



The Direct Relationship between Animal Health and Food Safety Outcomes

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Introduction

It is critical that decision makers understand the relationship between animal health and food safety.

Many groups in society, including politicians, activists, scientists, and stakeholders, are advocating significant changes to livestock production practices. These changes include modification of stocking densities, limitations on antimicrobial use, and requirements for outdoor “experiences.” Such changes may affect animal health, productivity, and food quality. Simultaneously, many consumers are demanding virtually risk-free food at least cost, and they believe that food safety should be addressed on-farm as well as during processing. It is critical that decision makers understand the relationship between animal health and food safety, which is a complex association requiring careful evaluation of many variables.

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The Gentle Doctor, 1976 cast; and Veterinary Medicine Mural, 1938; by Christian Petersen (Danish-American, 1885–1961)

Commissioned by the College of Veterinary Medicine. Casting gift of Dr. and Mrs. J. E. Salsbury. In the Art on Campus Collection, Iowa State University, Ames, Iowa.

Objectives

This paper will focus on direct and indirect impacts that animal health may have on public health.

The objectives of this paper are to (1) discuss the quantifiable impact animal health has on public health risk due to foodborne illness from meat, milk, eggs, and poultry; (2) identify the factors that impact animal health; and (3) highlight specific research needs. This paper will focus on direct and indirect impacts that animal health may have on public health.

Pressures to Change Livestock Rearing Methods

If changes affect animal health, they may well also affect public health.

There are many pressures and trends to change the way livestock are raised. If these changes affect animal health, they may well also affect public health. Figure 1 shows the relationship between animal health and public health. Various policy changes may negatively impact animal health, resulting in more marginally or not visibly ill pigs, which tips the scales toward reduced public health. These proposed changes and their consequences need to be considered carefully. Trends include

- Sustainability (social, environmental, economic),
- Local production,
- Economies of scale,
- Housing,
- Antibiotic use, and
- Animal welfare.

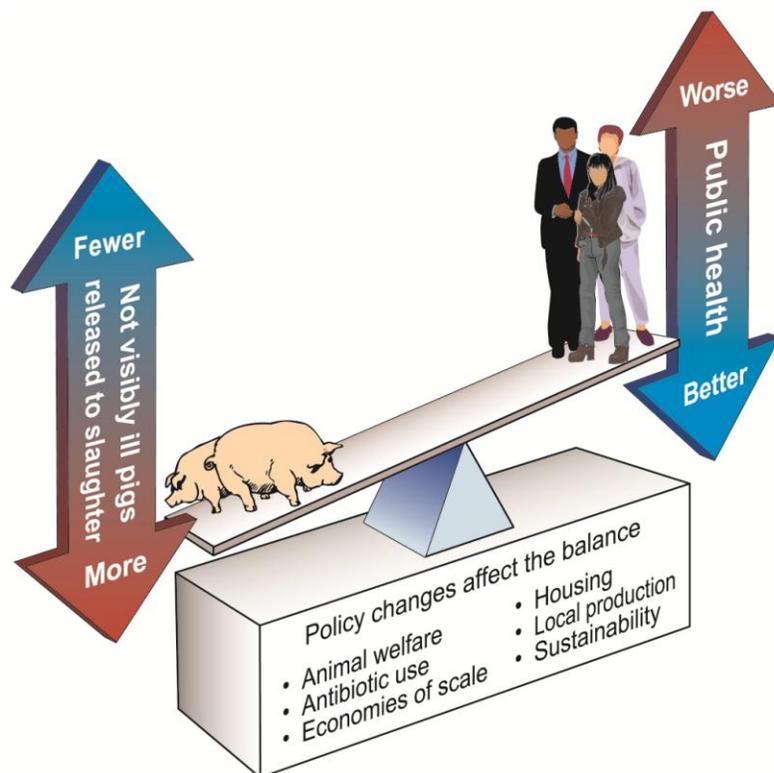


Figure 1. Conceptual model of the relationship between animal health and public health. As on-farm animal health improves (fewer subclinically ill pigs), the incidence of foodborne human illness may decrease (better human public health).

There is a significant push for locally raised products.

The health impacts of organic production must be considered, as the organic accreditation process states that for animal products to be sold under this label they must not be treated with antibiotics or synthetic anthelmintic (worm-preventing) drugs.

A long-standing premise of the U.S. food safety inspection system is that healthy livestock are essential for a safe food supply.

Questions arise concerning the potential impacts of these [not visibly ill] animals entering the food supply on public health risk from foodborne pathogens.

Three general indications support the premise that healthy animals make safer food and, conversely, that unhealthy or marginally healthy (not visibly ill) animals increase foodborne risk.

According to a recent National Academy of Sciences report on sustainability, “U.S. farmers are under pressure to satisfy multiple demands” (NRC 2010). These pressures will change the way livestock are raised, impacting practices such as housing, feeding, and location of production.

There is a significant push for locally raised products, with programs such as “Know Your Farmer, Know Your Food” (USDA 2011). In every country, economics is a leading consideration in the drive toward consolidation and intensification of production methods (FAO 2004). Animal and human health impacts of shifting from low-cost outdoor housing to controlled environments with higher stocking densities need to be evaluated. The European Union has severely curtailed the use of disease-preventive antibiotics in food-animal production (Casewell et al. 2003; Ferber 2003) and has begun to legislate how animals are housed (e.g., banning of confinement housing such as gestation stalls for pigs). Subsequent to these bans, treatment of pigs for clinical disease has reportedly increased in Denmark and the Netherlands (DANMAP 2010; MARAN 2007).

The health impacts of organic production must be considered, as the organic accreditation process states that for animal products to be sold under this label they must not be treated with antibiotics or synthetic anthelmintic (worm-preventing) drugs (USDA–AMS 2011). Additionally, organic production may mean “natural” or pasture-based rearing. When coupled with animal welfare concerns, significant housing changes might impact animal health. For example, increased exposure to the soil and vermin may increase the prevalence of zoonotic diseases in livestock.

Healthy Animals Make Safer Food

The recent focus of the “One Health” concept highlights the premise that animal health is important to human health and well-being; this is particularly noted regarding zoonotic diseases, which transmit directly from animals to humans (One World, One Health 2008). Additionally, the impact of animal health on the incidence of human foodborne diseases needs to be considered. A long-standing premise of the U.S. food safety inspection system is that healthy livestock are essential for a safe food supply. This premise is the primary motivation for the U.S. Department of Agriculture’s (USDA) antemortem inspection and gross pathological postmortem inspection as initiated in the Meat Inspection Act of 1906.

In addition to overtly ill animals, there is a growing body of evidence showing that chronically, previously, and not visibly ill animals are more likely to be contaminated with foodborne pathogens after processing in the abattoir (slaughterhouse). These animals, however, may go unnoticed during antemortem (live animal) inspection, and thus questions arise concerning the potential impacts of these animals entering the food supply on public health risk from foodborne pathogens.

Evidence to Support the Direct Public Health Impact of Animal Health

Three general indications support the premise that healthy animals make safer food and, conversely, that unhealthy or marginally healthy (not visibly ill) animals increase foodborne risk: (1) USDA Food Safety and Inspection Service (FSIS) federal regulations, (2) indirect evidence, and (3) epidemiologic studies with risk modeling.

USDA Food Safety and Inspection Service Regulations

The USDA's FSIS Public Health Veterinarians and other Inspection Program Personnel are given the responsibility for ensuring the safety and security of the nation's food supply.

The USDA's FSIS Public Health Veterinarians and other Inspection Program Personnel (IPP) are given the responsibility through the Federal Meat Inspection Act and the Poultry Products Inspection Act for ensuring the safety and security of the nation's food supply. This is accomplished, in part, through the examination of live animals (antemortem inspection) for disease and through inspection of each carcass after harvest (postmortem inspection) to ensure that they are safe for human consumption. Antemortem inspection is a screening process to remove obviously diseased animals from the food supply and to identify animals that require a more extensive postmortem examination by an FSIS veterinarian. When conducting antemortem inspections, the IPP evaluate animals for signs of disease as well as any signs that the animals may have been recently treated, resulting in illegal drug residues.

Those animals that are considered healthy enough for harvest then receive postmortem inspection. The IPP again inspect the carcasses for signs of disease or contamination (as in the case of not visibly ill animals), or for indications that they may have been recently treated (e.g., injection sites). The IPP either can have contamination removed or, if they suspect a disease condition, can have the carcass and all the internal parts held for veterinary examination. In some cases, the entire carcass is condemned. The FSIS has delineated certain conditions that can be correlated definitively to public health in humans (e.g., infectious conditions and fecal contamination). In addition, the IPP are trained to identify certain zoonotic conditions—those conditions that are known to infect humans (USDA-FSIS 2009).

Indirect Evidence

Indirect evidence suggests that subclinically ill (not visibly ill) animals also contribute to public health risk.

Indirect evidence suggests that subclinically ill (not visibly ill) animals also contribute to public health risk (Andreasen, Musing, and Krogsgaard 2001; Russell 2003) (see Figure 1). Subclinical illness may therefore increase carcass contamination in a variety of ways. Animals stressed or immune compromised by long-term, low-grade illness are more likely to be infected with foodborne pathogens, especially *Salmonella* (Salak-Johnson and McGlone 2007; Noyes, Feeney, and Pijoan 1990). Additionally, animals with abscesses or other significant lesions will require extra trimming or further handling during the harvest process, and this handling may increase the likelihood of cross-contamination (Olsen et al. 2003; Rosenquist et al. 2006). Finally, certain illnesses or conditions may increase the chance of human error during the harvest process. For example, an adhesion may cause intestines to adhere to the body cavity; during evisceration, extra force may be required, leading to leakage or spilling of intestinal contents. Given the percentage of swine carrying *Salmonella* in the gastrointestinal tract at the time of harvest, if leakage occurs, there is approximately a 40% probability of *Salmonella* contamination (Hurd et al. 2002; Hurd et al. 2004; Rostagno et al. 2003). Carcass contamination is assumed to lead to product contamination and foodborne illness.

Other concerns include the presence of abscesses on the liver or around the heart sac in cattle, which can lead to abscess spillage when removing the viscera.

Other concerns include the presence of abscesses on the liver or around the heart sac in cattle, which can lead to abscess spillage when removing the viscera. Peritonitis, a common inflammation of the peritoneal cavity, may arise from a number of causes. Animals sent to slaughter that unknowingly healed improperly will appear healthy at antemortem inspection but are subsequently identified by the internal adhesions. These compromised animals are at increased risk for potential cross-contamination during harvest.

In pigs, the spleen can be the site of multiple abscesses when recovering from a bacterial infection.

Lung lesions observed at harvest are a good measure of pig health on-farm.

The connection between subclinical animal health and carcass contamination with foodborne pathogens has been directly demonstrated.

The probability of *Salmonella* contamination in carcasses with lesions identified at the abattoir was 90% (adjusted odds ratio 1.9) higher than that in carcasses lacking lesions.

A model has been developed that predicts the increase in the days of human illness (due to campylobacteriosis) per year according to the number of subclinically ill poultry harvested.

In pigs, the spleen, which has several important functions because of the large number of macrophages, including filtering the bacteria from the body, can be the site of multiple abscesses when recovering from a bacterial infection, which, if accidentally cut, could serve as a source of cross-contamination. Additionally, splenic torsion leading to adhesions of the spleen and liver to the intestines may cause difficulties during the evisceration process.

Lung lesions observed at harvest are a good measure of pig health on-farm. Morrison, Pijoan, and Leman (1986) investigated the relationship between growth rate and feed conversion in pigs with lung lesions. In 13 of 23 studies, they observed that a reduction in growth rate and feed conversion was associated with pigs that had lung lesions but observed no association in the remaining 10 studies (Morrison, Pijoan, and Leman 1986). A more recent study (Regula et al. 2000) found the presence of lung lesions at harvest to be associated with lower average daily gain, an indicator of animal health.

Epidemiologic Studies with Risk Modeling

Epidemiologic Studies Demonstrating a Relationship

The connection between subclinical animal health and carcass contamination with foodborne pathogens has been directly demonstrated. Russell (2003) found that chicken flocks diagnosed with airsacculitis lesions (similar to pneumonia) at the time of processing had lower average bird weights, higher levels of fecal contamination on the carcass, and increased *Campylobacter* loads on the meat than flocks without airsacculitis.

In another study, pig carcasses affected with lesions indicative of chronic internal infections were two to five times more likely to be contaminated at the end of harvest with the foodborne illness-causing bacteria *Campylobacter* (Hurd et al. 2008). A more recent USDA-funded study quantified the relationship between “peelouts” and carcass contamination (Hurd et al. 2012). A peelout occurs when the pleural and peritoneal lining must be removed because of adhered visceral tissue (e.g., lungs, liver, etc.; Figure 2). The probability of *Salmonella* contamination in carcasses with lesions (12% of 182 carcasses tested) identified at the abattoir was 90% (adjusted odds ratio 1.9) higher than that in carcasses lacking lesions (8% of 176), after controlling for replicate identity and antimicrobial use (Figure 2).

Risk Modeling

A model has been developed that predicts the increase in the days of human illness (due to campylobacteriosis) per year according to the number of subclinically ill poultry harvested (Singer et al. 2007). This model shows that even minor changes in *Campylobacter* loads in poultry products could have substantial impacts on public health. The change in human illness days is modeled as a function of the proportion of the illness rate from consuming subclinically ill but contaminated birds. The results were modeled across a range of potencies from 1 to 20; potency reflects the correlation between animal health and carcass contamination. As shown in Figure 3, the change in human illness days was very sensitive to small changes in increased animal illness percentage.

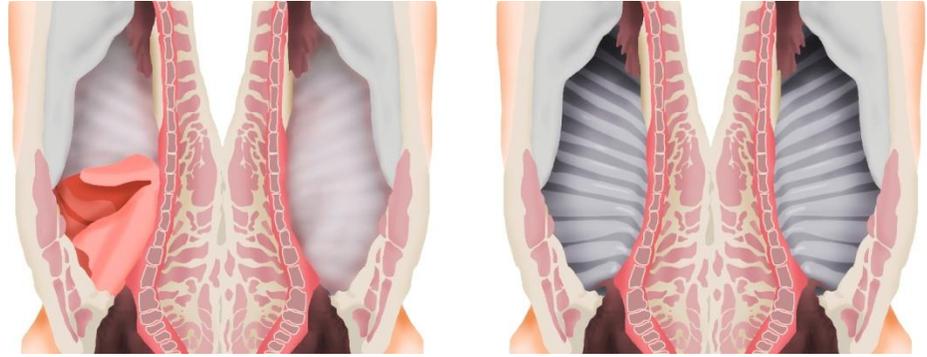


Figure 2. A lesioned carcass that cultured *Salmonella* positive and thus classified as a peelout (left), compared to the nonlesioned carcass cultured *Salmonella* negative that was classified as a nonpeelout (right). The lesioned carcass was 90% more likely to be contaminated with *Salmonella* at the end of harvest process (Hurd et al. 2012).

When applying these results to the 95 million pigs annually harvested in the United States, the 90% contamination risk of these pigs requiring extra handling can be seen to have major public health implications.

When applying these results to the 95 million pigs annually harvested in the United States, the 90% contamination risk of these pigs requiring extra handling (Figure 2) can be seen to have major public health implications. For example, a change in the prevalence of lesioned carcasses from the observed 7.1% to 10.7% (a 50% increase) could translate into an increase of 140,220 *Salmonella*-contaminated carcasses entering the U.S. food supply.

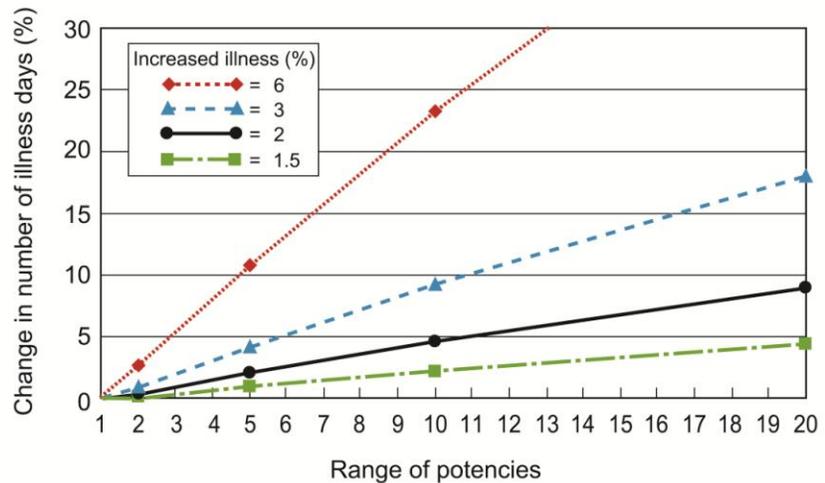


Figure 3. Changes in the total number of human illness days per year due to *Campylobacter* expressed relative to increased animal illness percentage. The percentage change in illness days is shown as a function of potencies, reflecting the contamination difference between chicken servings from not visibly ill versus healthy chickens. (Source: Adapted from Singer et al. 2007.)

Adequate and proper nutrition of animals clearly plays an important role in ensuring animal health.

Factors Known to Affect Animal Health

Nutrition

Adequate and proper nutrition of animals clearly plays an important role in ensuring animal health. Animal nutrition research spanning more than a hundred years

Livestock producers use a variety of husbandry practices, housing strategies, and biosecurity measures to decrease disease risk and promote animal health.

As an example, maintaining animals on slatted or mesh floors, as is common in modern swine production and some poultry systems, decreases animal contact with manure and thus with fecalborne pathogens.

Animal drinking water can be contaminated by manure, bird and rodent pests, and other potential disease carriers, all of which can be vectors or fomites for foodborne pathogens.

Housing livestock indoors can also provide advantages in managing many foodborne organisms.

has defined the nutrients required by animals. Using this information, diets can be formulated from feeds and ingredients to meet these nutrient requirements with the expectation that animals will be not only healthy and free of nutrient-related deficiency diseases but also productive and efficient contributions to human food. The health of an animal is a direct function of its nutritional status. Precision nutrition for food-producing animals provides for optimum digestion, immune and endocrine functions, reproduction, and growth, as well as minimum animal impact on the environment (NRC 2002, 2012; Preston 2011).

Animal Management

Livestock producers use a variety of husbandry practices, housing strategies, and biosecurity measures to decrease disease risk and promote animal health. Such practices, designed primarily to decrease livestock diseases and improve productive efficiency, may also inherently lower the prevalence of foodborne pathogens. Stress from any source can increase susceptibility to pathogens and shedding. (e.g., molting with feed withdrawal increases *Salmonella* enteritidis shedding in layer hens [Ricke et al. 2010]).

As an example, maintaining animals on slatted or mesh floors, as is common in modern swine production and some poultry systems, decreases animal contact with manure and thus with fecalborne pathogens (Mench, Sumner, and Rosen-Molina 2011). Internal parasite loads also are decreased with the use of slatted or mesh floors (Moncol 1993). Hurd and colleagues (2003) observed that swine held in abattoirs (two to four hours) on slatted floors had a lower prevalence of *Salmonella* compared with swine maintained on solid floors for the same period of time.

Animal drinking water can be contaminated by manure, bird and rodent pests, and other potential disease carriers, all of which can be vectors or fomites for foodborne pathogens. Common husbandry advancements, such as the use of nipple waterers and closed, float-ball-style watering systems, can decrease these contamination risks (Bahnsen et al. 2006; Carlson et al. 2011). The improved hygiene of swine production systems, which occurred with the transition from low-management outdoor production to more intensely managed indoor systems, is primarily responsible for the sharp reduction in *Trichinella spiralis*-infected pigs in the United States (Burke, Masuoka, and Murrell 2008; CDC 2009; Gebreyes et al. 2008). This is a very significant public health improvement.

Housing livestock indoors can also provide advantages in managing many foodborne organisms. Because outdoor environments cannot be cleaned or disinfected easily, pathogens can persist in the soil, standing water, outdoor structures, and other micro-environments, infecting successive generations of livestock (Callaway et al. 2005). Other studies have shown that *Campylobacter* and *Salmonella* are more common in chickens having outdoor exposure than in birds raised in conventional indoor housing (cages) (Kijlstra, Meerburg, and Bos 2009). Dairy cows were shown to be at greater risk of subclinical mastitis when kept in outdoor environments compared with cows kept in barns (Busato et al. 2000). According to several studies, outdoor production can also promote infection of the zoonotic parasite *Toxoplasma gondii* in poultry and swine (Dubey et al. 2004; Gebreyes et al. 2008; Hensel and Neubauer 2002; Kijlstra et al. 2004). This organism has been related in prenatal infections to death or severe brain and eye damage, especially where the mother has not been previously exposed and acquires an infection during her pregnancy (Stedman 1976).

Other common practices used to prevent livestock disease include limiting contact between groups of animals having varying degrees of pathogen exposure.

For improvements in animal health to be adopted, they must also be sustainable.

Vaccination for important animal disease-causing agents has long been a vital tool of animal health.

Antibiotics have a major, positive effect on improving animal and human health.

Antibiotic use to prevent and treat animal disease is essential for the health of food animals.

It should be clear that the health of the animals within the food animal production system impacts many aspects of the system far removed from the animals themselves.

Other common practices used to prevent livestock disease include limiting contact between groups of animals having varying degrees of pathogen exposure (e.g., “all-in-all-out” animal flow). Certain rigorous biosecurity measures are routine for some livestock farms, including requiring workers to shower, change clothes, and disinfect boots or transportable items upon entering and leaving livestock buildings. Access by outsiders typically is also limited; in those cases where visitors may be allowed, additional protective measures are enforced.

The continued questions by many stakeholders concerning the present intensive housing systems for food production animals that have been developed to maximize animal health and improve efficiencies of production must not be overlooked. The move to less restrictive housing systems for food production animals in countries such as those in the European Union will no doubt influence husbandry practices in the United States. For example, the recent move by some retailers to start sourcing poultry products from cage-free systems and pork from swine operations that do not use gestation stalls must be considered, because poorly managed, less restrictive systems can have dramatic impacts on animal health. For improvements in animal health to be adopted, however, they must also be sustainable. For example, improvements in one aspect of the production system such as health must not come at the expense of another (e.g., animal welfare). We see much need for research to identify sustainable food animal production practices that protect human health but also are sustainable in terms of public expectations.

Animal Care

Animal care often involves oversight of all health-impacting issues including nutrition, housing, and ventilation, along with vaccination and strategic antibiotic use. Vaccination for important animal disease-causing agents has long been a vital tool of animal health (van Oirschot 1994). In addition, vaccination may be effective against specific foodborne pathogens (Denagamage et al. 2007; Filho et al. 2009).

Antibiotics have a major, positive effect on improving animal and human health. They are used in human and veterinary medicine to treat and prevent disease. Antibiotic use in food animals is highly regulated by the U.S. Food and Drug Administration. The use of antibiotics in food-animal production, however, raises some concerns about antibiotic resistance in bacteria that could affect the efficacy of antibiotics in the treatment of human infections. Concern about antibiotic resistance is not equivalent to actual risk. Resistant bacteria were present long before antibiotics were discovered and found in many places without livestock exposure (Roberts 2011).

There has been much speculation and research as to whether or not the use of antibiotics in animals may negatively affect the efficacy of antibiotics in humans; the low doses used as “growth-promoters” may be an unquantified hazard (Phillips et al. 2004). Antibiotic use to prevent and treat animal disease, however, is essential for the health of food animals.

Conclusions/Recommendations

In conclusion, it should be clear that the health of the animals within the food animal production system impacts many aspects of the system far removed from the animals themselves. This is the basis for current calls to understand “One World, One Health” (One Health Commission 2011). Thus, a change or modification in the “system” at the animal level may have secondary, unintended consequences in subsequent areas

In this paper, the authors have outlined how system changes to animal health will impact public health.

The issue of trade-offs between animal health and foodborne risk is one that needs further research.

Based on the research described here, it is evident that the national policy impacts of changing animal health can and should be modeled.

downstream from the farm. The Food and Agriculture Organization of the United Nations concluded that continued improvement in productivity, efficiency, and intensification is necessary to sustain and decrease livestock's environmental impact (FAO 2006). In this paper, the authors have outlined how system changes to animal health will impact public health.

The Academy of the American Society of Microbiology has made recommendations for global food safety (AAM 2010). These recommendations include an exhortation to conduct systems-based research that evaluates the risk-risk trade-offs for suggested interventions. This issue of trade-offs between animal health and foodborne risk is one that needs further research.

Based on the research described here, it is evident that the national policy impacts of changing animal health can and should be modeled. Suggested future research topics include the following:

- Studies on parameters such as the potency ratio (probability and microbial load) and the relationship between on-farm health observations and lesions that may or may not increase contamination are needed.
- Research is necessary on the frequency of these subclinical or “not visibly ill conditions” during harvest of pork, beef, and poultry.
- Data are needed on the correlation of these “not visibly ill conditions” during harvest and the actual contamination related to the conditions to assist in determining if anything can be done prior to slaughter to prevent these concerns.
- Research on nutrient regulation of gene expression will bring forth new improvements in efficient animal production and health.
- Ecological studies and quantitative risk assessments on the role of low-dose antibiotic use in food-producing animals and human health are needed.
- More information is necessary regarding the effects of production practices perceived to be more humane, such as free range and outdoor production, on zoonotic and foodborne pathogen load and persistence, as well as presence of internal parasites.
- The possible changes leading to the adoption of less restrictive animal housing systems will require investment in research efforts to find ways of ensuring high standards of welfare but also maximizing animal health.
- Examination of the unintended consequences of changes to current production practices without thorough scientific research and risk analysis is needed.

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