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Invited Review

A glimpse of the future in animal nutrition science. 1. Past and future challenges

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ABSTRACT - If the world population continues to increase exponentially, wealth and education inequalities might become more pronounced in the developing world. Thus, offering affordable, high-quality protein food to people will become more important and daunting than ever. Past and future challenges will increasingly demand quicker and more innovative and efficient solutions. Animal scientists around the globe currently face many challenging issues: from ensuring food security to prevent excess of nutrient intake by humans, from animal welfare to working with genetic-engineered animals, from carbon footprint to water footprint, and from improved animal nutrition to altering the rumen microbiome. Many of these issues are most likely to continue (or to exacerbate further) in the coming years, but animal scientists have many options to surmount the obstacles posed to the livestock industry through tools that are presently available. The frequency, interval, and intensity of livestock impacts, however, differ across regions, production systems, and among livestock species. These differences are such that the generalization of these issues is impossible and dangerous. For instance, when we discuss domesticated ruminant nutrition in the human food context, we look for the most efficient ruminant feeds that complement, rather than compete with, grains grown for direct human nutrition. Greater scrutiny and standardization are needed when developing and validating methodologies to assess short- and long-term impacts of livestock production. Failure in correctly quantifying these impacts may lead to disregard and disbelief by the livestock industry, increased public confusion, and the development of illusionary solutions that may amplify the impacts, thereby invalidating its original intent.

Key Words: challenges, issues, livestock, ruminant, production

Introduction

Many contemporary issues in animal agriculture have already been identified and thoroughly discussed (CAST, 2010; NASEM, 2016; Owens et al., 2014; Pethick et al., 2011; Poppi and McLennan, 2010; Scollan et al., 2011; Tedeschi et al., 2015), including perspectives for regionalized beef industries (Arelovich et al., 2011; Bell et al., 2011; Galyean et al., 2011; Hocquette and Chatellier, 2011; Millen et al., 2011). Additional issues exist, including the identification of bacteriophages to beneficially alter the ruminal microbiome, consortium formation for big data analysis, and water quality and scarcity (Roche et al., 2009).

The livestock sector has undergone tremendous transformation in recent decades that have sparked worldwide attention, such as increasing pressure on ecosystems and natural resources, flow of live animals and products of animal origin, and its impact on smallholders (FAO, 2009). One of the key problems the livestock industry faces today is similar to past problems and it will likely become a problem in the future, if not even worse: it is how to feed livestock low-cost, readily available, and high-quality feedstuffs in a suitable manner without compromising their productivity. Other industries are also looking for the same solution and competing for the same resources: skilled labor, space (land), and feedstock. One example is the biofuel industry. Corn has been the main feedstock for the ethanol industry (Schepper, 2007), but

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with the technological advancements in the biofuel sector, fuel production from biomass (i.e., organic matter) by thermochemical conversion (Verma et al., 2012) will strongly compete with livestock production, more specifically ruminants, if regulatory measurements are not established. Consumers will eventually have to choose between biofuel for their cars or high-quality food on their plate.

This paper will focus on providing a broad picture of key aspects of livestock production by describing contemporary issues in the field of livestock nutrition, more specifically in cattle, sheep, and goats for meat production. A companion paper will discuss contemporary and upcoming tools and practices to solve these challenges (Tedeschi et al., 2017).

Past and future challenges

Collectively, major contemporary issues in animal agriculture include production sustainability, environmental pollution (e.g., greenhouse gas (GHG) emissions and water scarcity), food safety, *Feed the Future*, animal welfare and health, antibiotic resistance, and land use. Animal production faces another emerging, potentially alarming, challenge: animal-free product is the technology that aims to partially or completely replace livestock. From a simplistic point of view, removing livestock from the equation would basically solve many of the problems associated with their husbandry, including GHG emissions and the excretion of nutrients into the environment. This is the motto of this ambitious fast-emerging industry that seeks to produce animal products without the animals. These are animal-like products rather than animal-free animal products. Although the concept may be based on pharmacological and nutritional research, there is still the need for science to validate the nutritious efficacy of these animal-like products as well as the impact of their long-term human consumption. There are many organoleptic and chemical characteristics that these synthetic products may not be able to mimic. Furthermore, this biotechnological industry focusses on the production of animal-free products without considering other beneficial impacts of animals on our society.

Livestock, specially ruminants, convert human-inedible, human-unpalatable sources of energy and protein into high-quality protein food for human consumption, despite a large variation in the conversion ratio among different species (Tedeschi et al., 2015). The protein quality of beef and milk is 1.87 greater than the quality of the potentially human-edible protein from feeds. When combined with the human-edible conversion efficiency, animal products for human consumption are 2.15 times greater than plant sources on a protein-equivalent basis (Ertl et al., 2016). This finding places animal products on a much better perspective when comparing their environmental impact and overall contribution to the humankind. Livestock is much more than food and nutrient security; they provide financial security (wealth), draft power, fertilization through manure spreading, fuel (dung), and weed control through mixed crop-livestock farming systems among many more (Smith et al., 2013) and several other ecosystem services (Havstad et al., 2007). Cattle represent 15% of total food energy and 25% of dietary protein consumption around the world (Porter et al., 2016). Small ruminant products constitute a relatively small share of the globally-produced ruminant meat and milk, being about 17 and 4%, respectively (Opio et al., 2013). Globally, goats produce 60% of the milk and 38% of the meat from small ruminants; the remaining is from sheep. Nonetheless, sheep and goats comprise 55% of the global domestic ruminant population (cattle, buffalo, sheep, and goats), which accounted for 3.612 million head in 2010 (Opio et al., 2013).

Beef production systems face several criticisms regarding its harm to the environment. The Food and Agriculture Organization (FAO, 2006) reported that rangelands occupy 3.4 billion ha, animal feed production uses another 33% of the total arable land, and on top of that, about 2.4 million ha of forest are turned into pasture every year. Similarly, the Intergovernmental Panel on Climate Change (IPCC, 2014) reported that agriculture currently accounts for 10 to 12% of global emissions of GHG and it is projected to represent from 36 to 63% by 2030. The portion associated with livestock production is uncertain, but expected to increase. These estimates, however, are not widely accepted by the scientific community.

The methane (CH_4) produced by livestock could be merely viewed as a form of recycling: the grass fixes CO_2 through the photosynthesis process and, if the grazing is controlled, the field can be a net C sink (D'Silva and Webster, 2010). The issue starts when enormous quantities of grain are given to cattle. According to D'Silva and Webster (2010), 70% of corn produced annually in the United States is given to livestock. If meat demand follows the present pattern of population growth, by 2050, livestock will be consuming an amount of corn that could feed four billion people. In addition, feedlots require more water (as well as other natural resources) than grazing animals. Because manure production is concentrated in small areas within feedlot systems and it is rich in freshwater contaminants (e.g., N, P, K) as well as minor nutrients (e.g., Zn, Mg, S, Na, Cu), manure produced by confined beef cattle can potentially be a source of water, air, and land pollution (Eghball and Power, 1994).

Although the demand for livestock products is increasing worldwide (Delgado et al., 1999), livestock producers are faced with many challenges that increase production risk and uncertainty. These include a changing climate, conflict, disease, and competition for land and water, and interests such as mining, oil and gas exploration/production, expansion of crop production, biofuel schemes, urban sprawl, and, in some cases, land degradation (Estell et al., 2012; Herrick et al., 2012).

Sustainable intensification

Sustainable intensification has been defined in many ways. Tedeschi et al. (2015) presented many terms used to define sustainability and provided a graphical representation of their expected outcome over time. There is a substantial overlap among definitions, but in essence, the root of sustainable intensification is to produce more, using fewer resources, in a social-economic-environmental responsible, yet profitable, way. Sustainability does not necessarily imply organic agriculture, though some organic components might be needed to establish sustainable farming systems (Reganold and Wachter, 2016). Lamb et al. (2016) laid out the "land sparing" concept for parts of Europe. It essentially seeks to increase yields, leading to a reduction on farmland area to produce the same amount of food/feed, allowing farmland to be spared and used to offset GHG emissions. The authors indicated that "land sparing includes the active restoration of habitats on spared land and our main scenario assumed the restoration of wet peatland (on spared organic soils) and native broadleaved forest (on spared mineral soils)". How exactly the yield will be increased and how the spared farmland will capture more GHG is unclear and, somehow, elusive at this point, given the currently technology. These are hurdles that must be surmounted to lay down guidelines of what is effectively doable in practice.

In the livestock arena, the upper-bound livestock productivity gains of Lamb et al. (2016) assumed that technological advancements would lead to continued genetic gains through breeding and improved animal health and nutrition. The authors did not provide exact ways in which these improvements could offset livestock GHG emissions. In ruminant production, for instance, the maximum mitigation potential ranges from 4 to 7% depending on the level of adoption rate (historical adoption rates to full adoption rates) of technologies such as cultivated pastures, better nutrition, changes in land-use practices, and changing breeding (Thornton and Herrero, 2010). Lamb et al. (2016), however, acknowledged that their technological advancements might be untenable in practice, leading us back to the starting point. These authors also alluded the fact that reducing meat consumption would alleviate the growth of GHG emissions and perhaps a legislative incentive would be needed in the form of taxation on meat. Governmental enforcements like this one will most likely not work in the long run. The scientific literature is replete with examples of unintended consequences when trying to manipulate or control public behavior or even changing established production channels (NRC, 2010; 2015). For example, De Oliveira Silva et al. (2016) indicated that, for the Brazilian cerrado conditions, increasing beef cattle production could decrease GHG emissions as long as deforestation is managed adequately.

In many ways, modern cattle production systems are more sustainable and emit less GHG than before. In the United States, Capper (2011) reported that to produce one billion kilograms of beef, the industry in 2007 used 69.9% of animals, 81.4% of feedstuffs, 87.9% of the water, and 67% of the land compared with the industry in 1977. This significantly reduced wastes: 81.9% of manure, 82.3% of CH_4, and 88% of nitrous oxide (N_2O) for the same amount of beef. These values indicate a decline of 18.1, 17.7, and 12% in manure, CH_4, and N_2O production, respectively, by the beef industry in 30 years. However, the modern dairy industry in the United States has achieved even greater efficiency gains (Capper et al., 2009). In Australia, Wiedemann et al. (2015), using life-cycle assessment analysis, concluded that from 1981 to 2010, the beef industry decreased GHG emission intensity by 14% (15.3 to 13.1 kg CO_2 equivalent/kg body weight) due to heavier carcasses, increased performance for grass-fed and feedlot animals, and improved survival rates. In Canada, Legesse et al. (2016) indicated that increased average daily gain, improved reproductive efficiency, reduced time to slaughter, increased crop yields, and a shift toward high-gain diets that enable cattle to grow faster were the main factors responsible for a decline of 14% in GHG emissions, 15% in N_2O emissions, and 12% in CO_2 from fossil fuel in 2011 when compared with 1981 to produce the same cattle slaughter weight. Many of these assessments, however, did not include land use (e.g., production of grain to feed feedlot animals) and the direct land use change (i.e., deforestation for beef cattle pastures) or the dairy sector contribution to the meat production.

Pretty et al. (2011) listed important lessons learned from sustainable intensification applied to real conditions in Africa, including the combination of scientific knowledge and farmer experience, the development of trust among key players (individuals and agencies), the improvement of communication through extension programs, the engagement of industry and private companies for products and services, and the increase of the public awareness of the importance of a robust and resilient agriculture. Tedeschi et al. (2015) alerted that actions are needed to implement successful programs for sustainable livestock intensification. They also emphasized that good intentions for creating "catchy phrases" may actually backfire the good intentions if interested groups apply it in corrosive ways.

Global climate change

Global warming is generally associated with the increase of atmospheric CO_2 and other GHG. Even though water vapor accounts for about 36 to 66% of the warming, it is not directly responsible for global climate change (Pilkey Jr et al., 2011). Global warming potential (GWP) is an index that indicates how much a gas is estimated to contribute to the greenhouse effect (i.e., radiative forcing) when compared with CO_2, which has a GWP of 1. There are uncertainties associated with the GWP estimates due to variations in lifetime and radiative efficiency and GWP estimates change as more information becomes available. The latest estimates of GWP index for CH_4 and N_2O (without climate-C feedbacks) for a 20-year time horizon are 84 and 264, respectively, and for a 100-year time horizon, they are 28 and 265, respectively (IPCC, 2013). Here reside the issues surrounding the agriculture contribution to the global warming.

Some have advocated, rather emphatically, that drastic changes in the near future are needed to prevent global temperatures from increasing by more than 2 ^{o}C above the pre-industrial level (The 2015 Paris Agreement; http://www.cop21.gouv.fr/en/). Hedenus et al. (2014) analyzed three mitigation scenarios (productivity improvements, technical mitigation measures, and dietary changes) and concluded that if productivity improvement and technical mitigation are combined, the livestock sector would be able to maintain its current emission of CO_2 equivalent (CO_2e) at 7.7 Gt CO_2e/year in 2070. Nevertheless, if reductions in consumption of meat and milk due to human dietary changes are included, the emission could decrease from 3 to 5 Gt CO_2e/year in 2070, depending on the level of dietary change. The authors concluded that reduced ruminant meat and dairy consumption is necessary to reduce GHG emission drastically by 2070.

Climate change may impact livestock production systems as well (Thornton, 2010), though the intensity and breadth of its impact may not be consistent everywhere (Nardone et al., 2010). Changes in the pattern of rainfall will directly and indirectly cause havoc on livestock production through droughts (Doreau et al., 2012). Hot environment will impair the growth and reproductive performance of livestock (Nardone et al., 2010). In grazing systems, climate change may result in extreme weather events, drought, floods, productivity losses due to physiological stress imposed on plants and animals from a temperature increase standpoint, and water availability. Indirectly, grazing systems will have to cope with changes in the ecology of forage species, increase in variability of both forage quality and quantity, and an increase in host-pathogen interactions that may lead to more numerous (and intense) disease epidemics (Thornton, 2010), affecting the carrying capacity of the land. Similarly, non-grazing systems will share problems regarding the scarcity of feed and water driven by extreme weather events. The high prices of resources such as feed and energy will be of serious concerns. Hence, future animal and plant scientists will have to develop more tolerant and resistant species to warmer climate through genetic breeding programs and diversity discovery.

Water scarcity

Increased scrutiny has been given to water usage by the livestock industry, marking the end of the era when drinking water was inexpensive and abundant. Greater attention has been given to the amount and quality of water that animals are consuming (Beede, 2012). Livestock can be responsible for a great proportion of water usage in dry and semi-arid areas. For example, livestock consume about 23% of total water use in Botswana (FAO, 2006, 2009). The NRC nutrient requirements for dairy (NRC, 2001) and beef cattle (NASEM, 2016) and sheep and goats (NRC, 2007) have predictive equations for water intake depending on their physiological stage (maintenance, growth, lactation, dry), but reliable estimates of additional provisions for water requirements to accommodate environmental extremes are lacking. Therefore, precise and accurate assessment of water requirements for ruminants needs to be developed.

In September 2000, world leaders committed to fight against poverty, hunger, illiteracy, and discrimination against women by signing the United Nations Millennium Declaration, which lead to the elaboration of the Millennium Development Goals (MDG). Among many goals, the MDG

#1 is to “eradicate extreme poverty and hunger” and the MDG #7 is to “ensure environmental sustainability” by granting access to safe drinking water as well as basic sanitation (WHO, 2015). This set of goals emphasizes the concerns regarding optimization of water-related resources in light of the report that freshwater withdrawal has increased nearly seven-fold last century (Gleick, 2000).

Because the agriculture sector is classified as a water-dependent activity (UN-WWAP, 2016), there is greater pressure for those involved in production and technology generation to develop water-friendly production systems. The water footprint concept was introduced in a conference in 2002 (Hoekstra, 2003). This concept accounts for the freshwater (good quality water) used to produce goods (i.e., agricultural or industrial), the so-called virtual water content of a given product (Figure 1). For instance, this empirical indicator highlights the amount of hidden water used during the fabrication (i.e., consumption and trades on use of water resources) of different products; for livestock, these include water needed for feed crop cultivation, livestock farming, food processor, retailer, and consumer preparation (Hoekstra, 2010; Hoekstra, 2012). Therefore, one can optimize the management of world freshwater resources based on the water footprint (Hoekstra and Chapagain, 2007), because it considers direct and indirect use of all components of the water usage geographically (e.g., country, province, state) and temporally (Hoekstra et al., 2011). The blue water footprint denotes the volume of surface and groundwater consumed; the green water footprint refers to the rainwater consumed in the whole supply chain of a product that was originally stored in the soil or remaining temporarily on the soil top or vegetation, which eventually evaporates or transpires through plants. Similarly, the grey water footprint of a product refers to the volume of freshwater that is required to assimilate the pollutant load in the process. In this context, agriculture accounts for approximately 92% of the world water consumption (Mekonnen and Hoekstra, 2012) and 85% of blue water utilization (Shiklomanov, 2000).

Mekonnen and Hoekstra (2012) compared the water footprint of diverse livestock production systems in different countries (Figure 2) and concluded that the average water footprint of any animal product is greater than the water footprint of crop products with equivalent energy and protein values (e.g., the average water footprint per calorie for beef is 20 times greater than that for cereals). This leads to the relatively large water requirement of animal products. The authors also indicated that grazing animals have a greater water footprint than mixed and feedlot (industrial) systems, because feed efficiency is greater in the mixed and feedlot systems. Thus, per unit of product (i.e., meat) about three to four times more feed (and more water to produce the feed) is required in the grazing system. On the other hand, based on the calculations of virtual water requirements of livestock reported by Brown et al. (2009), we conclude that the sum of blue and green water used to produce feeds returns to the environment as vapors and accounts for more than 99% of total consumed water, being the remaining part drinking and servicing water.

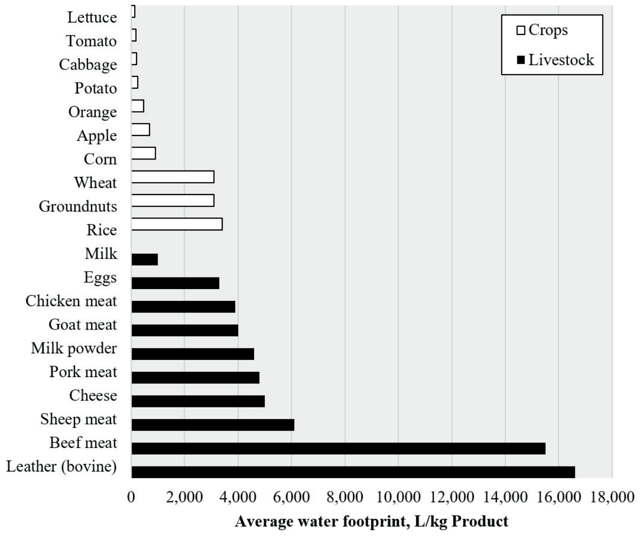

Figure 1 - Average water footprint (L/kg product) of livestock products and crops. Adapted from Hoekstra and Chapagain (2008).

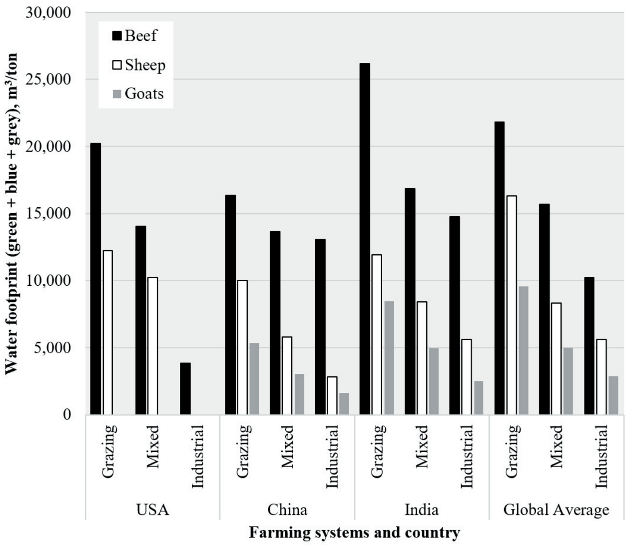

Figure 2 - Water footprint usage (L/kg meat) of beef, sheep, and goats for the United States, China, India, and global average for three farming systems. Adapted from Mekonnen and Hoekstra (2010b, 2010a) and Mekonnen and Hoekstra (2012).

Given this controversy, a special attention should be given to the water consumption assessment from a methodological standpoint. We contend that water use for evapotranspiration in forage production should not be considered a natural resource deprivation if rainfall cannot be destined to other purposes in the same area. On the other hand, grey water might be relevant depending on the production system and the stocking rate (e.g., feedlot). Given these considerations, other approaches than the volumetric of Hoekstra et al. (2011) (i.e., Water Footprint Network) have been proposed. The water footprint lifecycle assessment (Ridoutt and Pfister, 2010) estimates the amount of water that is diverted from one production process in support of another process. The net water footprint basically estimates the green water footprint of cultivated lands as evapotranspiration changes from natural crop covers (Atzori et al., 2016). In this regard, Vanham and Bidoglio (2013) critically reviewed the volumetric water footprint of production methodology recommended by the Water Footprint Network and concluded the water footprint of production concept is still incomplete. On the other hand, the life-cycle assessment method also has some limitations related to its focus on blue water only, whereas the net water footprint is highly dependent on local values of evapotranspiration of natural crops. Published estimations of water footprint of animal products using different methods are highly variable, ranging from 1.9 to 1,000 L of water per kg of milk and from 3.3 to 15,400 L per kg of beef meat (Atzori et al., 2016).

Considerations have to be made regarding the differences among production systems. Animals under grazing conditions disperse the manure across the pasture; thus, little management is needed, because the material is not concentrated and decomposes in the soil, thereby increasing its organic matter and water retention. On the other hand, feedlot animals are concentrated in a small area that results in increasing the amount of manure needing management (Eghball and Power, 1994). For instance, grazing systems require less blue (surface and groundwater) and grey (dilution of pollutant load) water than confined systems, on a global average: 708 versus 1,395 L/kg meat for beef, 441 versus 1,016 L/kg meat for sheep, and 285 versus 431 L/kg meat for goats, respectively (Mekonnen and Hoekstra, 2012).

More important than whether feedlot requires more or less water per unit of meat than grazing systems, innovative strategies should be developed to reduce the total amount of water usage and manure disposal in both systems. Animal scientists should seek for production alternatives that reduce blue water usage and increase green and grey water usage. Solution examples include selection for water efficiency (both at animal and production levels); increase of diet formulation accuracy through precision feeding that reduces soil and water contamination with excess of nutrients; more efficient manure collection and treatment (e.g., anaerobic fermentation) before applying the manure as fertilizer; and best methodology standardized to measure water footprint considering its impact on the final calculated value, to obtain comparable results before planning effective mitigation strategies in the long period or within production sectors.

Land use

Globally, livestock production occurs in almost 70% of all agricultural land. Livestock grazing alone accounts for the primary land use on almost 26% of the total land surface (approximately 3.4 billion ha) and 471 million ha support crops grown for livestock feed (33% of arable land) (FAO, 2006). Large portions of the globe are not suitable for row crop agriculture. For example, climatic extremes in temperature and precipitation on the U.S. southern Great Plains largely preclude grain and pulse production without unsustainable inputs. As a result, grazing ruminants provide the most viable food production source in that region (Steiner et al., 2014). There are similarly marginal lands, encompassing nearly 26% of the world's surface, whether in arid and semi-arid climates, that have challenging topography, short growing seasons, or unstable soils where only ruminants can convert sparse, sporadic vegetation into food that humans can consume (Boval and Dixon, 2012). These lands (rangelands and grasslands) also provide an array of ecosystem services such as food, fiber, water, recreation, minerals, and medicinal plants for both rural and urban populations (Havstad et al., 2007) and are a major store of soil organic C (10 to 30% of global stock) (Scurlock and Hall, 1998). Although small ruminants (e.g., sheep and goats) have lower conversion efficiency (feed to meat and milk) than dairy and beef cattle, raising them in non-arable, arid and semi-arid, and mountainous regions is important to provide animal products to the population of many developing countries. Without the unique ruminant digestive system to convert fibrous grasses and forbs into energy and protein, nearly a billion humans who inhabit these regions would face even greater food challenges (Boval and Dixon, 2012).

When kept in ruminant production, savannahs and grasslands provide numerous ecosystem services beyond simple food production. These include soil health, water quality and harvest, biological diversity, nutrient stabilization and cycling and, arguably, climate change mitigation (Steiner et al., 2014). Ruminant nutritionists at the plant-animal interface have generally failed to make this point when discussing grassland science within the context of human benefits, preferring instead to focus solely on food production.

The predicted scenarios may have to cope with some uncertainties depending upon the resilience of agricultural systems to change (Vermeulen et al., 2013). Since most solutions are based on reduction of consumption or increase in productivity, the rise in land values will impose a challenge to livestock production systems. Solutions for land use and livestock production will include increasing productivity of feed forage rather than greater land usage or relegating livestock to marginal lands, which in turn would further impair their productivity. Lemaire et al. (2005) argued that a wider perspective on ruminant nutrition from grasslands over the last 50 years should have included multi-disciplinary research and marketing priorities that went far beyond animal product.

Animal products and human health

These are antagonistic times for nutrition scientists. On the one hand, animal scientists have to increase livestock productivity to nourish the human population. On the other hand, animal and human nutritionists have to educate the population (at least that portion that is overfed) to consume less animal products for health reasons. This problem is mostly biophysical and demographic and some indicated that a global revolution might be needed to solve it (Ehrlich and Harte, 2015a,b).

Alarmist news about the unhealthy consumption of red and processed meat are ubiquitous, but the epistemology of their cause-and-effect relationship is at best convoluted and contradictory in some instances without a definite conclusion and recommendation. Late in 2015, the World Health Organization (http://www.who.int/en/) reported that eating processed meat (e.g., bacon and hot dogs) increases the risk of cancer. Bouvard et al. (2015) highlighted the key outcomes related to the carcinogenicity of the consumption of red meat and processed meat deliberated by a working group that, during a meeting held in October 2015 at the International Agency for Research Cancer in Lyon, France, evaluated more than 800 epidemiological studies published in several countries. Based on the assessment of Bouvard et al. (2015), there were positive associations with high versus low consumption of processed meat (e.g., meat that underwent salting, curing, fermentation, smoking, or other processes to enhance flavor or preservation) and colorectal cancer in 12 of 18 cohort studies. In spite of the conclusion of the working group that “there is sufficient evidence in human beings for the carcinogenicity of the consumption of processed meat”, they ruled out that effect of the consumption of red meat due to limited evidence and inconclusive research data. Studies published earlier than 2013 linked the consumption of red or processed meat to colorectal cancer, which led the working group to classify the consumption of red meat as “probably carcinogenic to humans” (Bouvard et al., 2015).

Many publications have exposed the conundrum about the consumption of animal fat versus refined carbohydrates (e.g., sugar) on human health (Barendse, 2014; Salter, 2013; Willett, 2005) and eloquent discussions about the topic have emerged, resurrecting the sugar conspiracy theory (http://www.theguardian.com/society/2016/apr/07/the-sugar-conspiracy-robert-lustig-john-yudkin). The sugar conspiracy claims that the greater danger of sugar, not fat, to human health has been known and revealed since 1972 by a British scientist (Yudkin, 1972) and yet modern dietary guidelines have ignored the scientific facts. Harcombe et al. (2015) conducted a meta-analysis of randomized controlled trials prior to 1983 that investigated dietary fat, serum cholesterol, and the development of coronary heart disease (n = 2,467 males in six dietary trials). Although the serum cholesterol was significantly lower in the low-fat groups, there was no difference in coronary heart disease, leading the authors to question the validity of the dietary recommendations introduced in the United States in 1977 and in the United Kingdom in 1983. Similarly, in addition to the failure of low-fat diets to decrease obesity and cardiovascular risk, Feinman et al. (2015) called for a reappraisal of dietary guidelines based on a positive correlation between increased carbohydrate intake and the incidence of type 2 diabetes. Animal products can be a rich source of nutraceutical and anticarcinogenic compounds, especially conjugated linoleic acid and omega-3 fatty acids. Animal nutritionists might refine animal diets to modulate milk and meat content of conjugated linoleic acid and omega-3 to increase their presence in human diets (Nudda et al., 2014).

Animal and human nutritionists cannot be caught up in the web of politically driven discussions, guesswork, or good intentions about animal products and human health. They must study the facts and devise solutions without slanting to one side or another based on mere speculations. The excessive consumption of saturated fat, refined carbohydrates, and processed meat in conjunction with the lack of or improper exercise (physical activity) are the main causing agent of many human health problems. Despite unfounded popular oppositions to genetic engineering, transgenic animals might accelerate the production of healthier animal products in the future, but government regulations have to act quickly and judiciously (Murray and Maga, 2016).

Antibiotics use and antimicrobial resistance

Antibiotics are one of the most important medical discoveries of the 20th century and will remain an essential tool for treating animal and human diseases in the 21st century (Seal et al., 2013). Not until recently has the obsession of consumer for "healthy" food drawn much attention to the use of antibiotics in livestock (Egger-Danner et al., 2015). The generalized concern about antimicrobial use in meat production is associated with molecule residuals and antibiotic resistance development in pathogenic species that are particularly dangerous for human health. The United States Centers for Disease Control and Prevention consider antimicrobial resistance to be one of the most serious health threats of the nation, because it causes about 700,000 deaths per year around the globe and is associated with high uncertainty and potential risks for future use (Centner, 2016). There are too many unanswered questions about antibiotic resistance, leading to controversial theories and beliefs (Williams-Nguyen et al., 2016).

Antibiotic resistance is engendered with mutation of specific genes. Antibiotics modify the bacteria environment and the microorganism that, due to random mutations, survive and reproduce despite the drug, may carry genes that confer antibiotic resistance to the entire lineage. Antibiotic resistant bacteria (ARB) develop in the gastrointestinal tract of treated animals, where bacteria proliferation is highly favored (Sun et al., 2014). Contamination and diffusion of ARB from livestock to humans is facilitated by the transfer of resistance genes between bacterial species contracted by humans through the food chain or through infected animals, their feces, or contaminated environments (Cheney et al., 2015). Isolation of ARB is frequent in fresh and processed meat from slaughterhouses, processing plants, packaging materials and retail outlets (Aarestrup, 2004). There is a high degree of correlation between veterinary antimicrobial use and antimicrobial resistance in food-producing pigs, poultry, and cattle (Chantziaras et al., 2014). The overuse of drugs in veterinary practices related to food animals, pet, and human medical treatments contributes to bacterial mutation and acquired resistance (Holmes et al., 2016). Therapeutic, subtherapeutic, and nontherapeutic antibiotics are used in livestock production for disease treatment, prevention, and as growth promoters, respectively. All uses have been identified as contributors of resistance (Centner, 2016).

The global estimates of antibiotic use seem to be greater in monogastric animals than in cattle. Van Boeckel et al. (2015) estimated that the global average annual consumption of antimicrobials per kilogram of animal produced was 45, 148, and 172 mg/kg for cattle, chicken, and pigs, respectively. These authors estimated that between 2010 and 2030, the global consumption of antimicrobials will increase by 67%, from 63,151±1,560 tons to 105,596±3,605 tons. Antibiotic consumption in India, for example, is expected to rise by 312% by 2030 (Laxminarayan et al., 2016). The major drivers of this increase in developing countries are abrupt rises in animal protein demand and meat consumption, exponential growth of intensive livestock systems to support meat demand, massive antibiotic use to keep animals healthy and productive (Van Boeckel et al., 2015), and easy access to antibiotics. The emergency will be amplified by the poor or nonexistent regulation of the antimicrobial use in developing countries.

The United States Food and Drug Administration (FDA) reported that antimicrobial use in food animals accounts for nearly 80% of the annual antibiotic consumption (FDA, 2013). For this reason, the reduction of therapeutic usage and of nontherapeutic administrations are highly encouraged to delay the development of ARB. In this sense, successful alternatives to antibiotic growth promoters are urgently required to keep high meat production levels without menacing public health (Millet and Maertens, 2011; Seal et al., 2013). On the other hand, there is a strong need for antimicrobial methods with narrow spectrum of efficacy to maintain the safety level of the meat production and selectively act on pathogenic bacteria while protecting beneficial ones (Seal et al., 2013). Laxminarayan et al. (2016) reported the Danish and Swedish exemplary antimicrobial use reduction in the last 20 years without reduction in the size of the meat industry. The authors also warned of the lack of long-term reliable data on the beneficial effects on productivity of growth promoters. Sub-therapeutic effects that enhanced production by 5 to 15% in studies before the 1980s are currently less effective, with improvements in production below 1% or no significance in studies after 2000s (Millet and Maertens, 2011).

Centner (2016) reviewed many actions by the United States government to limit the use of antibiotics, such as those that included prohibition of nontherapeutic uses of antibiotics in food animals and governmentally sponsored labeling program that encouraged the reduction in antibiotic usage. Risk reduction will be possible by enhancing danger assessment from antibiotic use data (Sundberg, 2006) and then including valid antimicrobial options. Rios et al. (2016) reported that viable alternatives to antibiotics might be bacteriophage therapy, lysin therapy, antimicrobial peptides (amphiphilic polypeptides), and bacteriocins. Genomic tools derived from next generation sequencing will allow for a better definition of pathogen profile, the evolution of the gene-resistance mutation, and the focus on host-pathogen interaction to enhance beneficial effects of the microbiome (Raszek et al., 2016).

Preservation of biodiversity

Diverse ecosystems tend to be not only more resilient (Sanderson et al., 2007) but also more productive (Tilman et al., 1997) and better able to provide year-round nutrition to ruminants (Lambert and Guerin, 1989). Within the ruminant context, this encompasses soils, plants and, more radically, raising multiple domesticated animal species in areas where we currently have only one or two (Muir et al., 2015). Despite popular misconceptions, the same way that the prevention of deforestation by conservation programs does not hamper the loss of biodiversity by anthropogenic disturbances (Barlow et al., 2016), excluding ruminants from an stable ecosystem does not necessarily enhance its diversity (Riginos et al., 2012). Natural systems are full of examples of how grazing diversity enhances overall carrying capacity (Odadi et al., 2011), especially, but not exclusively, the complementarity of grazers and browsers, body size, and feed selectivity (McNaughton, 1985). Future research in ruminant nutrition could harness diverse soil-plant-animal ecosystems more efficiently, whether native, rangeland, or cultivated, to enhance resilience and stability as well as productivity (Tedeschi et al., 2015).

There are more than 790 catalogued cattle breeds from 13 species of the Tribe Bovini spread out in Europe, Africa, Asia, Oceania, and Americas (Porter et al., 2016). Although many indigenous African cattle breeds (about 150) have been identified and used commercially, the majority of African cattle population remain unspecified (Mwai et al., 2015). This highlights the importance of compiling the biodiversity of livestock species, because some species from the sub-Saharan Africa (e.g., Turkana, Ugogo Grey, Azaouak) that are tolerant to drought, heat, and diseases (Mwai et al., 2015), may hold the genetic makeup needed to thrive in different production scenarios in the future (e.g., global warming). This biodiversity likely exists in other domesticated species.

Alkemade et al. (2013) reported that biodiversity (i.e., mean species abundance) in rangeland is decreasing because of the livestock production intensification and continuous conversion of rangeland into cropland. However, the authors indicated that the impact level of livestock on loss of rangeland biodiversity is expected to decrease by 2030. Biodiversity preservation, however, embodies the keeping of non-livestock herbivores as well. Ripple et al. (2015) reported that about 60% of large non-livestock (wildlife) herbivores, including 33 Bovidae species, are threatened with extinction in the sub-Saharan Africa because of not only hunting and land use, but also resource competition and disease spread by domesticated livestock production. Unfortunately, the loss of biodiversity is expected to continue increasing to unprecedented levels because of indirect ecological change drivers, such as human population growth (land and water usages) and GHG emissions (climate change) that cause species extinctions, species over-abundance and community structure imbalances, habitat loss and degradation, and shifts in distribution of species and biomes (Pereira et al., 2010).

In addition to the discovery of livestock tolerant (or resistant) to drought, heat, and diseases, other animal species (indigenous) from the biodiversity pool may provide the energy and protein sources needed to feed the 9.55 billion people expected by 2050 (United Nations, 2013). Cawthorn and Hoffman (2014) listed many non-traditional, indigenous species from different regions of the world (e.g., too dry, too cold, too hot, mountainous) that are currently converting human-inedible plants (e.g., shrubs and trees) into food, including yaks (*Bos grunniens* and *Bos mutus*) in central Asia, dromedary camels (*Camelus dromedarius*) in northern Africa and eastern Asia, goat (*Capra aegagrus hircus*) in many developing countries, water buffalo (*Bubalus bubalis*) in Asia and India, and many wildlife species (e.g., antelope, bison, kangaroo, deer, wild boar, warthog, rabbits, hares, pikas, capybara, and paca). Detailed characteristics, such as nutritional properties, production, challenges, and opportunities, exist for some alternative, non-traditional species, including bison (Galbraith et al., 2014), deer (Wiklund et al., 2014), kangaroo (Spiegel and Wynn, 2014), rabbit (Dalle Zotte, 2014), and water buffalo (Naveena and Kiran, 2014). Hoffman and Cawthorn (2012) provided additional information about meat composition of wildlife species consumed around the world.

Animal welfare

There is considerable public interest in animal welfare, because people naively (or not) believe that the livestock industry has always inflicted gratuitous pain or severe discomfort to animals. Hemsworth and Coleman (2011), however, state that the livestock industry is also concerned about animal welfare only because harmed animals deteriorates animal productivity.

Among several definitions, the terms "animal welfare" or "animal well-being" refer to the physiological or biochemical changes of an animal while trying to cope with or respond to internal challenges or ante-mortem conditions at a given moment of observation (Gregory and Grandin, 1998). It can also denote the mental and physical health of an animal in relation to its environment (Smith and Pearson, 2005). The publication of *Animal Machines* in 1964 by Ruth Harrison brought awareness to the public concerning the welfare of farm animals (Broom, 2005). Since then, animal welfare has sensitized our society in terms of ethical concerns regarding how their food is produced. Guidelines for animal welfare have emerged, including the Terrestrial Animal Health Code (http://www.oie.int/en/international-standard-setting/terrestrial-code/access-online/) by the World Organization for Animal Health (OIE) acknowledging the "five freedoms" [freedom from fear and distress; physical and thermal discomfort; pain, injury, and disease; and to express normal patterns of behavior, (Webster, 2001)]. The root of many issues related to animal welfare are, however, linked to ignorance (not knowing what to do), inexperience (knowing what to do but not knowing how to do it), incompetence (inability to do it), and inconsideration (carelessness) (Gregory and Grandin, 1998). Incompetence and inconsideration are pointed out as the most difficult to correct. In this sense, animal scientists (i.e., the ones that educate people to deal with animals), should work on efficient ways to convince those who handle the animals of the relevance of animal welfare. The relevance of animal welfare relies on three reasons: sense of fair play, thus respect for animals; inadequate animal welfare may cause poor product quality; rising trade barriers for products which attain a deprived welfare image (Gregory and Grandin, 1998).

To ease beef cattle management, animals are usually castrated, dehorned, and identified with ear tags. These handling procedures may cause temporary pain to the animals. According to FAO (2001), livestock transport between farm and slaughterhouse is the greatest stressor and injurious process in the production chain, causing poor animal welfare and loss of production (i.e., waste due to bruising, tramping, suffocation, dehydration, and injuries). Understanding that animal welfare has huge economic implications in animal production is crucial to establish the limits between science and philosophy and measure the quality of animal welfare. The subjectivity of animal welfare relies on methodological difficulties for measuring feeling of creatures that do not communicate in a conventional way.

Public concern about food safety (e.g., bovine spongiform encephalopathy or avian influenza) have sparked a greater interest by the consumer about animal welfare. Surveys have indicated that consumers are willing to pay extra for farm-enhanced animal welfare (Harper and Makatouni, 2002; Verbeke, 2009; Miele et al., 2011). There are many opportunities to manipulate human-animal interactions towards a common beneficial ground to both parties (Hemsworth and Coleman, 2011). In the future, animal scientists should focus on developing non-invasive techniques (e.g., remote sensor technologies) to assess animal welfare (i.e., criteria to score animal welfare objectively without causing pain or discomfort to the animal), improve traceability of animal products (i.e., meat), educate handlers and management personnel, design improved facilities and strategies to take into account animal welfare, and enhance educational programs at K-12 schools to initiate students on the science of animal husbandry of the 21st century.

Conclusions

The livestock industry has been subjected to and will continue to face greater scrutiny by the public, regulatory governmental agencies, and stakeholders in general. A vast number of publications has documented the effects of livestock production on the environment (carbon and water footprints), animal products and human health, antibiotics use and antimicrobial resistance, and animal welfare among many others. The frequency, interval, and intensity of livestock impacts, however, differ across regions, production systems, and among livestock species, in such a way that the generalization of these issues is impossible and dangerous. Greater scrutiny (e.g., effect of animal products on human health), clarity (e.g., greenhouse gas emissions), and standardization (e.g., water footprint) are needed when developing and validating methodologies to assess short- and long-term impacts of livestock production. Failure in correctly quantifying these impacts may lead to disregard and discontentment by the livestock industry, increased public confusion, and the development of illusionary solutions that may actually amplify the impacts, invalidating its original intent.

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