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# Microbial spoilage, quality and safety within the context of meat sustainability

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ABSTRACT

Meat is a nutrient-dense food that provides ideal conditions for microbes to grow and defines its perishable nature. Some organisms simply spoil it while others are a threat to our health. In either case, meat must be discarded from the food chain and, being wasted and consequently an environmental burden. Worldwide, more than 20% of the meat produced is either lost or wasted. Hence, coordinated efforts from farm to table are required to improve microbial control as part of our effort towards global sustainability. Also, new antimicrobial systems and technologies arise to better fulfill consumer trends and demands, new lifestyles and markets, but for them to be used to their full extent, it is imperative to understand how they work at the molecular level. Undetected survivors, either as injured, dormant, persister or viable but non-culturable (VBNC) cells, undermine proper risk evaluation and management.



## 1. Introduction

Even if Lutz, Sanderson, and Scherbov (2001) predicted that the world population should stop growing by the end of the century, our number is expected to reach 9.6 billion by 2050. Demand for animal-based proteins will continue to rise, but to an extent that will vary from country to country according to various factors such as geography and culture (Sans & Combris, 2015). A fair part of our food supply will keep travelling the world, but parallel to this, the need to maintain viable agricultural social communities and to buy locally are still very much present. Food security during pandemic outbreaks (*e.g.*, Ebola in West Africa) and related land biosecurity protocols remind us that no one should solely depend on others to feed its people. More than ever, agriculture and food production remain vital economic activities.

Integration of agri-food activities from farm to table has closely linked commercial partners and it takes, in this continuum, only one intermediate performing poorly to destroy the efforts of a whole sector of activities. These interactions have fostered traceability protocols, but also liability to one another. Consumer trends and demands continue to drive the food industry whether as mass productions or niche markets (Table 1). Challenges reside in designing safe food without compromising quality and shelf life while responding to consumers' demands for minimally processed foods with fewer additives, but that remain easy to prepare. Development of novel strategies and antimicrobial systems therefore requires thorough knowledge of the physiological response expressed by microorganisms to be controlled.

Safety of our meat supply could be challenged in various ways. Except for chemical contaminants build up through reaction with meat constituents (*e.g.*, nitrosamine), chemical contaminants are likely to remain at the same level or to decay with time. This is a major distinction compared to microbial contaminants that have the potential to increase in numbers if the conditions allow growth to occur or resume. With respect to meat sustainability, it can be improved by increasing productivity, but reduction of waste and spoilage is also part of the solution. In this context, microbial control is a major issue. Novel interventions need to be integrated from farm to table and based on a thorough understanding of microbe near-death physiology at the molecular level. Examples of effective microbial control are presented here.

## 2. Economic burden of safety, waste, and spoilage

WHO (2015) reported 420–960 million foodborne illnesses and 310,000 to 600,000 deaths in 2010 representing 25–46 million Disability Adjusted Life Years (DALYs); amongst the culprits, namely *Salmonella Typhi* and non-typhoidal *Salmonella enterica*, *Campylobacter* spp. *Taenia solium*, enteropathogenic *Escherichia coli*, hepatitis A virus, norovirus and aflatoxin. In terms of food waste, FAO (2011) indicates that 1.3 billion tons of food are lost or wasted every year. With respect to meat, more than 20% of the 263 million tons of meat produced worldwide do not reach consumption, which represents 75 million bovines raised for nothing (FAO, 2016). Animal products, including meat, are

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**Table 1**
Consumer trends and demands as defined by Fread (2014).

| Designations | Description |
|---|---|
| Foodies | Curious, variety of foods, pleasure |
| Healthies | Healthy foods, more natural, less preservative |
| Greenies | Socially responsible (ethic, environment) |
| Speedies | Convenient food, minimal preparation |
| Cheapies | Value-conscious, limited spending |
| Newbies | Immigrant with "culinary culture" |

nutrient dense, but highly perishable food commodities. In order to reduce waste, spoilage, recalls linked to contamination with pathogens, *etc.* innovative and effective strategies to improve microbial control have to emerge in order to improve our sustainability towards meat and meat products. These new approaches may also include tighter management systems. For example, Moisson Beauce, which is a non-for-profit organization, helps people living with difficult socio-economic situations. It carries many activities like a food bank and reinsertion programs. In partnership with a grocery chain, they have implemented a meat recuperation program in order to reduce waste and to provide beneficiaries with more nutritious foods (Fournier, 2015). In this case, meat is frozen before the best before date and processed in provincially inspected kitchens before being served to beneficiaries of charitable organizations. Alternatively, meat could be sold at some point at a discount price before the end of shelf life. But if the product is not handled properly by the consumer, poor eating experience and safety issues may arise.

## 3. Microbial control begins at the farm

With the exception of lymph nodes, muscles of healthy animals contain little to no microorganisms (Huffman, 2002). Hence, the animal health status prior to slaughter is paramount in securing meat quality and safety. On top of veterinary surveillance, biosecurity measures at the farm must be established to protect the animal from diseases and contamination by undesirable organisms. Obviously, reducing risk of economic losses caused by animal death and herd dissemination is the logical reason to embark on a biosecurity program. On top of biosecurity protocols, many producer associations have developed a HACCP system at the farm. Although, these tend to be more of type 2 (minimizing microbial growth) than actual type 1 (procedures where cell counts are reduced, in order to prevent or eliminate hazards), they are deemed valuable with respect to microbial safety (Gill, 2000).

Free-range farming is seen as a less intensive system for animal production, but it does, nonetheless, require stockmanship to be done properly and effectively with respect to welfare and productivity. Furthermore, higher incidence of parasitic infection was reported when pigs are raised with access to outdoor facilities compared to more conventional production systems (Eijck & Borgsteede, 2005). So, parameters such as quality of pastures, feed, water facilities, pest and wildlife control remain important to control disease and contamination that will lead to increased mortality, loss of productivity and more carcass waste. Couple of years ago, pork producer associations in Canada have promoted less severe cooking for whole muscle cuts as "pink cooking" for customers to enjoy a more pleasing eating experience. It was deemed safe considering the microbial quality achieved by producers but such practices would not be recommended for free-range pigs as less severe cooking can lead to safety issues when incidence of parasites is increased. Much to proof that new intervention must be studied thoroughly to avoid introducing unsuspected risks.

Before being transported to slaughter houses, animals are submitted to a feed withdrawal to reduce problems associated with motion/transport sickness, notably nausea, vomiting, diarrhea, known to favour contamination to spread between them, but also losses (death or non-ambulatory; Bradshaw et al., 1996; Isaacson, Firkins, Weigel, Zuckermann, & DiPietro, 1999; Ritter et al., 2006). Preslaughter fasting is now a standard procedure and parameters for its proper application vary not only amongst species but also amongst producers. That is why it is deemed preferable to refer to fasting efficacy rather than fasting time. Conversely, a too long fasting will affect animal welfare, as hunger makes them more irritable; fights are more frequent leading to bruises on the carcasses. When they are properly fasted, the volume of the gastro-intestinal (GI) tract is reduced along with risks of perforation during evisceration as well as carcass and equipment contamination.

Excessive feed withdrawal will also have a negative effect on carcass yield. With pork, it takes four to eight hours before nutrients get absorbed by the small intestine and 9 h to reach blood stream. Hence, it takes 10 to 12 h before the feed consumed materialized into carcass gain (Faucitano, Chevillon, & Ellis, 2010). Undigested material left in the digestive tract is an unnecessary expense for the producer and represents an extra waste to manage at slaughter (Murray, 2001). Effective feed withdrawal reduces the incidence of Pale, Soft and Exudative (PSE) meat. If unduly extended, muscle reserves will get exhausted leading to Dark, Firm and Dry (DFD) meat (Faucitano, Chevillon, et al., 2010). Its high pH favours microbial growth, leads to early spoilage of the meat and reduces shelf life. Furthermore, hungry animals may drink more in order to reduce discomfort and water fill up the stomach (Saucier et al., 2007), which is counterproductive with respect to reducing GI tract volume (Rabaste et al., 2007).

Many factors are susceptible to influence meat quality including preslaughter stress, truck design, seasons, roads, animal density, duration of transport, and feed withdrawal (Faucitano & Schaefer, 2008; Weschenfelder et al., 2012; Weschenfelder, Maldague, et al., 2013; Weschenfelder, Torrey, et al., 2013). In fact, stress inflicted on animals before slaughter may interfere with their health and welfare leading to poor meat quality and microbial contamination (Faucitano, Chevillon, et al., 2010). After death, muscles remain metabolically active until reserves are exhausted in anaerobic conditions since breathing has ceased. If the animal is submitted to a prolonged stress before slaughter (*e.g.*, long transport), reserves will get exhausted prior to slaughter, limited production of lactic acid will occur and ultimate pH (pHu) after 24 h of chilling will be higher leading to DFD meat. This higher pH is favourable for microbial growth (Faucitano, Ielo, et al., 2010), the meat will spoil faster and shelf life will be reduced. However, when pH is higher, myofibrillar proteins are far from their isoelectric point producing a net charge causing repulsion between the fiber networks. Water then has more space and meat retaining it will have a dry appearance. This improved retention leads to reduced cooking losses, better yield and quality in processed meat (Interbev, 2006).

If stress is inflicted shortly before slaughter (*e.g.*, use of electric prod), it leads to poor quality PSE meat as well as low cooking yield although its low pH refrain microbial growth compared to DFD meat. More recently, intermediate quality classes have been defined in pork, namely, Red, Soft and Exudative (RSE) and Pale, Firm and Non-exudative (PFN). Much remains to be unveiled with respect to this newly suggested classification, but we have demonstrated that, after DFD, RSE meat spoils the fastest (Faucitano, Ielo, et al., 2010). So, proper pre-slaughter management is important to control contamination and to obtain quality meat with optimized shelf life.

## 4. Improving quality and shelf life while reducing waste

Many small fruits (*e.g.*, cranberry, strawberry) and plants (*e.g.*, tea leaves, onions) contain large amounts of phenolic compounds, including ellagic and gallic acids, which are known for their antimicrobial and antiviral activity *in vitro* as well as *in vivo* (Buzzini et al., 2008; Leusink et al., 2010; Rozoy, Bazinet, Araya-Farias, Guernec, & Saucier, 2013). Cranberry is very rich in proanthocyanidins, which have inhibitory effects on *Staphylococcus aureus* and *Escherichia coli* growth in meat (Daglia, 2012) and lipid oxidation in fresh turkey and ground