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The multiple dimensions of One Health

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The Ultimate Challenge

We live in a complicated, interconnected world that is changing rapidly. In fact, in Thomas Friedman's recent book called "Thank You for Being Late – An Optimists Guide to Thriving in the Age of Accelerations", he explains how our lives are being transformed on many levels all at once by changes in technology, globalization, climate change, and biodiversity (Friedman, 2016). He further suggests that although these changes are occurring faster than our human ability to adapt, if we slow down and use our time to reimagine work, politics, and community, we can overcome these stresses.

As the global human population continues to increase, it is accelerating the stress placed on finite natural resources such as land, water, and air, which are the foundations of life on earth. The recent climate change report released by the United Nations in October of 2018 was an urgent call to action. Climate scientists indicate that if the rise in the earth's temperature exceeds 1.5°C, we will experience the most devastating effects of climate change including destruction of ecosystems and unpredictable weather patterns. Therefore, our ultimate challenge is to find ways to feed a growing population of people without destroying the planet. Fortunately, the United Nations adopted 17 sustainable development goals that can serve as guidelines to implement universal, integrated, and transdisciplinary approaches for transforming the world by 2030 (United Nations, 2015). Producing and consuming nutrients are the common thread that sustains life, and not surprisingly, food is the common link among these 17 sustainable development goals. Using these guidelines, The Economist (2018) developed a global food security index to provide a common framework for understanding the fundamental causes of food insecurity in countries and geographical regions around the world. Some of the key findings in this report were:

- Climate change will affect food production for marine and terrestrial systems as environmental conditions change
- Fertile land, fresh water, and oceans are essential resources that provide the foundation for food security
- Political stability is essential for agricultural production and relief efforts
- Financial risks threaten food affordability, especially for low-income households
- Global trade contributes to food security, but importing countries are vulnerable to increasing protectionism

Similarly, the Barilla Institute for Food and Nutrition (Parma, Italy) developed a Food Sustainability Index to quantitatively and qualitatively characterize the sustainability of national food systems based on food loss and waste, sustainable agriculture (water use, land use, biodiversity, human capital, greenhouse gas emissions), and nutritional challenges (life quality, life expectance, dietary patterns). The most recent report published in 2018 showed that countries that tend to have high incomes, high levels of human development, smaller populations, and slower rates of urbanization, made more progress in improving sustainability of food production than other countries. The countries with the highest ranking in the Food Sustainability Index were France, Japan, Germany, Spain, and Sweden. However, more progress is needed in these top ranking countries, and we need to accelerate the rate of food sustainability improvement in lower ranking countries if we are going to have a significant global impact on food security and sustainability.

One Health

Leonardo da Vinci, who is regarded as one of the most diversely talented geniuses who ever lived, once said "realize that everything connects to everything else". This simple statement completely describes the interconnectivity of the challenges we are facing in feeding the world sustainably and the concept of One Health. The many technological advances and economic benefits that previously provided global health improvements, have now led to an enormous environmental and ecological footprint that is having adverse effects on human health (McMichael and Butler, 2011). One Health has been defined as the collaboration of multiple disciplines and sectors working locally, regionally, nationally, and globally to achieve optimal health by recognizing the interconnections between people, animals, plants and their shared environment. The Centers for Disease Control and Prevention identified 3 key factors that are changing the interactions between humans, animals, and the environment, which have led to the emergence and re-emergence of several diseases (https://www.cdc.gov/onehealth/basics/index.html):

1. Human populations are increasing and expanding in new geographic areas, resulting in more people living in close contact with wild and domestic animals, which increases the likelihood for transmission of diseases from animals to humans.

2. Climate change, deforestation, and intensive agricultural production practices have altered land use. These changes in environmental conditions and habitats create new opportunities for disease transmission to animals.
3. Increased international trade and travel increase the likelihood and rate that diseases can spread around the world.

Although the original concept of One Health included the interactions between humans, animals, and the environment, the environmental component is often neglected (Essack, 2018).Furthermore, the effects of climate change cannot solely focus on human health (Watts, 2018), and must include the interactive effects with animal health and the environment (Zinsstag et al., 2018). **Therefore, achieving One Health must involve transcending and interconnecting all of the components of the global food system** including:

- ecosystem resilience and biodiversity
- sustainable land and soil resources
- abundant and clean water
- climate change
- human, animal, and plant health
- innovative technology for food production, storage, and transport
- equitable food access, production, and distribution
- demographic changes
- culture and lifestyle
- government policy

If all of these components can be optimized, we will have healthier nations that have broad access to abundant, safe, affordable, and nutritious foods produced by thriving farms that are efficient, resilient, sustainable, and profitable. However, if we are going to accomplish this, we need a new paradigm that is transdisciplinary and places more emphasis on the interconnections of ecosystems, soil, water, plant, and microbiome resources with animal and human health. Furthermore, Adeel (2017) indicated that achieving all water-related UN sustainable development goals and interconnections is crucial for achieving universal health, food security, gender equality, sustainable consumption, resilient urbanization, and conservation of marine and terrestrial ecosystems.

“Breaking Down Walls”

The first step in achieving One Health and sustainable food production is to “break down walls” between individual disciplines and interconnect and transcend all disciplines and organizations that are involved in the global food system. This will require a major paradigm shift because most of us became knowledgeable experts in our respective disciplines by becoming reductionist scientists in a narrowly defined field of study. While this level of scientific discovery and translation into practice is still essential, our challenge is to collaborate and integrate this knowledge across disciplines and countries using a systems-based approach to achieve greater impact in solving these complex problems. For example, Nakamura et al. (2019) summarized the scientific literature related to research involving the UN’s sustainable development goals and observed that European nations dominated in sustainability related research, with the greatest levels of bilateral and multilateral international collaboration than other nations or regions. North America and the Asia-Pacific regions contributed less to global sustainable development goal research and international collaboration than Europe, with Africa, Arab countries, and Latin America contributing the least, despite major concerns in these regions. These results indicate that there is tremendous need to foster international research collaborations if we are going to be successful in achieving sustainable development and One Health goals. We also need to be conscious of the need to integrate social sciences with the biological sciences to develop meaningful strategies for feeding the world sustainably. For example, Sörqvist and Langeborg (2019) indicated that human heuristic behaviors related to environmental sustainability can actually be more harmful than doing nothing at all. In fact, it is rare to find thoughtful, science-based strategies combined with effective execution of actions in our changing world geopolitical leadership. In other words, we need action, not just rhetoric to solve these problems. Geopolitics often becomes an obstacle that prevents collaborative, transdisciplinary science that can lead to real change in overcoming these challenges in our global food system. Smyth et al. (2017) suggested that achieving improved food security has been limited due to the lack of acknowledgement and rejection of science-based evidence by non-governmental environmental organizations, which has resulted in food security becoming a political issue. Brown et al. (2019) indicated that achieving the Paris Agreement goal of limiting the average global temperature increase to 1.5 °C will unlikely be achieved, because plans in individual countries to address this problem remain vague and insufficient. It is very disconcerting to observe that most of the many government policy decisions and regulations are made based on limited consideration of scientific knowledge. We must let science guide our decisions if we are going to be successful in addressing these global challenges.

One Health – Earth

The health of earth is rapidly deteriorating. To gain an appreciation for the interconnectedness and multiple dimensions of One Health and implications for the global pork industry, it is essential to begin with a brief description of the many challenges that are being created by global climate change. Climate scientists predict that the increase in average global temperature will exceed 1.5°C increase by 2030 if greenhouse gas emissions that cause global warming, continue to increase at the current rate. The stability of earth depends on sea ice in the Arctic and Antarctica because it reflects solar radiation to prevent global warming. Unfortunately, the amount of sea ice has been declining at a rate of about 13% per decade since 1980. If this rate continues, the earth will be ice-free by the year 2040. Therefore, if we don't prevent this increase in global temperature, there will be devastating consequences on ecosystems and unpredictable weather patterns that will exacerbate our challenges of achieving global One Health. The stability of ecosystems depends on the interconnections of diverse habitats, where humans, animals, plants, insects, oceans, and microbiomes are co-dependent and flourish. If rainfall is more predictable and certain, then ecosystems can survive more richly and with variety. However, the outcomes of climate change include changes or loss of habitat for wildlife; species extinction; changes in animal location and migration patterns; as well as more severe and frequent droughts, floods, and wildfires. Furthermore, increased length of growing seasons, extended periods of extreme heat, and changes in precipitation patterns will lead to lost crops. Hurricanes will become stronger and more intense, sea levels will continue to rise, and more frequent flooding will occur, resulting in less and lower quality fresh water leading to drinking water shortages. There will also be increases in some species of plant and animal pests that will alter the health of ecosystems. All of these changes will have negative consequences for the health of microbiomes, soil, water, plants, animals, and humans and availability of resources to produce and deliver food.

One Health – Agriculture

Changes in atmospheric temperatures and carbon dioxide, along with an increased frequency and intensity of extreme weather events will likely reduce crop yields. This will not only affect food security for the growing human population but will also have dramatic effects on reducing the availability of grains and by-products for use in animal feeds. Furthermore, although increased temperatures during the growing season will likely accelerate plant growth, it will alter the nutritional composition of grains and forages through reductions in protein and mineral content. Changes in climate conditions will likely promote more fungi and mold growth in feed grains, leading to increased production of mycotoxins, which have detrimental effects on animal health and productivity. In addition, increased frequency and duration of extreme heat will lead to more heat stress that decreases animal fertility and growth, as well as increases susceptibility to disease. Warmer temperatures, wet climates, and increased carbon dioxide will alter the composition of weeds, insects, and fungi in ecosystems, and enable some species to thrive while others will not. For example, populations of mosquitoes are expected to increase dramatically under warm, wet conditions. Because mosquitoes are vectors for transmission of numerous human and animal diseases, achieving One Health will become more challenging. The increased prevalence of parasites and insects will likely increase pesticide use and change the approaches and practices used by veterinarians for preventing and treating diseases. Ultimately, all of these changes could lead to decreased food availability and reduce access to food by interrupting food delivery, increasing food spoilage and food prices, and decreasing nutritional quality of food. These disruptions are already occurring our global food system, but if they continue to increase, they will lead to more humanitarian crises and cause national security concerns.

One Health – Animal Agriculture

Climate change is expected to have profound negative direct and indirect effects on the health and well-being of food producing animals (Lacetera, 2019). Direct effects include an increase in extreme weather events that can affect transport of feed and feed ingredients from manufacturing to farms; flooding can reduce crop and pasture production; and extreme cold and snowstorms can cause health problems and death of cattle in open ranges. Nardone et al. (2010) also noted that the carrying and buffering capacity of agro-pastoral systems may also be reduced. Equally important will be the increased frequency and duration of extreme heat that will lead to prolonged heat stress, which causes disruptions in metabolism, increased oxidative stress, immune suppression, and death of animals in extreme cases (Lacetera, 2019). The indirect effects include potential reductions in the quantity and quality of feedstuffs and drinking water, low adaptability of genotypes to heat stress, along with potential for increased survival and distribution of pathogens and vectors (Nardone et al., 2010). All of these factors will create even greater challenges for achieving nutrient utilization efficiency and sustainably feed a growing world population that is consuming a greater proportion of animal-derived food products in their daily diet. The global livestock industry accounts for 70% of all agricultural land use, 30% of total land surface use, 8% of water use, and is also responsible for 18% of greenhouse gas emissions. Therefore, changes in animal production practices, especially focused on the sustainability and environmental impacts of feed ingredients, will be essential for reducing the negative environmental impacts of food animal production on global climate change.

Future Perspectives for One Health in Pork Production

Pork is the most widely consumed animal-derived food in the world. In fact, pork production is expected to continue to increase during the next 30 years (Alexandratos and Bruinsma, 2012) due to continued increases in human population and dietary trends toward more animal protein consumption per capita (Lassaletta et al., 2014; Bai et al., 2018). Therefore, the global pork industry will continue to be an important contributor to feeding the world sustainably. We need to move toward a new paradigm that involves designing and implementing holistic, systems approaches to deal with the current and emerging challenges in pork production to achieve One Health. Producing safe and wholesome pork is much more than being free of drug and chemical residues, and food borne pathogens. We need to become more focused on prevention (process controls) rather than focusing on treating disease. Certification schemes need to be harmonized and implemented uniformly among countries rather than relying on carcass inspections and sample testing for identifying unsafe physical, chemical, and microbiological components before they enter the food chain. One health in pork production involves developing new strategies for early detection and surveillance to prevent the spread of pathogens during increasing global mobility of people, animals, feed ingredients, and food. Furthermore, pork production has contributed the unintended consequences of antimicrobial resistance and its effects on soil, water, plant, animal, and human microbiomes. We need to develop and implement strategies to mitigate these effects. One Health in pork production involves balancing the needs for high quality protein for the growing human population while preserving and optimizing the use of finite resources. It involves recycling and re-purposing of food waste nutrients into swine feed to reduce carbon footprint of pork production. One Health also involves coping with effects of climate change such as heat stress, grain shortages, natural disasters, and changes in ecosystems that can all influence swine health and productivity. Achieving One Health in pork production in the future will involve using genomics techniques to develop commercial swine genotypes that are resistant to specific pathogens. Veterinary practices will need to evolve into a new paradigm to ensure that pork production farms implement practices that improve environmental sustainability, feed and food safety, higher standards for biosecurity, and cope with the many consequences of global climate change.

Prophylaxis vs. treatment

We need to implement more effective disease prevention and food safety approaches rather than continuing to rely on treatment of sick pigs, and inspections and testing of carcasses before entering the food chain. Numerous feed and food quality control schemes have been developed and implemented to varying degrees in the global food chain. These include but are not limited to ISO, HAACP, GMP+ certifications. However, different countries have different standards and expectations of quality management, which creates a tremendous problem for harmonization of global trade of feed and food products. Process controls (HARPC) for sanitary feed and food manufacturing, packaging, transport, and storage must be further developed and implemented to reduce the risk of pathogen transmission in complex global supply chains. Block chain technology applications have tremendous possibilities, and the eventual implementation of this technology in agriculture and food production will greatly improve transparency in feed and food safety. However, implementation of block chain technology will depend on our ability to digitize products for traceability throughout the chain. In fact, the recent outbreaks of African Swine Fever and Classical Swine Fever in Asia, as well as the Porcine Epidemic Diarrhea virus in North American created an urgency to implement new process controls and create heightened biosecurity for feed mills and transport. These heightened measures are an important step toward minimizing the risk of transmission of these viruses and other devastating foreign animal diseases from endemic countries to those that are free of these viruses. However, despite the emerging opportunities to further develop and implement quality control and sanitary measures in all aspects related to One Health in pork production, we still need to increase implementation of well-established practices such as vaccinations, animal hygiene, and on-farm biosecurity measures. There is also tremendous potential to determine host effector mechanisms of disease resistance that may lead to the development of new biotherapeutics for disease control and growth optimization in pigs. Molecular genetic tests have been developed and are being used to select pigs for improved traits. Genetic markers associated with immunity and disease resistance have been identified, and studies have shown that different vaccine responses can be attributed to different genetic lines. Research results have also shown that inheritance is associated with E. coli F18 infections (Fryendahl et al., 2003), which has led to breeding companies providing E. coli F18 resistant breeding stock. Recent studies have also shown that porcine reproductive and respiratory syndrome virus can be controlled through genetic improvements in disease resistance and tolerance (Rowland et al., 2012; Burkhard et al., 2018). These types of research discoveries led Topigs Norsvin (swine breeding company) to identify the major genetic marker associated with natural resistance to PRRS, and to incorporate it into their genetic selection program.). However, although disease resistance can be quantified, it is more difficult to measure disease tolerance, which is poorly understood in pigs (Nakov et al., 2019). Other studies have shown that using CRISPR editing can provide resistance to cornonavirus infection in pigs (Whitworth et al., 2019). Therefore, the development of new gene editing approaches offer promising opportunities for developing commercial genotypes that are resistant to many of the common pathogens that are threats to One Health in global pork production.

Disease surveillance and early detection

Information technology, global markets, and climate are changing faster than our human ability to adapt (Friedman, 2016). We have very sophisticated and complex analytical technology that allows us to detect very low concentrations of substances that may be hazardous to health, but although miniscule amounts of various compounds can be detected, it does not necessarily mean that they pose any health concern. The use of “big data” has enabled practitioners to achieve precision public health by conducting more widespread and specific research trials using segmented populations at risk for various health problems, surveillance and signal detection, predicting future risk, targeting interventions, and understanding diseases (Dolley, 2018). Data-driven business models (Brownlow et al., 2015) have been used to develop similar models for precision livestock farming that can improve animal health and welfare and transparency of production processes (Smith et al., 2015). Various types of sensors are available and are being evaluated for applications in pig production systems to identify behavior changes that can lead to early detection of reduced health and welfare (Matthews et al., 2016). Sensors can be used for animal identification, automatic weight detection, water intake monitoring, and pig coughing (Vranken and Berckmans, 2017). Neural networks linked with sensors to collect environmental data can be used for early detection of respiratory disease in pigs (Cowton et al., 2018), and using sound data and audio surveillance systems can be used for detection of pig wasting diseases (Chung et al., 2013). Technology is also under development to use bio-sensing and photonics technologies for early and rapid field detection of swine viruses by non-specialized personnel (Montagnese et al., 2019).

Global trade and human mobility

Advances in transportation and global infrastructure have provided almost unlimited distribution of feed, food, and other consumer goods around the world. However, we still have enormous inefficiencies and inequities in global food distribution. In fact, about one-third of the food produced globally is lost or wasted before and after it reaches consumers (FAO, 2011). This has led to abundant amounts of food not reaching vulnerable populations of people, along with wasting valuable land, water and energy resources, and contributing to increased greenhouse gas emissions through disposal of food waste in landfills. The most effective options for reducing food waste is to implement practices to reduce waste, followed by feeding hungry people, and recycling these nutrients into animal feed, rather than composting, using anaerobic digestion for energy consumption, or disposing in landfills (Papargyropoulou et al., 2014). Several studies have been conducted showing that recycling food waste into swine feed can recapture lost economic value, serve as excellent energy and nutrient sources (Fung et al, 2018; Jinno et al., 2018; Fung et al, 2019), and can have a dramatic impact on reducing environmental footprint (Salemdeeb et al., 2017). However, concerns about proper thermal treatment to destroy pathogens has limited some governments from approving legislation for this purpose. International travel by humans is another major risk factor for transmission of human and animal diseases (Tatem et al., 2006; Lindahl and Grace, 2015), with nearly 940 million international trips taken by people in 2010 (WHO, 2012). Global increases in economic activity, tourism, and human migrations are causing a dramatic increase in movement of disease vectors and the pathogens they carry (Tatem et al., 2006). Tonnes of live animal and unprocessed animal products are shipped internationally around the world every day, which provide many opportunities for rapid transmission of zoonotic pathogens and foreign animal diseases (Marano et al., 2006). Smuggling of wild animals into countries has always been a high risk factor for human health, and controlling illegal imports is a constant problem. Furthermore, import restrictions do not apply to all species that may be a health threat because it is not always known which animals carry disease. Much more attention is needed to screen passengers and their belongings at country ports of entry to prevent the unwanted introduction of zoonotic and foreign animal diseases. Foreign animal diseases are major global trade and market disrupters that affect feed ingredient demand and prices, ability to export and import meat to and from countries, and affect food prices and food security for consumers. Global trade has dramatically increased the risk of transmission of pathogens from endemic countries to other countries, which not only can have devastating effects on domestic pork production but also creates trade barriers. The awareness of the significance of global trade on the potential risk of transmission of foreign animal diseases has increased as a result of recent outbreaks of Porcine Epidemic Diarrhea Virus and African Swine Fever Virus in pig populations around the world. The ability of viruses to survive in feed ingredients for extended periods of time was evaluated recently by Dee et al. (2018). These researchers determined the survival (PCR, virus isolation, and/or bioassay) of 11 viruses of global significance to the livestock industry, using Trans-Pacific or Trans-Atlantic transboundary models of representative feed ingredients, transport times, and environmental conditions. Senecavirus A (surrogate for Foot and Mouth Disease Virus), Feline Calicivirus (surrogate for Vesicular Exanthema of Swine Virus), Bovine Herpes Virus Type-1 (surrogate for Pseudorabies Virus), Porcine Reproduction and Respiratory Syndrome Virus, Porcine Sapelovirus (surrogate for Swine Vesicular Disease Virus), African Swine Fever Virus, and Porcine Circovirus Type-2 maintained infectivity during several weeks of transport. More of these viruses survived in conventional soybean meal, lysine HCl, choline chloride, and vitamin D than in organic soybean meal, soy oil cake, distillers dried grains with solubles, and complete feed. These results showing that feed ingredients can serve as vectors for virus transmission has led to a heightened level of biosecurity in some global feed ingredient supply chains. Research is underway to conduct risk assessments and implement sanitary process controls in feed ingredient supply chains to reduce the risk of introducing foreign animal pathogens though feed ingredients imported from countries that are undergoing outbreaks of African Swine Fever. Feed ingredient selection and sourcing not only affects the potential risk of pathogen transmission, but it can also affect environmental sustainability of pork production. Many by-products, such as rendered animal by-products, have been used as economical nutrient sources in swine diets for many years, while also contributing to improved environmental sustainability. However, if inadequate thermal treatment is used, these ingredients can potentially serve as vectors for transmission of undesirable pathogens to pigs. The first case of Porcine Epidemic Diarrhea Virus in North America was attributed initially to a source of spray dried porcine plasma that was fed to pigs. Although a direct cause and effect link was not been definitively confirmed, it led many veterinarians in North America to recommend using only grain-based ingredients in swine diets. However, as several studies subsequently showed, soybean meal and corn can be greater risk factors for transmitting corona viruses than spray dried porcine plasma and other rendered animal by-products (Trudeau et al., 2017). Therefore, feeding strictly grain-based diets does not reduce the risk of virus transmission to pigs, and in doing so, it actually increases gut health problems, and reduces feed efficiency and growth rate. Trade barriers among countries also exist based on different standards and perceptions about the relative food safety risks. More than 70% of genetically engineered crops and biomass is fed to food-producing animals. Regulatory and peer-reviewed studies have shown that genetically engineered crops are safe for feeding to livestock, where more than 100 regulatory submissions have shown equivalent composition and safety between genetically engineered vs. conventional crops, and no rDNA fragments have ever been detected in meat, milk, and eggs (Van Eenennaam, 2013). Government regulations have disproportionately focused on potential risks, rather than the benefits, which has slowed the adoption of genetically engineered crop use in small and poor developing countries. Although metabolic growth enhancers (e.g. ractopamine) have enabled to pork industry to improve the efficiency and sustainability of pork production, government policies in various countries around the world differ in their assessment of safety and acceptance of using these technologies, which has led to trade barriers (Davis and Belk, 2018). Furthermore, various countries use different standards for maximum residue limits of antibiotics in meat and organ tissues, which further impacts market accessibility in global trade. These are only a few more examples of why we need to let science guide regulatory decisions when attempting to feed the world sustainably. There continues to be a need for global harmonization of reasonable feed and food safety standards to overcome food insecurity in many countries.

Contributions to and impacts of climate change on pig production

Climate change plays a dual role in achieving One Health in pork production systems. First, we need to implement technologies that reduce negative environmental impacts of pork production systems. Secondly, we need to develop strategies to try to mitigate the consequences of climate change on pig health, welfare, and productivity. During the past 80 years, the U.S. pork industry has achieved a 76% reduction in land use, 25% reduction in water use, 8% reduction in global warming potential, and a 7% reduction in energy use (National Pork Board, 2019). Although progress has been made, more concerted and dramatic efforts are needed to achieve further reductions. Lassaletta et al. (2019) developed a model of pig production systems in 26 geographic regions to characterize the shared socioeconomic pathways and identify key factors that will determine their future sustainability. These factors include using improved genotypes with greater productivity and efficiency, use of alternative feed sources that do not compete with human food, reduce crude protein content in swine diets, optimize use of swine manure as fertilizer for crop production, and moderation of human consumption of pork. Nutrition is the primary means to minimize the negative environmental impacts of pork production. Many life cycle assessment studies have been conducted to characterize environmental impacts of food animal production in various countries (de Vries et al., 2010; Tan and Yin, 2017; Weiss and Leip, 2012). Sustainability indicators for nitrogen (Groenestein et al., 2019), phosphorus (Li et al., 2019), and nutrient use (Uwizeye et al., 2016) have been described for livestock production systems. Dourmad et al. (2013) reviewed the impact of pig nutrition on nitrogen, phosphorus, copper, and zinc in pig manure, and emissions of ammonia, greenhouse gases and odor. Several studies have been conducted to assess the environmental footprint (e.g. acidification potential, eutrophication potential, renewable and non-renewable resource use) in classifying feed ingredients used in swine diets (Eriksson et al. 2005; Kebreab et al., 2016; Mackenzie et al., 2016; Wilfart et al., 2016). This approach is useful for developing supply chain management programs for sourcing grain and other feed ingredients that minimize the carbon footprint of pork production systems. In fact, several multinational feed companies, large swine integrators, as well as governmental and industry organizations have developed environmental sustainability programs with the goal of producing a “zero carbon” pig. Furthermore, new feed ingredients, such as insect meal, microalgae by-products, and bacteria meal, are emerging into the feed ingredient market that are not only more environmentally sustainable, but also appear to have unique chemical compounds that may play a significant role in enhancing pig health and performance. Although several studies have been conducted to determine environmental impacts and sustainability of feed resources, implementation of meaningful practices are only beginning. Climate change will increase the frequency and duration of excessive heat exposure and stress on pigs. Oxidative stress is a major challenge for optimizing pig health and performance. Although there are many commercial antioxidants used to preserve vitamin potency and minimize oxidation of lipids in animal feeds, the use of antioxidant compounds to minimize systemic oxidative stress in pigs has not been adequately evaluated. Furthermore, although some immunity enhancing feed ingredients and additives exist, more attention is needed on developing products that improve innate immunity because new strains of pathogenic viruses and bacteria continue to emerge.

Ecosystem resilience and biodiversity

The biodiversity of ecosystems is extremely important role in achieving One Health of pork production, but is rarely considered. One of our greatest challenges is to continue to use global agricultural land for animal feed, biomass, and human food production while simultaneously maintaining natural ecosystems and reducing climatic and environmental impacts. Intensification of agriculture, which includes the use of fossil fuels, has reduced biodiversity and negatively affected many of the ecosystem services that food production relies upon (Tsiafouli et al., 2017). Several human interventions have led to loss of habitat, biodiversity, and destruction of ecosystems. Use of pesticides have drastically diminished bee populations, which are essential for crop pollination. The need to provide more environmentally friendly alternatives to burning fossil fuels has led to the diversion of grains and oilseeds to biofuels production and provided economic incentives for using monoculture crop production systems, which have created new challenges for weed and pest control, and negatively affected ecosystem biodiversity. Conversion of non-aerable land to aerable land reduces the ability of trees and plants to sequester carbon dioxide. Therefore, new frameworks need to be developed that integrate knowledge from diverse ecosystem components across multiple scales and time to preserve and enhance ecosystem services provided to agricultural systems (Tsiafouli et al., 2017). Soybeans and soybean meal are the main protein sources used in swine diets in many countries around the world. The expansion of soybean production in countries like Brazil, has led to deforestation of thousands of hectares of land. Deforestation is a major ecosystem concern because of the loss of biodiversity and forests that utilize carbon dioxide. As a result, multiple organizations, such as the Consumer Goods Forum have developed global sustainable soy sourcing guidelines. Similarly, the United Soybean Board, American Soybean Association, and the U.S. Soybean Export Council have also established goals for the U.S. soybean industry to reduce land use by 10%, reduce soil erosion by 25%, increase energy use efficiency by 10%, and reduce greenhouse gas emissions by 10% by the year 2025.There is tremendous interest in defining and understanding the microbiome of ecological systems on many levels. Complex, diverse microbial communities are found everywhere in the environment and have a major influence on the health of soil, plants, forests, oceans, animals, and humans. We have known for a long time that humans and animals have microorganisms both internally and externally, but we are only just beginning to understand the role of the microbiome in the health and well-being of the host (Miller et al., 2018). The Earth Microbiome Project began in 2010 with the goal of developing a global catalog of the uncultured microbial diversity on earth. One of the initial findings of this ambitious research effort has shown that major shifts in microbial composition of prairie soils in the Midwestern U.S. has occurred due to agricultural use, which has changed the relative abundance of Verrucomicrobia and its influence on carbon dynamics (Gilbert et al., 2014). The science of microbiome communities is only beginning, but promises to be a key component for developing meaningful strategies to improve One Health on many dimensions. Phosphorus is an essential nutrient for living organisms and is a critical resource for the bioeconomy and food security. However, phosphate rock is a finite resource and global reserves are decreasing (Mogollón et al., 2018). If inorganic phosphorus fertilizer and manure are not managed properly, phosphorus can have an ecologically damaging effect on freshwater eutrophication. Global trade of phosphorus has changed the global phosphorus cycle resulting in critical nutrient imbalances among countries and ecosystems (Nesme et al., 2018). The over-abundance of phosphorus that has reduced water quality, and the eventual global depletion of phosphorus reserves for future agricultural production, has led to a convergence of phosphorus security and water quality initiatives (Leinweber et al, 2018). In fact, the European Sustainable Phosphorus Platform is one example of a collaborative effect involving over 150 organizations to improve phosphorus utilization efficiency in agriculture and food production while developing strategies to reuse, recover, and recycle phosphorus in a circular economy. In addition, a recent report by the United Nations identified 5 major environmental challenges including 1) synthetic biology and biotechnology, 2) ecological connectivity, 3) melting permafrost (carbon dioxide losses), 4) maladaptation to climate change, and 5) disruption of the global nitrogen cycle (UNEP, 2019). The increase in livestock and agricultural production, along with transportation, energy and industry, have led increased emissions of nitrate in water, and ammonia and nitrous oxides in air, which has significant negative effects on climate change, air quality, and the ozone layer. The European Nitrogen Assessment estimated that 80% of the nitrogen used in food production is wasted, with an associated global cost of 300-400 billion US$ per year. These results continue to emphasize the need for precision nutrition when formulating and feeding swine diets to minimize nitrogen excretion in manure and reduce ammonia and nitrous oxide emissions in order to contribute toward improving global One Health. Finally, Aleksandrowicz et al. (2016) conducted a review of impacts of changing human diets on greenhouse gas emissions, land and water use, and health, and concluded that environmental and health benefits are possible by shifting current Western diets to a variety of more sustainable diets. In fact, Rose et al. (2019) argued that environmental sustainability should be included as a key component when educating individuals and groups about dietary choices, and in setting national dietary guidance recommendations. Consumer purchasing decisions contribute substantially to environmental degradation, resource depletion, and social problems (Gandenberger et al., 2011, Gardner et al., 2004). This concern has led to many public and private initiatives to communicate sustainability information about food to consumers Grunert et al., 2014). In fact, ecolabelindex.com has identified 463 ecolabels (e.g. Rainforest Alliance, World Wildlife Federation, Ocean Conservancy) in 199 countries and 25 industry sectors. However, although consumers have medium to high levels of concern about sustainability issues, they have lower levels of concern when making food choices (Grunert et al., 2014). Therefore, the future use of eco-labeling of food products will be dependent on actual behavioral changes of consumers when making food purchasing decisions.

Antimicrobial paradigm shift

The development of antimicrobial resistance in the global microbiome is one of the greatest threats to One Health. We have developed and used many chemicals such as antimicrobials, herbicides, and pesticides that have provided many benefits in global health, and contributed immensely toward feeding the world by preventing and treating diseases. However, these technologies have led to unintended consequences that have caused the development of antimicrobial resistance and food safety concerns (Barton, 2014). Studies have shown the antibiotic resistant genes spread from the pig production environment to meat throughout the pork production chain, including the feed supply (Liu et al., 2019). Österberg et al. (2016) reported that although antimicrobial resistance to *E. coli* was less common in pigs produced in organic systems compared to conventional systems, there were large differences in resistance between countries within each type of production system. Scoppetta et al. (2017) evaluated antibiotic use and development of resistance on 14 farms in the Umbra region of Italy and reported that farms varied in their level of antibiotic resistance. In addition to the development of bacterial resistance, inappropriate use and unintended carry over from feed to food of antibiotic residues continues to be a threat to One Health. Although the World Health Organization has designated antimicrobial resistance as serious threat to global public health, the U.S. has lagged behind the E.U. in restricting or banning the use of antibiotic in animal agriculture. All global governments and society must take action to address this problem, but efforts by federal government policy makers and regulators have been insufficient (Martin et al., 2015). Interesting new scientific discoveries are beginning to reveal that advances in biotechnology may result in restoring the efficacy of antibiotics by using antibiotic-peptide conjugates (Marquardt and Li, 2018). Additional approaches for treating and controlling disease caused by microorganisms include CRISPR/Cas9 gene editing technology, genetically modified bacteriophages, peptides, and nanoantibiotics, along with improved vaccines, immunoglobulins, and eubiotics (Marquardt and Li, 2018). The discontinuation of using antibiotics for growth promotion purposes in many countries has led to the consideration and use of numerous “alternatives” to antibiotics, which vary in their efficacy. These feed additives must be evaluated based on direction, magnitude, and consistency of growth responses, while also determining if we adequately understand their mechanisms of action, if they are synergistic, antagonistic, or additive in combinations with other additives, and if they provide a predictable return on investment when used. Unfortunately, the mode of action of most of these feed additives is not well understood, which prevents their strategic use in optimizing swine health in the absence of antibiotics. In addition to health and food safety concerns from antibiotic use, many segments of consumers have developed strong preferences and make food choices based on how their food is produced. This has led to many restaurants, food service providers, and supermarkets to provide animal-derived food products produced with various types of food claims ranging from organic, “no antibiotics ever”, “no medically important antibiotics”, “no growth-promoting antibiotics”, to “judicious use of antibiotics”. The use of these label claims has provided incentives for many pork producers to adopt production practices that greatly reduce or eliminate antibiotic use in their production systems to meet these market demands. However, in doing so, more management pressure is required to achieve greater biosecurity and hygiene standards in these production systems, which are at greater risk for increased mortality and reduced productivity and efficiency. Another less known contribution to antimicrobial resistance is a result of extensive use of herbicides and pesticides in crop production. Increasing pesticide use in agriculture has resulted in the selection and emergence of multiple antibiotic resistance in pathogenic strains (Curutiu et al., 2017; Jørgensen et al., 2018). Furthermore, studies have shown that herbicides also contribute to the development of antimicrobial resistance (Jiang et al., 2018; Kurenbach et al., 2015). This is an increasing concern because climate change is expected to alter the survival of selected weeds and pests, which may lead to further increases in pesticide and herbicide use in the future. Furthermore, the consequences of extensive and long-term use of antibiotics, herbicides, and pesticides on altering microbiomes of soil, water, and ecosystems is not well defined but has major implications for our ability to achieve One Health.

The science paradox

In some ways, we live in a “science illiterate” and “sound bite” society where limited, or lack of scientific knowledge and context leads to an inability for people to distinguish scientific facts from fiction, leading to the wide dissemination of inaccurate information through various social media venues. This results in many people making uninformed decisions about the need to optimize the balance between the environment, human, animal, and plant health for future sustainability. In other ways, people with greater science literacy and education have more polarized beliefs on controversial science topics based on religious and political beliefs (Drummond and Fischhoff, 2017). People who consider themselves to be political conservatives and supporters of free-market capitalism are less likely to believe in climate change and have concerns about its impacts (McCright et al., 2016; Bohr, 2014; Hamilton, 2011; Lewandowsky et al., 2013; McCright and Dunlap, 2011). However, there appears to be little association between religious or political polarization on acceptance of nanotechnology and genetically modified foods (Drummond and Fischoff, 2017). The relationship between scientific literacy and sources of information affect overall consumer knowledge and perception of genetically modified organisms and foods (Wunderlich and Gatto, 2015). In contrast to the findings by Drummond and Fischoff (2017) of the effect of education level on acceptance of climate change science, people who are familiar with genetic engineering tend to be more resistant to the use of bioengineering than those who have greater scientific knowledge of the technology (Wunderlich and Gatto, 2015). In the U.S., there has been a resurgence of infectious human diseases resulting from lack of comprehensive vaccinations, which has created increasing public health concerns. Studies have shown that people who have greater trust in health care professionals are more knowledgeable about the risks and benefits of vaccines, with individuals who are older, more affluent, and educated, being more likely to choose vaccination for themselves and their families (Song, 2014).

Healthy food

Meat consumption has been a core component of human survival for centuries, but its role in a healthy diet has been greatly debated for several decades (McNeill et al., 2017). Pork is the most widely consumed animal protein in the world, and research evidence suggests that the consumption of lean pork results in similar changes in human body composition compared with lean beef and chicken (Murphy et al., 2014). Pork not only contains all of the essential amino acids required by humans, but it is also a rich source of minerals (phosphorus, selenium, zinc, and iron) and vitamins (thiamin, B_{12}, B_6, and niacin). Achieving adequate daily consumption of these essential nutrients is difficult to achieve for meeting daily requirements of people consuming vegan or vegetarian-based diets. However, the amount of fat in pork products can vary from 10 to 16% depending on the amount of trimming, and consumption of saturated fatty acids has been shown to be associated with increased risk of cardiovascular disease (Jakobsen et al., 2009; Skeaff and Miller, 2009; Micha and Mozaffarian, 2010; Mozaffarian et al., 2010). Compared to beef and lamb, pork has less fat, greater concentrations of polyunsaturated fatty acids, and lower trans fatty acid content, which makes it a healthier meat choice for humans because substitution of saturated and trans fatty acids for polyunsaturated fatty acids in the diet reduces the risk of cardiovascular disease (Scollan et al., 2017). In fact, the concentrations of long-chain *n*-3 fatty acid content of intramuscular fat of pork, can be increased by feeding diets containing linseed and linseed oil (Nuernberg et al., 2005; Haak et al., 2008; Guillevic et al., 2009), flaxseed (Turner et al., 2014), rapeseed oil (Bertol et al., 2013; Gjerlaug-Enger et al., 2015), fish oil (Haak et al., 2008), and microalgae (Meadus et al., 2010) to growing-finishing pigs. While the use of fish oil in swine diets is not sustainable within the broad scope of global One Health, the use of microalgae is certainly is more sustainable, and initial studies have shown it has nutritional benefits in swine diets (Lei, 2018). However, we also need to be cognizant of the potential for harmful mycotoxins, such as aflatoxins, which are known to be carcinogenic, to be deposited in pork meat when pigs are fed mycotoxin-contaminated diets (Völkel, et al., 2011). A recent study conducted by Lee et al. (2017) showed that about 54% of 1,920 urine samples collected from pig slaughter facilities in Vietnam contained an average of 0.63 μg/kg of aflatoxin M_1. With the increased likelihood of global climate change increasing the prevalence and concentrations of mycotoxins in feed grains and grain by-products, more attention needs to be devoted to understanding the potential adverse effects on human health from consuming pork containing mycotoxins and their metabolites.

Conclusions

We live in a complex, globally interconnected and diverse world where numerous changes are occurring rapidly at an accelerating pace that are affecting our ability to feed the world sustainably and achieve One Health. We must “break down walls” between narrowly focused disciplines, accelerate our collaborations on many One Health dimensions, and begin using more holistic systems approaches for discovering and applying scientific knowledge if we are going to have a meaningful impact of solving the many complex problems in food and pork production systems. Scientific discoveries and human interventions have created enormous improvements in food security, food safety, and overall well-being for many segments of the global population. However, many of these interventions have led to many unintended consequences on many levels and dimensions that have created serious challenges including climate change, the development of antimicrobial resistance, and the future sustainability of the planet. We must let science guide our decisions to overcome these challenges by working collaboratively across scientific disciplines, government agencies, industries, academia, countries, and regions to not only discuss science based strategies but to also act on them. There are many dimensions of One Health that must be considered in future to protect precious resources on earth and ensure well-being and health for all.

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