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Editors

W. Christopher Scruton
Stephen Claas

Layout

David Brown

Logo Design

Ruth Cronje, and Jan Swanson;
based on the original design by Dr. Robert Dunlop

Cover Design

Sarah Summerbell

Where should we allocate resources to reduce foodborne risks?

Dr. Peter Davies
MAF Professor of Food Safety and Public Health, Massey University, New Zealand

Introduction

An estimated 76 million annual cases of foodborne illnesses in the USA[1] bear witness to the fact that systems for food safety assurance have fallen short of public expectations. Over the last decade, factors that elevated food safety to a front-page issue included the following:[2]

- Highly publicized outbreaks of foodborne disease in developed countries
- Active surveillance providing better estimates of the incidence of foodborne disease
- Consumer advocacy for better "protection" against foodborne hazards
- Revolutionary changes in regulation of the meat industry
- Increasing trade in food products and international trade agreements promoting freer trade
- Implementation of "quality assurance" programs, or control programs for specific foodborne pathogens, by other pork-exporting countries

Pivotal outbreaks in 1992-93 (e.g., *E. coli* O157:H7 "Jack-in-the-Box" outbreak in the USA; *S. infantis* outbreak linked to pork in Denmark) fuelled an existing groundswell of "full belly" consumer angst about the food (and particularly meat) supply that had evolved due to multiple factors, the most significant being the emergence of BSE and variant CJD in the United Kingdom. The outbreaks contributed respectively to the passing of the HACCP/Pathogen Reduction Act ("Mega-Reg") in the USA in 1996, and the implementation of a national *Salmonella* control program by the Danish swine industry.[3] These were major milestones in a paradigm shift that resulted in the following:

- Questioned the efficacy of traditional meat inspection systems for protecting consumers from microbial foodborne hazards
- Shifted attention to the contribution of the animal production sector to the risk of foodborne disease

The "farm-to-table" concept (acknowledging that all participants in the continuum of food production and consumption bear some responsibility for reducing the risk of foodborne disease) emerged as the fashionable paradigm for food safety. However, the high level of consensus about the appropriateness of a "farm-to-table" approach has yet to be matched by meaningful analysis of how this should be achieved. In particular, generic calls for control of foodborne pathogens in food animal populations have somewhat naively presumed that such an approach is feasible and efficacious and have rarely touched on economic constraints. The appeal of a farm-to-table strategy has generally outpaced the development of tactics to implement it. Despite the popular appeal of "pre-harvest" control of foodborne hazards, the "Mega-Reg" stopped short of involvement at the pre-harvest level. The likely wisdom of that decision resides in the fact that, at that time, epidemiologic knowledge of most (at least bacterial) foodborne hazards in animal populations was inadequate to enable reliable and cost-effective control measures to be mandated. Over the last decade, research into the epidemiology of foodborne pathogens in animal populations has been a growth industry. The 4th International Symposium on the Epidemiology and Control of *Salmonella* and Other Foodborne Pathogens in Pork in Germany in 2001 attracted 169 scientific contributions. This paper will discuss some of these developments in the context of optimizing risk management of foodborne pathogens in pork.

Horses for courses

The perennial economic question is how best to allocate limited societal resources to maximize societal benefits (in this case, reducing the costs of foodborne illnesses). Crudely, we can divide the food supply continuum into sectors of production, processing, distribution, and consumption. Within each sector, a range of interventions might be applied to reduce risk of foodborne hazards, and the goal is to define the optimal mix of interventions across the continuum that delivers maximum risk reduction at minimal cost. The value of any given intervention will be determined by the following:

- Efficacy (including spectrum of hazards controlled)
- Cost
- Probability of post-intervention contamination

The ideal intervention would have low cost, be effective against all significant hazards, and be implemented near to the point of consumption (minimizing the risk of subsequent contamination). However, for biological hazards with relatively complex ecologies, it is optimistic to expect single interventions (particularly far "upstream" from consumers) to provide adequate protection. Measures taken to manage consumer risks from BSE in the UK illustrate how a "portfolio" approach of pre-harvest and post-harvest measures can be employed to minimize risk. Banning of the feeding of ruminant materials to ruminants, and removal of high risk animals (cattle older than 30 months) and tissues ("specified risk materials") from the food chain are combined to minimize risk of animal and human exposure to infective materials. This approach is founded upon knowledge of the predominant modes of transmission of the agent, and the epidemiologic and pathophysiologic mechanisms of disease. It is also facilitated by the low probability of cross-contamination or multiplication of the agent in post-processing sectors of the food supply chain.

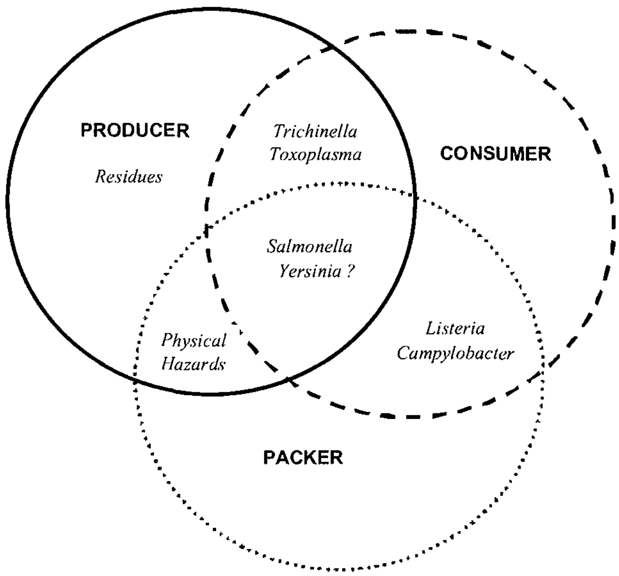
Detailed hazard analysis is the first prerequisite for designing an "optimal" risk management system (**Table 1**). Although such prioritization of hazards is essential for targeting resources to the relevant hazards, detailed understanding of the epidemiology of individual hazards[5] (including characteristics of testing protocols) is equally necessary to tailor effective risk management systems. It is self-evident that the optimal mix of interventions will differ for physical, chemical, and biological hazards. It is equally self-evident that the optimal mix of interventions will differ among biological hazards with different physical, ecologic, and epidemiologic characteristics. Furthermore, the nature and intended use of specific products (e.g., ready-to-eat product) will often influence the risk management options. Appropriate allocation of responsibilities for risk reduction must be founded on adequate understanding of the biology and control options for each hazard. For the sake of discussion, **Figure 1** presents a simplified framework (ignoring regulatory measures and the distribution sector) for identifying which sectors should be involved in risk reduction for a range of hazards linked to pork.

Table 1: Major foodborne pathogens in the USA and relative importance of pork as a source.

USDA ranking[1]	Pathogen	Relative Importance of pork[A,B]
1	*Salmonella*	++
2	*Campylobacter jejuni/coli*	+
3	*Toxoplasma gondii*	+++
4	*E. coli* O157:H7	-
5	*Listeria monocytogenes*	++
6	*Trichinella spiralis*	++++
6	*Yersinia enterocolitica*	++++
8	Other (non O157) SLT *E. coli*	?
9	*Shigella*	-
10	*Clostridium botulinum*	+
11	Other (non SLT) *E. coli*	?
12	*Vibrio vulnificus*	-
13	Hepatitis A virus	-
14	Norwalk virus	-
15	*Staphylococcus aureus*	-
15	*Arcobacter spp.*	++
17	*Clostridium perfringens*	+
18	*Bacillus cereus*	-
19	*Vibrio parahemolyticus*	-
20	*Taenia solium*	++++
21	*Vibrio cholerae*	-
22	*Crytosporidium*	+
23	Other *Vibrio spp.*	-
24	Giardia	+
25	Taenia saginata	-

ATable ignores potential cross-species contamination after slaughter (e.g. *S. aureus*)
BSubjective scale where: ++++ pork unquestionably main source among meats (excluding game), +++ pork considered main source, but other sources also important, ++ pork not main source, but still considered an important source, + pork a known source but other sources thought more important, - pigs not yet shown to be a source.

Figure 1: Spheres of responsibility for producers, packers, and consumers with respect to reducing foodborne risks associated with pork.



Carving the responsibility pie

The framework for distribution of responsibilities outlined in **Figure 1** is purely conceptual, but underpins the fact that interventions need to be applied strategically at those points where the greatest impact on ultimate risk will be achieved. However, participants in all sectors should be motivated by their own self-interest to ensure that they take what measures they can to reduce risk. Public education should reinforce that the food supply will never be risk free, and that appropriate kitchen hygiene and cooking practices can mitigate the risk of multiple potential foodborne hazards. Processors want to be meticulous in development and implementation of good management practices and process control, as brand image can be destroyed almost overnight by adverse events, be they disease outbreaks or product recalls. Companies must minimally meet regulatory goals for microbiological safety, but for commercial or other reasons may aspire to higher standards that are nationally and internationally competitive. The broad spectrum of hazards that can be addressed by reducing risk of fecal contamination of products has underpinned the historic regulatory emphasis on this sector. However, understanding of the relative costs and benefits of specific intervention options at the plant level needs continual refinement, and it is not unexpected that the relative value of different risk reduction options will vary among plants.

Few would argue that consumers should bear significant responsibilities in risk reduction for chemical or physical hazards. Similarly, considering current epidemiologic knowledge, availability of effective interventions, and probability of downstream contamination, it is hard to make a case for pre-harvest control of *Campylobacter* or *Listeria spp.* (and also *Yersinia*) in swine production. As with the case of BSE, pre-harvest control holds most promise for biological agents that have relatively simple epidemiology (i.e., limited modes of transmission) and are unable to replicate in products. It is for these reasons that improvements to production systems and relatively simple interventions have led to marked reduction in the prevalence of *Trichinella spiralis* and *Toxoplasma gondii* in swine in the USA.[6] The pre-harvest initiatives undertaken to reduce risk of these parasitic zoonoses in the USA are appropriate. However, the case is less clear for bacterial agents with more complex ecology.

The example of *Salmonella*

The most fertile ground for debate on allocating resources for risk reduction is found when potential risk reduction measures exist across all sectors of the food supply continuum. This is the scenario with *Salmonella*, and the technical feasibility of pre-harvest control of *Salmonella* using microbiological testing and regulation has been demonstrated by the Swedish poultry and swine industries.[7] However, perhaps the most eloquent statement of the difficulty and cost of implementing the "Swedish model" for *Salmonella* control is that, despite its apparent success, after some 40 years it has not been adopted by any major swine- or poultry-producing nation. The push for pre-harvest control of *Salmonella* gained considerable momentum from the implementation of the Danish *Salmonella* control program, which has focused on pre-harvest interventions in herds identified serologically to present the highest infection risks.

The concept of pre-harvest food safety assumes management decisions can be taken that will to reduce exposure of animals to potential hazards, thereby ultimately reducing risk to consumers. There are two general approaches for the control of foodborne pathogens:

- Establishment and maintenance of pathogen-free animal populations (Swedish model)
- Reduction of prevalence in endemically infected herds through improved production systems and management (Danish model)

To assess the relative merits of these approaches, one must understand the principal sources of infection for herds, risk factors for spread of infection within infected populations, and the feasibility of applying effective, commercially viable control measures. As stated previously, selection of interventions should consider efficacy, cost and probability of downstream contamination. Although it is evident from the Danish experience that some progress is achievable using management interventions to reduce rather than exclude *Salmonella* on farms, the efficacy and cost of specific interventions is not well understood. This program has required an annual investment of the order of $14 million per annum (or approximately $0.70 per pig marketed), and a modeling approach was recently used to gain some insight into the question of future resource allocation for *Salmonella* control in Denmark.[8] The model predicted that improvement of any single factor had a limited impact on the level of contamination, and the largest reduction was observed when several factors were improved concurrently. As one would expect, lack of data was identified as a major limitation to the model.

However, in the USA it appears that a high probability of downstream infection, particularly in lairages,[9,10] is a particular concern with respect to the investment in pre-harvest controls, at least at the individual farm level. Similarly, recent studies in Holland found that holding in lairage for two hours or more led to substantial risk of *Salmonella* infection of pigs from herds.[11,12] Data from Denmark suggest that cross-contamination at lairage may be less important.[13] However, the data in the USA indicate that pre-harvest control on individual farms is likely to be unrewarding (in terms of ultimate risk reduction for consumers) unless separate slaughter is possible for low risk and high risk populations as suggested in Holland and practiced in Denmark. Quality assurance claims founded on pre-harvest procedures for *Salmonella* are highly questionable unless separate slaughter is also conducted. Developing interventions targeting the immediate pre-slaughter management should clearly be a priority in the US swine industry.

Quantitative risk assessment and modeling

The food safety wave of the 1990s saw the adoption of risk assessment and decision support approaches that sought to integrate existing knowledge and to address uncertainty and information gaps regarding the epidemiology of foodborne pathogens.[14,15] Predominantly these involved risk assessment methodologies for purposes of risk-based characterization of control points, comparison of intervention strategies, and targeting areas requiring future research. While aspiring to address the entire farm-to-table continuum, most models have been focused in the downstream sectors. Again, this is to be expected due to the complexity of live animal production systems and limited knowledge of the effect of pre-harvest interventions. Even for specific pathogen-product pairs, quantitative risk assessment models are complex and uncertainties abound. To date these models have contributed most in advancing understanding of the systems involved and areas requiring further research more so than practical outcomes that have guided producer, processor or consumer behaviors. Lack of information about the efficacy of specific interventions at all levels continues to be a major impediment to translating advances in risk assessment to effective risk management. These approaches are probably best used for specific pathogen-product pairs and may be useful for risk communication.[16]

Looking forward

The current level of research activity into methods for reducing risk of major foodborne pathogens promises to deliver new intervention options in pre-harvest and post-harvest sectors. Recent candidates include administration of sodium chlorate or organic acids in water prior to slaughter, and the use of bacteriophages.[17-19] Irradiation, the intervention that dare not speak its name, has many desirable attributes, but its future will depend on the balance between changing consumer attitudes and technological advances that may render it obsolete. For microbial pathogens, technological advances at the harvest and post-harvest level are likely to be more rapid than at the pre-harvest level, and more effective risk management in downstream sectors may ease some of the current pressures for control of foodborne pathogens at the farm level.

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