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Assessing the Public Health Impact and Effectiveness of Interventions To Prevent *Salmonella* Contamination of Sprouts

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ABSTRACT

Sprouts have been a recurring public health challenge due to microbiological contamination, and *Salmonella* has been the major cause of sprout-associated outbreaks. Although seed treatment and microbiological testing have been applied as risk reduction measures during sprout production, the extent to which their effectiveness in reducing the public health risks associated with sprouts has not been well investigated. We conducted a quantitative risk assessment to measure the risk posed by *Salmonella* contamination in sprouts and to determine whether and how mitigation strategies can achieve a satisfactory risk reduction based on the assumption that the risk reduction achieved by a microbiological sampling and testing program at a given sensitivity is equivalent to that achieved by direct inactivation of pathogens. Our results indicated that if the sprouts were produced without any risk interventions, the health impact caused by sprouts contaminated with *Salmonella* would be very high, with a median annual estimated loss of disability-adjusted life years (DALYs) of 691,412. Seed treatment (with 20,000 ppm of calcium hypochlorite) or microbiological sampling and testing of spent irrigation water (SIW) alone could reduce the median annual impact to 734 or 4,856 DALYs, respectively. Combining seed treatment with testing of the SIW would further decrease the risk to 58 DALYs. This number could be dramatically lowered to 3.99 DALYs if sprouts were produced under conditions that included treating seeds with 20,000 ppm of calcium hypochlorite plus microbiological testing of seeds, SIW, and finished products. Our analysis shows that the public health impact due to *Salmonella* contamination in sprouts could be controlled if seeds are treated to reduce pathogens and microbiological sampling and testing is implemented. Future advances in intervention strategies would be important to improve sprout safety further.

Sprouts have been a popular produce item due to their well-recognized nutritional value *(13)* and other perceived benefits, such as purported anticarcinogenic and anticholesterolemic properties *(8)*. Nevertheless, sprouts also present a special public health challenge because of the unique germination process involved in their production, which provides an ideal environment for bacterial growth, and because sprouts are often eaten raw, without a pathogen destruction step. Contaminated sprouts have been linked to numerous foodborne illness outbreaks, including one of the most deadly in modern history, which occurred recently in Germany and caused dozens of deaths and thousands of hospitalizations *(22)*.

The U.S. Food and Drug Administration (FDA) has long recognized the public health concerns posed by contaminated sprouts *(26)*. In 1999, a peak year in sprout-associated outbreaks of illness, the FDA issued two sprout-specific guidance documents recommending that seed be treated to reduce pathogens immediately before sprouting, and because seed treatment cannot be guaranteed to eliminate all pathogens, microbiological testing of spent irrigation water (SIW) to ensure that the contaminated product does not enter market channels *(27, 28)*. Although the immediate effect after the issuance of the guidance appeared to be encouraging, longer-term control of the health hazard remains elusive, as sprout-associated outbreaks continue to occur *(7)*. Although some industry segments have adopted some or all recommendations in the sprout guidance, adoption has not been universal. Correct and consistent industry implementation of the recommendations in the guidance needs to be strengthened, an in-depth understanding of why sprouts have been a persistent challenge, what is missing in our current intervention strategies or their implementation, and, ultimately, how to improve sprout safety, will be the key to finding the solution and protecting the public health.

In recent years, both the scientific community and the sprout industry have been searching diligently for new interventions, especially effective seed treatments. Although many emerging treatments appear to be as or more effective than the 20,000 ppm of calcium hypochlorite recommended in the FDA guidance, treating seed to reduce pathogens is unlikely, by itself, to be able to eliminate the contamination in sprouts *(7, 24)*. On the other hand, the benefit of

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microbiological testing in reducing the sprout-associated public health risk has not been well evaluated. More importantly, the fundamental questions regarding the harm that contaminated sprouts pose to public health and the extent that currently available interventions help to reduce public health risks have not been fully characterized. Conventional laboratory experiments lack the capacity to answer such macrolevel questions. The uncertainties in the data related to sprout contamination and mitigation efficacies need to be addressed. Quantitative risk assessment has been successfully applied to study microbiological contamination and risk to public health in a variety of different food commodities *(2, 4–6, 9, 11, 14, 16–21, 23, 32)*. In this study, the quantitative risk assessment approach was used to examine the public health impact associated with *Salmonella* contamination in sprouts and how this impact is affected by implementing a seed disinfection treatment or a microbiological sampling and testing program. We also evaluated the reduction in public health risks conferred by combining seed disinfection with microbiological testing to see if it could be a feasible solution in minimizing the negative impact to public health caused by consumption of contaminated sprouts.

MATERIALS AND METHODS

Efficacy of treating seed to reduce pathogens. Seeds are considered to be the primary source of *Salmonella* contamination in the majority of outbreaks associated with sprouts; thus, treating seed to reduce pathogens prior to sprouting has been an important intervention strategy for risk reduction. According to literature, the average pathogen reduction achieved by the 20,000-ppm calcium hypochlorite treatment is approximately 3 log *(7)*. Although recent studies have suggested the potential superiority of physical treatments, especially high pressure, for pathogen inactivation on seeds, physical treatments, along with other types of seed treatments, including combination treatments *(7)*, need to be further validated both in laboratories and in commercial settings. Because it is the most common *(25)*, 20,000 ppm of calcium hypochlorite treatment was used in this study as a representative seed treatment.

Quantifying the effect of a microbiological sampling and testing program in risk reduction: an assumption. Seed treatment alone is unlikely to eliminate microbiological contamination in sprouts *(7, 24)*. An important additional intervention strategy is microbiological sampling and testing. Unlike seed treatment that directly inactivates pathogens, an effective microbiological sampling and testing program can reduce the public health risk by detecting and preventing contaminated sprouts from entering the market, thereby lowering potential exposure to consumers. The risk reduction achieved by each of these interventions, i.e., seed disinfection and microbiological testing of SIW, can be considered to be equivalent, if one considers sprout safety based on all sprouts produced in the nation as a whole, rather than by individual companies. For example, a direct inactivation of 90% of *Salmonella* by seed treatment for the sprouts produced annually by the industry is equivalent to the risk reduction that can be achieved from a sampling and testing program with a 90% efficacy (successful detection rate), leading to the removal of the contaminated sprouts, because in both cases, 90% of the pathogen will be inactivated or removed and only 10% of *Salmonella* will remain in the sprouts to which consumers could be exposed. Furthermore, the success rate of testing can be converted to log reduction because the number of *Salmonella* in posttest sprouts would be (100% − efficacy) multiplied by the original *Salmonella* load (X), which equals log[X(100% − efficacy)].

Ideally, a sampling and testing program should be performed at all three critical control points of sprout production, that is, seeds, SIW, and the finished product. The residual pathogens that have survived in the finished sprouts can be calculated as follows:

$$P_F = P_S - T_S - D_S + P_g - T_W - T_F \quad (1)$$

where P_S and P_g are the initial pathogen load on seeds and the level of pathogen growth during germination, respectively, T_S, T_W, and T_F represent the pathogen reduction resulting from the removal of contaminated seeds or sprouts from positive testing results of seeds, irrigation water, and finished sprouts, respectively, and D_S denotes the direct inactivation of pathogen by disinfection treatment on seeds. Therefore, by assuming sprouts that were associated with a positive test result (whether through seed, SIW, or finished product testing) will be destroyed, diverted, or otherwise removed from the market, we are able to quantitatively assess the efficacy conferred by a microbiological sampling and testing program in reducing the risk posed by contaminated sprouts.

Health metrics. The effectiveness of an intervention to microbiological contamination is often represented by the log reduction of a targeted pathogen. However, it would be better understood, especially by the general public, if the risk reduction can be expressed in terms of the actual health outcome caused by the pathogen. *Salmonella* can cause a variety of health conditions with different severities, ranging from gastroenteritis to death. To quantitatively evaluate the health impact to consumers caused by *Salmonella*-contaminated sprouts, we used the disability-adjusted life year (DALY) as the metric, which simultaneously takes into consideration both the duration and severity of the health effect of *Salmonella,* with gastroenteritis or death being equivalent to 0.015 or 35 DALY, respectively *(30)*.

Risk assessment. In the current study, because there are multiple uncertainties and data gaps, such as the initial load of pathogen on seeds, actual efficacy of seed disinfection, the effectiveness of microbiological sampling and testing, and the growth rate of the pathogen under different sprouting conditions, a quantitative risk assessment approach that takes into account data uncertainty and variability was used to model the health impact of *Salmonella*-contaminated sprouts. Based on the current knowledge of these uncertain factors, we chose uniform distribution, normal distribution, pert distribution to define the initial *Salmonella* load on seeds, the efficacy of seed treatment and *Salmonella* growth rate during germination, and sampling and testing efficacy, respectively (Table 1). All data used in the models were collected from published scientific literature, except for the efficacy of sampling, which was assumed to be 80% for seeds and finished sprouts (values for a pert distribution were 0.56, 0.76, and 0.8 for efficacy of sampling and testing) and 99% for the SIW (values of 0.69, 0.94, and 0.99 for efficacy of sampling and testing were used for the pert distribution; Table 1). In the absence of published data, this value serves as an example to demonstrate the potential benefit of a microbiological testing program in reducing public health risk associated with contaminated sprouts. The details of the quantitative risk assessment model are shown in Table 1. All assessments were performed using @RISK 5.7.1 for Excel (Palisade Corporation, Ithaca, NY). The simulation was run 10,000 times, and the median value rather than the mean was chosen to represent the

TABLE 1. *Quantitative assessment model for health impact of* Salmonella *contamination in sprouts*

Identification	Calculation	Note	Reference(s)
A1	0.07	Low level of *Salmonella* contamination on seeds (most probable number [MPN]/100 g)	*1, 12, 15*
A2	10	High level of *Salmonella* contamination on seeds (MPN/100 g)	*1, 12, 15*
A3	0.02	Prevalence of *Salmonella* contamination in seed lots	*31*
A4	A1*A3	Low-level contamination after adjusted for prevalence (log/g)	
A5	A2*A3	High-level contamination after adjusted for prevalence (log/g)	
A6	RiskUniform(A4,A5)	Initial *Salmonella* contamination	
A7	RiskPert(0.56,0.76,0.8)	Sampling and testing efficacy for *Salmonella* on seeds	*10,* assumption
A8	1-A7	*Salmonella*-associated risk reduction due to sampling and testing of seeds	
A9	LOG(A8)	Conversion to log risk reduction	
A10	A6-A9	Contamination level after sampling and testing on seeds	
A11	RiskNormal(3.08,2.03)	Log reduction by seed disinfection	*7*
A12	A10-A11	Contamination level after seed disinfection	
A13	RiskNormal(3.32,1.07)	*Salmonella* growth during germination	
A14	A12+A13	Contamination level after germination	
A15	RiskPert(0.69,0.94,0.99)	Sampling and testing efficacy for *Salmonella* in SIW	*10,* assumption
A16	1-A15	*Salmonella*-associated risk reduction due to sampling and testing of SIW	
A17	LOG(A16)	Conversion to log risk reduction	
A18	A14-A17	Contamination level after sampling and testing of SIW	
A19	RiskPert(0.56,0.76,0.8)	Sampling and testing efficacy for *Salmonella* in sprouts	*10,* assumption
A20	1-A19	*Salmonella*-associated risk reduction due to sampling and testing of sprouts	
A21	LOG(A20)	Conversion to log risk reduction	
A22	A18-A21	Contamination level after sampling and testing in sprouts	
A23	POWER(10,A22)	Final *Salmonella* density in sprouts (MPN/g)	
A24	RiskTriang(3.5,65.4,217.5)	Amount of sprouts per serving (g)	*3*
A25	A23*A24	*Salmonella* dose per serving of contaminated sprouts (MPN)	
A26	$1\text{-}(1+A24/\beta)^{-\alpha}$	Probability of illness due to *Salmonella* contaminated sprouts (beta Poisson, $\alpha = 0.1324$, $\beta = 51.45$)	*32*
A27	0.0457	Health impact (DALY loss) due to *Salmonella* infection	*30*
A28	A26*A27	Health impact due to *Salmonella*-contaminated sprouts	
A29	0.0025	U.S. consumers eating sprouts on a given day (rate)	*3*
A30	2.897E+08	U.S. population	*3*
A31	A29*A30*365	Annual number of Americans eating sprouts	
A32	RiskOutput(A28*A31)	Total DALY loss per year for U.S. population due to consumption of *Salmonella*-contaminated sprouts	

most likely estimate for the health impact due to the skewness of the simulation results. A cutoff of 5% at both ends was applied to the result to further reduce the effect of extreme values.

RESULTS

No interventions. We first examined the health impact of *Salmonella*-contaminated sprouts, assuming that no interventions, i.e., no seed treatment or microbiological testing, were implemented. The result (Table 2) showed that the median annual loss of DALYs was very high at 691,412 for the U.S. population. Even in the best scenario, where the initial *Salmonella* load on seeds was minimal and the pathogen growth during sprouting was at the slowest rate (best-case scenario), there was still a high loss of 19,350 DALYs. Compared with the initial *Salmonella* load, the exponential growth of the pathogen during sprouting is more harmful to public health, as indicated by the higher regression coefficient value that describes the robustness of association between risk factors and DALY loss (0.84 versus 0.56; Table 3).

Seed treatment. When seed treatment to reduce pathogens was introduced into the model, the overall health impact was dramatically decreased to a level of 734 DALYs. The benefit of the treatment outweighed the harmful health impact of both the initial *Salmonella* load and pathogen growth during sprouting (coefficient value: –0.51 versus 0.18 or 0.31). Under the best-case scenario, the DALY loss is nearly a no-impact 0.54 DALY; however, the worst-case scenario results in DALYs similar to having no interventions (769,648 DALYs). If the efficacy of seed disinfection could be improved to an ideal pathogen reduction target of 5 log, the median DALY loss would be 8.93.

Microbiological testing. Although a microbiological detection test itself in food by using currently available methodologies is relatively reliable, it can be a challenge if

TABLE 2. *Health impact (DALY loss) due to consumption of* Salmonella *contaminated sprouts and the effectiveness of risk intervention on the health of the general U.S. population*

Risk interventions	Median (most likely scenario)	5th percentile (best scenario)	95th percentile (worst scenario)
No intervention	691,412	19,350	4,259,653
Seed treatment			
Overall	734	0.54	769,648
5-log reduction	8.93	0.19	419
Testing			
Seeds	220,383	5,095	2,851,718
SIW	68,702	1,373	1,705,757
Sprouts	220,319	5,026	2,871,528
Testing 3×[a]	4,856	96	223,405
3× with 95% efficacy	111	2.42	5,110
Seed treatment + testing			
Testing seeds	199	0.14	241,312
Testing SIW	58	0.04	81,255
Testing sprouts	192	0.14	251,600
Testing seeds + SIW	16	0.01	21,705
Testing 3×[a]	3.99	0.002	5,793
Testing 3×[a] with 95% efficacy	0.09	0.00006	132

[a] Testing seeds, spent irrigation water (SIW), and finished sprouts.

the methods have not been rigorously evaluated for use with sprouts. In addition, the uncertainty of sampling efficacy further lowers the effectiveness of this intervention strategy. If testing were performed only at the stage of either seeds or finished sprouts, the median DALY loss would be very high (>220,000); testing for SIW is much more effective, with a median DALY loss of 68,702 (Table 2). However, if the testing were to be conducted at all three critical control points (i.e., seeds, SIW, and finished sprouts), the health impact could be minimized to a level close to the one achieved by seed disinfection (4,856 DALYs, compared with 734 DALYs for seed disinfection). Furthermore, if the sampling and testing were performed in such a way as to achieve a 95% efficacy, then the median DALY loss would be further reduced to a less harmful level of 111.

Seed treatment plus microbiological testing. Under an ideal scenario, i.e., both seed treatment, sampling, and testing at all three critical control points were implemented, the health loss resulting from *Salmonella*-contaminated sprouts would be minimized to 3.99 DALYs. Sprout safety could be assured by implementing seed disinfection in conjunction with three points of testing at a 95% efficacy (most likely DALY loss: 0.09); in a worst-case scenario, only 132 DALYs will be lost, with unlikely death. On the other hand, skipping the testing of finished sprouts would not pose an excessive threat to public health (median DALY loss: 16). Finally, the combination of seed disinfection and the testing of SIW, as recommended by the FDA's proposed Produce Rule (*29*) would decrease the risk to 59 DALYs.

TABLE 3. *Impact (regression coefficients) of risk factors or interventions on* Salmonella*-associated DALY loss*

Risk factors/ interventions	No interventions	Seed disinfection	Testing 3×[a]	Seed disinfection + testing 3×[a]
Initial load	0.56	0.18	0.40	0.15
Salmonella growth	0.84	0.30	0.61	0.25
Seed disinfection	NA[b]	−0.51	NA	−0.43
Testing seeds	NA	NA	−0.17	−0.06
Testing SIW	NA	NA	−0.04	−0.02
Testing sprouts	NA	NA	−0.04	−0.01

[a] Testing seeds, spent irrigation water (SIW), and finished sprouts.
[b] NA, not applicable.

DISCUSSION

Microbiological contamination of sprouts can have a serious effect on public health; however, neither the magnitude of its impact nor the extent to which interventions can mitigate risk are fully understood. In this study, we used the quantitative risk assessment approach and systematically investigated the public health impact of *Salmonella* contamination in sprouts and the effectiveness of major interventions currently available to reduce public health risk. Our results demonstrated that a high health loss of 691,412 DALYs could occur if no interventions were applied to *Salmonella*-contaminated sprouts. The use of 20,000 ppm of calcium hypochlorite as a seed disinfection treatment can significantly reduce the loss to 734 DALYs. Microbiological testing of the sprout SIW alone would not be sufficient (68,702 DALYs) to achieve a level of risk reduction comparable to that offered by seed treatment; however, if the testing were performed at all three critical control points, i.e., seed, SIW, and finished sprouts, an improvement in the risk level to 4,856 DALYs could be achieved, a level approaching that of 20,000 ppm of calcium hypochlorite seed treatment (734 DALYs). Furthermore, if a 95% testing efficacy could be assured at all three testing stages, such a comprehensive testing program could be even more helpful in preventing DALY loss caused by contaminated sprouts (111 DALYs). Finally, in an ideal situation, where seed treatment is performed in conjunction with testing at three critical control points, the loss of health would be reduced to 3.99 DALYs, greatly improving sprout safety. Where the combination of seed treatment and the testing of SIW is performed, as recommended by the FDA guidance *(27, 28),* the risk could be decreased to 58 DALYs, an impressive improvement in public health outcome.

The findings of this study can be important in helping the sprout industry to identify appropriate risk management strategies for improving the safety of sprouts. Our results showed that seed treatment is the most important risk reduction step. Although the 20,000 ppm of calcium hypochlorite seed treatment is cited in the FDA sprout guidance, and most widely used *(7),* its implementation in commercial sprouting facilities has several disadvantages, including the potential hazard to workers and the environment with the high level of chlorine. Additional seed treatment methods that are effective and can be applied safely and consistently during commercial sprout productions are needed. Current seed treatment technologies are unlikely to be able to completely eliminate microbial contamination of sprouts; therefore, sampling and testing programs are critical complementary intervention strategies *(27, 28)*. Nevertheless, the benefits that such programs can confer to sprout safety have not been quantified previously. Based on national consumption levels and the assumption that contaminated sprouts that have tested positive will not enter market channels, we demonstrated that microbiological testing at multiple stages during sprout production could produce similar benefits in risk reduction to that of seed treatment. Although there are continuing needs to search for more effective seed treatments and although sampling and testing programs would improve the effectiveness of risk management programs as justified by this study, our results have also suggested that the industry could rely on current technology to achieve an effective control of *Salmonella* contamination in sprouts, if at least seed treatment plus testing of SIW were performed.

The conclusions from this study should be viewed in the context of the uncertainty of information and data gaps. We adopted 20,000 ppm of calcium hypochlorite, the reference seed treatment recommended by the FDA, in the risk assessment models, which could be different from other treatments, especially emerging technologies, such as high pressure treatment *(7),* in terms of efficacy of *Salmonella* inactivation. Similarly, the lack of well-defined and well-accepted sampling and testing programs prevents us from precisely estimating the benefit of such a program. The assumption made in this study regarding the effectiveness of testing relies on industry consistently and correctly implementing the FDA guidance, such as following appropriate sampling and testing procedures. However, this may not always be the case, especially when there is a lack of awareness or understanding of sampling and testing on the part of the sprout grower. Economic concerns regarding the cost of testing may also be a major deterrent. Although *Salmonella* has been the primary pathogen involved in the majority of sprout-associated outbreaks, it is necessary to also consider other pathogens, such as *Listeria monocytogenes, Escherichia coli* O157:H7, and the other non-O157 pathogenic serogroups, such as O104:H4, a newly emerged strain that caused a major outbreak recently in Germany *(22)*. In addition, the health impact of consuming contaminated sprouts could be significantly different in vulnerable populations, such as children, the elderly, or the immune compromised. Finally, it appears that the predicted high health impact obtained in this study when no interventions are applied is not supported by historical outbreak data. Although the possibility of overestimated risk resulting from inadequate data regarding prevalence of contamination, pathogen load, dose-response relationship, and DALY estimates of medical outcomes caused by *Salmonella* cannot be excluded, other historic factors, such as poor public awareness of the issue, changes in consumption patterns, underreporting of illness, and consequent failure to identify outbreaks, or failure to identify sprouts as the vehicle in outbreaks, could also play a role in the discrepancy between the estimates from the model and the reported outbreak data.

Although fine tuning of the model and assumptions will be necessary when additional information, especially data about the efficacy of sampling and testing programs, is available, the results would likely still align with those obtained in the current study that demonstrated that a significant risk reduction can be achieved based on current technology. Because even seed treatment alone could achieve a significant risk reduction and its combination with testing of SIW would further reduce the risk, it is reasonable to believe that sprouts could be a safe food if either seed treatment or sampling and testing programs can be improved. This study is the first to quantify the public health impact associated with *Salmonella* contamination in sprouts and to estimate the risk reduction that can be achieved as a result of different mitigation approaches. Further confirmation of the findings and continuing exploration of this approach to evaluate risk management strategies for other pathogens associated with sprouts are warranted.

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REFERENCES

1. Aabo, S., and D. L. Baggesen. 1997. Growth of *Salmonella* Newport in naturally contaminated alfalfa sprouts and estimation of infectious dose in a Danish *Salmonella* Newport outbreak due to alfalfa sprouts. *Salmonella Salmonellosis* 97:425–426.
2. Bollaerts, K. E., W. Messens, L. Delhalle, M. Aerts, Y. Van der Stede, J. Dewulf, S. Maes, D. Quoilin, K. Mintiens, and K. Grijspeerdt. 2009. Development of a quantitative microbial risk assessment for human salmonellosis through household consumption of fresh minced pork meat in Belgium. *Risk Anal*. 29:820–840.
3. Centers for Disease Control and Prevention. 2013. National Health and Nutrition Examination Survey 2007–2008. Available at: http://wwwn.cdc.gov/nchs/nhanes/search/nhanes07_08.aspx. Accessed 1 October 2015.

4. Danyluk, M. D., L. J. Harris, and D. W. Schaffner. 2006. Monte Carlo simulations assessing the risk of salmonellosis from consumption of almonds. *J. Food Prot.* 69:1594–1599.
5. Danyluk, M. D., and D. W. Schaffner. 2011. Quantitative assessment of the microbial risk of leafy greens from farm to consumption: preliminary framework, data, and risk estimates. *J. Food Prot.* 74:700–708.
6. Delignette-Muller, M. L., and M. Cornu. 2008. Quantitative risk assessment for *Escherichia coli* O157:H7 in frozen ground beef patties consumed by young children in French households. *Int. J. Food Microbiol.* 128:158–164.
7. Ding, H., T. J. Fu, and M. A. Smith. 2013. Microbial contamination in sprouts: how effective is seed disinfection treatment? *J. Food Sci.* 78:R495–R501.
8. Donaldson, M. S. 2004. Nutrition and cancer: a review of the evidence for an anti-cancer diet. *Nutr. J.* 3:19.
9. Duffy, S., and D. W. Schaffner. 2002. Monte Carlo simulation of the risk of contamination of apples with *Escherichia coli* O157:H7. *Int. J. Food Microbiol.* 78:245–255.
10. Fahey, J. W., P. J. Ourisson, and F. H. Degnan. 2006. Pathogen detection, testing, and control in fresh broccoli sprouts. *Nutr. J.* 5:13.
11. Franz, E., S. O. Tromp, H. Rijgersberg, and H. J. van der Fels-Klerx. 2010. Quantitative microbial risk assessment for *Escherichia coli* O157:H7, *Salmonella,* and *Listeria monocytogenes* in leafy green vegetables consumed at salad bars. *J. Food Prot.* 73:274–285.
12. Inami, G. B., S. M. Lee, R. W. Hogue, and R. A. Brenden. 2001. Two processing methods for the isolation of *Salmonella* from naturally contaminated alfalfa seeds. *J. Food Prot.* 64:1240–1243.
13. Kurtzweil, P. 1999. Questions keep sprouting about sprouts. *FDA Consum.* 33:18–22.
14. Latorre, A. A., A. K. Pradhan, J. A. Van Kessel, J. S. Karns, K. J. Boor, D. H. Rice, K. J. Mangione, Y. T. Grohn, and Y. H. Schukken. 2011. Quantitative risk assessment of listeriosis due to consumption of raw milk. *J. Food Prot.* 74:1268–1281.
15. Liao, C. H., and W. F. Fett. 2003. Isolation of *Salmonella* from alfalfa seed and demonstration of impaired growth of heat-injured cells in seed homogenates. *Int. J. Food Microbiol.* 82:245–253.
16. Liu, B., and D. W. Schaffner. 2007. Quantitative analysis of the growth of *Salmonella* Stanley during alfalfa sprouting and evaluation of *Enterobacter aerogenes* as its surrogate. *J. Food Prot.* 70:316–322.
17. Mataragas, M., M. H. Zwietering, P. N. Skandamis, and E. H. Drosinos. 2010. Quantitative microbiological risk assessment as a tool to obtain useful information for risk managers—specific application to *Listeria monocytogenes* and ready-to-eat meat products. *Int. J. Food Microbiol.* 141(Suppl.):170–179.
18. Murmann, L., L. G. Corbellini, A. A. Collor, and M. Cardoso. 2011. Quantitative risk assessment for human salmonellosis through the consumption of pork sausage in Porto Alegre, Brazil. *J. Food Prot.* 74:553–558.
19. Oscar, T. P. 2004. A quantitative risk assessment model for *Salmonella* and whole chickens. *Int. J. Food Microbiol.* 93:231–247.
20. Ottoson, J. R., K. Nyberg, R. Lindqvist, and A. Albihn. 2011. Quantitative microbial risk assessment for *Escherichia coli* O157 on lettuce, based on survival data from controlled studies in a climate chamber. *J. Food Prot.* 74:2000–2007.
21. Pradhan, A. K., R. Ivanek, Y. T. Grohn, R. Bukowski, I. Geornaras, J. N. Sofos, and M. Wiedmann. 2010. Quantitative risk assessment of listeriosis-associated deaths due to *Listeria monocytogenes* contamination of deli meats originating from manufacture and retail. *J. Food Prot.* 73:620–630.
22. Robert Koch Institute. 2011. Final report—EHEC O104:H4 outbreak. Available at: http://www.rki.de/EN/Home/EHEC_final_report.html. Accessed 23 April 2015.
23. Rocourt, J., P. BenEmbarek, H. Toyofuku, and J. Schlundt. 2003. Quantitative risk assessment of *Listeria monocytogenes* in ready-to-eat foods: the FAO/WHO approach. *FEMS Immunol. Med. Microbiol.* 35:263–267.
24. Sikin, A. M., C. Zoellner, and S. S. Rizvi. 2013. Current intervention strategies for the microbial safety of sprouts. *J. Food Prot.* 76:2099–2123.
25. Thomas, J. L., M. S. Palumbo, J. A. Farrar, T. B. Farver, and D. O. Cliver. 2003. Industry practices and compliance with U.S. Food and Drug Administration guidelines among California sprout firms. *J. Food Prot.* 66:1253–1259.
26. U.S. Food and Drug Administration (FDA). 1989. Seeds for sprouting prior to food use, i.e., dried mung beans, alfalfa seeds, etc. Compliance policy guide 7120.28, section 555.750. FDA, Washington, DC.
27. U.S. Food and Drug Administration. 1999. Guidance for industry: reducing microbial food safety hazards for sprouted seeds. Available at: http://www.fda.gov/Food/GuidanceRegulation/GuidanceDocumentsRegulatoryInformation/ProducePlantProducts/ucm120244.htm. Accessed 23 April 2015.
28. U.S. Food and Drug Administration. 1999. Guidance for industry: sampling and microbial testing of spent irrigation water during sprout production. Available at: http://www.fda.gov/Food/GuidanceRegulation/GuidanceDocumentsRegulatoryInformation/ProducePlantProducts/ucm120246.htm. Accessed 23 April 2015.
29. U.S. Food and Drug Administration. 2013. Standards for the Growing, Harvesting, Packing, and Holding of Produce for Human Consumption. Sprouts: Subpart M. Available at: http://www.fda.gov/downloads/Food/GuidanceRegulation/FSMA/UCM359285.pdf. Accessed 23 April 2015.
30. U.S. Food and Drug Administration Center for Food Safety and Applied Nutrition (FDA/CFSAN), Joint Institute for Food Safety and Applied Nutrition JIFSAN and Risk Sciences International RSI. 2014. FDA-iRISK version 1.0. FDA CFSAN. College Park, Maryland.
31. Willis, C., C. L. Little, S. Sagoo, E. de Pinna, and J. Threlfall. 2009. Assessment of the microbiological safety of edible dried seeds from retail premises in the United Kingdom with a focus on *Salmonella* spp. *Food Microbiol.* 26:847–852.
32. World Health Organization/Food and Agriculture Organization of the United Nations. 2002. Risk assessments of *Salmonella* in eggs and broiler chickens. Microbiological Risk Assessment Series. Available at: ftp://ftp.fao.org/docrep/fao/005/y4392e/y4392e00.pdf. Accessed 23 April 2015.