diseases, CDC Atlanta

**Members that were not present at the workshop**