MORE THAN MEAT: Contributions of Livestock Systems Beyond Meat Production

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Introduction

More than meat: contributions of livestock systems beyond meat production
Andrea J. Garmyn ................................................3

Infographic

Livestock provide more than food in smallholder production systems of developing countries ..................6

Feature Articles

Livestock provide more than food in smallholder production systems of developing countries
Liveness Jessica Banda and Jonathan Tanganyika ............................................7

The science behind the wool industry. The importance and value of wool production from sheep
Emma K. Doyle, James W. V. Preston, Bruce A. McGregor, and Phil I. Hynd .......................15

How agricultural rendering supports sustainability and assists livestock’s ability to contribute more than just food
Anna D. Wilkinson and David L. Meeker .........................24

From trucks to tips—examples of peripheral ways by which the meat industry impacts the U.S. workforce and economy
Phillip D. Bass .........................................................35

Animal Frontiers is published quarterly by the American Society of Animal Science (ASAS), Canadian Society of Animal Science (CSAS), the European Federation of Animal Science (EAAP), and the American Meat Science Association (AMSA). This magazine synthesizes information, through applied reviews, from across disciplines within the animal sciences. Animal Frontiers is provided as a benefit to the members of these societies.

The digital version of this magazine is online at www.animalsciencepublications.org/publications/af.
Smallholder dairy farming contributes to household resilience, food, and nutrition security besides income in rural households
Liveness Jessica Banda, Daniel Chiumia, Timothy Nthaziyake Gondwe, and Sera Rose Gondwe .......... 41

Horse meat production in northern Spain: ecosystem services and sustainability in High Nature Value farmland
Kizkitza Insausti, Lorea R. Beldarrain, Mª Paz Lavín, Noelia Aldai, Ángel R. Mantecón, José L. Sáez, and Rosa Ma Canals .......... 47

Utilization of by-products and food waste in livestock production systems: a Canadian perspective
Kim Ominski, Tim McAllister, Kim Stanford, Genet Mengistu, E. G. Kebebe, Faith Omonijo, Marcos Cordeiro, Getahun Legesse, and Karin Wittenberg ...................... 55

Youth livestock programs provide intangible benefits through life skill development
Chad Martin and Clint Rusk ............................................................. 64

Society News
Join us in the Biggest Little City in the World ......................... 72
Save the Date ................................................................. 73
CSAS Society News .............................................................. 74
The 72nd EAAP Annual Meeting will be held in Davos (Switzerland) ...................................................... 75

About the cover: More Than Meat: Contributions of Livestock Systems Beyond Meat Production
Introduction

More than meat: contributions of livestock systems beyond meat production

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Global meat production topped over 340 million tons in 2018, representing over 80 billion animals (Ritchie and Poser, 2019). An estimated 69 billion chickens, 656 million turkeys, 1.5 billion pigs, 302 million cattle, 574 million sheep, and 479 million goats were slaughtered worldwide for meat production in 2018 (Ritchie and Poser, 2019). Yet, these numbers represent only a small fraction of the total population, especially of the larger red meat species, presented as a snapshot of livestock counts at a given time in a year (2018) in Table 1 (FAO, 2020). A large portion of the global livestock population is not intended for meat production, at least not as its primary purpose. Moreover, depending on the species, 35% to 50% of the live weight of slaughtered animals is not used for human food (Meeker and Hamilton, 2006).

The goal of this issue is to highlight the ways that the livestock industry and products from livestock production can be more than just meat. There are tangible products from the livestock industry, including milk, eggs, and edible by-products, and also nonfood items, such as fiber and a wide array of rendered products. There are also many intangible benefits from livestock production such as direct and indirect employment opportunities in developed countries or as wealth or assets in developing countries. Some livestock are even used to help maintain rangelands for fire control or “upcycle” food waste, converting otherwise inedible foodstuffs into high-quality protein. Lastly, livestock production can play a critical role in youth development through programs such as 4-H and FFA, where children and young adults gain valuable life skills through raising and showing livestock as 4-H/FFA projects, in addition to youth and collegiate livestock judging activities. We would like to communicate the integral role that livestock play in the overall food and environmental system.

When asked what products that are derived from livestock, I think many would immediately recognize meat, milk, and eggs are sourced from animals. But what about the products other than those intended for human consumption? Doyle et al. (2021) provide an overview of the wool industry, highlighting the importance and value of wool production from sheep. Where else would we turn to other than Australia to provide this insightful review that covers fiber production on a biological level, on-farm determinants of productivity and profitability, and wool characteristics and processing.

What happens to the 35% to 50% of the animal that is not used for human food (Figure 1; Meeker and Hamilton, 2006)? Wilkinson and Meeker (2021) explain the process of agricultural rendering and discuss the “Big 4” rendered product markets: pet food/animal feed, fuel, oleochemical products, and fertilizer. Wilkinson and Meeker (2021) also highlight how rendering supports the three pillars of sustainability: environmental, economic, and social.

Next, we’ll delve into those intangible benefits—the ones we cannot sink our teeth into or hold in our hands. The meat supply chain provides so much more than just nourishment to those consuming animal-derived products, specifically meat. Dr. Phil Bass (2021) highlights the employment and economic benefits tied directly and indirectly to the meat supply chain. Bass (2021) focuses on three main areas in this assessment—live animal transportation, packing house personnel and material, and the restaurant dining industry.

In a series of contributions from Africa led by Dr. Liveness Banda, she discusses how livestock provide so much more than simply the food they produce in developing countries. Banda and Tanganyak (2021) highlight the nonfood roles of livestock in developing countries, including working animals for draught power, pest and weed control, social status or prestige, and a

| Species   | Number of animals |
|-----------|-------------------|
| Buffaloes | 233,719,311       |
| Camels    | 35,848,571        |
| Cattle    | 1,553,162,432     |
| Chickens  | 29,079,694,000    |
| Goats     | 1,184,298,887     |
| Horses    | 61,219,008        |
| Pigs      | 1,425,507,453     |
| Sheep     | 1,373,546,174     |
| Turkeys   | 466,872,000       |
| Total     | 35,413,867,836    |
form of savings. Next, she focuses specifically on smallholder dairy farmers, focusing on the ways dairy farming contributes more than milk for income to rural livelihoods (Banda et al., 2021). Dairy farmers often allocate land to food crops, cash crops, and pasture production, giving them more diversified sources of income and making them more resilient to food insecurity than nondairy farmers.

In a contribution from Spain, Insausti et al. (2021) describe European horse meat production systems. Equine farms play an essential socioeconomical role in the environmental preservation of mountain areas in many regions of southern Europe, since horses can efficiently digest cellulose. Although horse meat production (and consumption) is considered taboo in some areas around the world, these extensive systems play an important role in the sustainable development of mountain areas mainly through biomass management and subsequent fire prevention.

Ominski et al. (2021) offer a Canadian perspective to livestock upcycling. Livestock have the capability to utilize by-products and food waste and convert these low-value materials into high-quality protein. Although there is great potential, challenges do exist. Ominski et al. (2021) also discuss how to navigate regulatory restrictions, safety concerns, and logistical considerations for by-product or food waste utilization in livestock feeding systems.

Lastly, livestock production can play a critical role in youth development through programs like 4-H and FFA, where children and young adults gain valuable life skills through raising and showing livestock as 4-H/FFA projects, in addition to youth and collegiate livestock judging activities. When Dr. Anna Dilger and I were discussing the theme and articles we wanted to feature for this issue, the relationship between livestock production and youth development is one topic we were both intrigued and excited about. Even when I started initial discussions with Dr. Clint Rusk, I believe his words were “It’s an article that needs to be written.” Martin and Rusk (2021) go beyond these youth organizations and focus specifically on the benefits of 4-H livestock judging. Youth and young adults develop several life skills from their participation in judging activities—problem solving, decision making, dealing with pressure, self-motivation, self-discipline, organization, teamwork, and communication. It is a long list, and these skills are often sought after by future employers.

In closing, Dr. Anna Dilger and I would like to thank all of the authors around the globe for their contributions and also the reviewers who assisted in their publications. We hope this issue sheds some light on the nonfood roles of the livestock production and offers some regional perspective on those roles.

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Bass, P.D. 2021. From trucks to tips – examples of peripheral ways by which the meat industry impacts the United States workforce and economy. Anim. Front. 11(2):35–40.

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Livestock provide more than food in smallholder production systems of developing countries.

Livestock are an important part of rural livelihoods in most developing countries. While animal products provide an affordable source of nutrients for rural communities, livestock are much more than food. This review highlights key roles livestock play in smallholder production systems in developing countries.

System and socio-cultural practices. For instance, large animals such as cattle can provide transport, draft power or social prestige, while smaller animals like poultry, goats, and sheep may be more important as a direct meat source.

Livestock serve as a form of savings which can easily be liquidated into cash. They can benefit rural incomes both directly (e.g., through product sales and hiring out animals for services) and indirectly (e.g., as source of employment).

People of different genders benefit from livestock in different ways. For instance, women tend to engage in lower revenue commodities sold in informal markets.

Livestock have many important non-food roles, such as weed control, crop manure, draft power, insect repellent (via dung), leisure, and religious ceremony.

Despite the widespread benefits, there is a lack of specific research aimed at quantifying the value of livestock in rural livelihoods, especially non-food roles.

There is strong potential for the inclusion of livestock in rural development programs to help alleviate poverty. A better understanding of non-food livestock roles will help better account for their contribution to economic indicators in developing countries.
Feature Article

Livestock provide more than food in smallholder production systems of developing countries

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Implications

- Livestock serve as a form of savings, which can easily be liquidated into cash and provide many other benefits both directly and indirectly.
- Livestock are key to poverty alleviation and are an important development tool where benefits derived vary with the gender of beneficiaries.
- Livestock provide numerous benefits, which are both tangible and intangible, but they are not adequately valued.
- There is a need for more research to quantify and value various aspects through which livestock benefit communities in the developing world for efficient resource allocation.

Key words: assets, food, income, livelihoods, livestock

Introduction

Livestock play multiple and significant roles in the rural livelihoods of most developing countries where they provide both direct and indirect benefits to communities. Herrero et al. (2012) reported that livestock roles in the economies of developing countries are significant to millions of both producers and consumers that are often vulnerable and economically constrained. Livestock serve as a source of food, income, manure, traction, and transport as well as serve as financial aids and enhance social status among others. The various benefits of keeping livestock confirm that livestock form an integral and indispensable part of social life and sustenance of poor communities (Meissner et al., 2013).

According to Bettencourt et al. (2014), livestock uses can be classified as economic (source of cash income, means of saving accumulation and investment, and economic status), household use (feeding, transportation, fertilizer, and animal draught), sociocultural (social status, paying bridewealth, providing animals for communal feasts or sacrifices), and leisure (horse racing, cockfighting, bullfight, and hunting). In their review, Alonso et al. (2019) classified nonfood roles of livestock as economical (access to credit, draft power, transport, asset accumulation, household energy production, nonedible by-products [hides, horns, fiber, etc.], and construction material); environmental (manure, nutrient recycling, landscape amenity, improving pastureland, and carbon sequestration); and social (psychosocial well-being, traditional foods, cultural events, ritual and religion, exercise, sport, and recreation). Therefore, there is evidence that livestock do not only directly produce food but also provide key nonfood roles to communities. Sometimes, the roles are quite complex and span across value chains, but documentation of such roles is scanty. It is the objective of this manuscript to highlight the key roles of livestock in smallholder production systems in developing countries.

Livestock production systems and productivity

The roles of livestock are directly linked to production systems used and subsequent productivity. Livestock management has been classified into different production systems, which often depend on agroecological zones and production practices. The production systems are generally in two categories—mixed and sole production systems. This is based on whether livestock production is mixed with other enterprises such as crops, or it is the sole activity on the farm. Ruthernberg (1980) defined a farming system as a population of farms with a similar structure and function with a likelihood to have similar production functions. McConnell and Dillon (1997) further defined an agricultural system as “an assemblage of components which are united by some form of interaction and interdependence and which operate within a prescribed boundary to achieve a specified agricultural objective on behalf of the beneficiaries of the system.” The interactions and interdependence are evident in various production systems that have been classified. Farms that fall within the same production system tend to have broadly similar resources, pattern of productions, livelihood strategies, and challenges, and, therefore, similar development strategies and interventions apply to the farms. There are different livestock production systems that have been described.

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and various names and classification criteria have been used. Some of the criteria used to classify the production systems are intensity of production, extent of integration of farm enterprises, animal–land relationship, and agroecological zones (Seré and Steinfield, 1996; Damron, 2009; McDermott et al., 2010). Production systems that prevail in most developing countries are those falling into mixed production systems. Mixed systems have varying levels of integration of livestock and crop farming with varying degrees of nutrient recycling between systems. Sole livestock systems in developing countries are generally associated with nomadism, which has gradually declined over the years likely due to urbanization, land availability, human population increase, and climate change challenges.

The productivity of livestock will depend on the production system involved. Although the systems prevailing in rural communities of most developing countries are distinct, they generally tend to be low input–low output systems. As such, benefits derived from these animals are largely based on the population sizes of the livestock than individual animal productivity. The communities do not necessarily focus primarily on the quantity of products such as milk, meat, and eggs produced but other benefits as perceived by communities. Hence, the systems tend to be less efficient and are associated with high mortality and low productivity. However, the breeds that thrive in these production systems have adapted to the systems and tend to be more disease tolerant or resistant. The animals are generally adapted to low feed and water availability as well as harsh environmental conditions.

The various roles and benefits of livestock discussed below vary depending on the production system in association with specific species and prevailing environmental factors. The actual value of livestock varies from community to community depending on cultural practices. For instance, on the one hand, large stock such as cattle, donkeys, mules, and camels are important for draft power in addition to being a source of income, meat, milk, and other byproducts. They are also a form of savings and provide prestige and other social values. On the other hand, small stocks such as poultry, goats, and sheep may easily be slaughtered for consumption besides other roles they play. There are also other species that may not be consumed or are valued differently by some societies because of religious beliefs and such species include pigs and sheep. Hence, their utilization and benefits also vary based on their religious value.

**Gender roles in livestock production systems**

There also tend to be variations in terms of benefits linked with gender depending on cultural norms regarding ownership and management responsibilities. Kristjanson et al. (2014) reported differences in how women benefit from livestock depending on gender roles. Njuki et al. (2011) reported that women are likely to be engaged in commodities that generate lower revenues sold in informal markets than men. Men on the other hand have a high likelihood to control high revenue-generating commodities that are generally sold in formal markets. This is further evidenced by Yisehak (2008) who reported that in smallholder systems of Ethiopia, men owned most of the livestock species and were responsible for sales of live animals and meat, whereas women owned chickens, and, if involved with large stocks, they were primarily involved with milk management (Figure 1).

**Livestock in development programs**

Livestock in rural communities are mainly kept under low input and low output production systems, where feeding, housing, health, and breeding management is minimal. As such, their productivity tends to be low. Furthermore, the breeds kept are those that are adapted to the often, harsh tropical environments that characterize most developing countries. This presents an unexploited potential in these animals, and many government and nongovernmental organizations recognize this potential and tend to include livestock in rural development programs. Livestock have also been described as having distinct pathways that could facilitate poverty reduction. Many NGOs use livestock as a development tool and attempt to do this along with the promotion of appropriate livestock management practices. Such interventions have contributed to the increase of populations of livestock over time in different regions (Figure 2). Figure 2 shows that the population trends of major livestock species where the distribution of the populations and their changes between 2013 and 2018 vary with region. Some regions have some species dominating, which could be related sociocultural practices and/or adaptation of the animals to the production environment. However, trends show that some species are increasing, whereas others are inconsistent except in Africa where several species have an average increase rate of about 2%. More species seem to thrive in Africa and South Asia compared with other regions.

![Figure 1. Women involved in management of small stock (from left to right: restraining a goat and feeding poultry with one dairy cow in the background).](https://academic.oup.com/af/article/11/2/NP/6276808/120N967670808)
In South America, the major species dominating seem to be cattle and chickens, whereas, in South East Asia, it is chickens.

**Food Roles of Livestock**

Animal protein is a high-quality, easily digested protein that possesses a high biological value (Alonso et al., 2019). According to Dror and Allen (2011), livestock-derived foods have a specific nutrient composition that satisfies well the needs of the human body and reduces stunting and some key micronutrient deficiencies in humans (Alonso et al., 2019). Compared with plants and their derived products, meat and meat products provide essential nutrients that are important to the human diet (Byers et al., 2002). It is well established that meat is an integral part of a balanced diet that contributes valuable nutrients that are beneficial to the human health. Milk and milk products are useful foods throughout all human life periods because they adequately supply nutrients for the promotion of skeletal, muscular, and neurologic development. Poultry provides meat, eggs, and other products. For instance, chickens provide a cheap source of animal protein and readily available meat (Yared et al., 2019) that contains essential amino acids required for human beings, and eggs are richly endowed with nutrients (Lahkotia, 2002). Observations show that there tend to be more edible animal parts in developing countries than in developed countries. Parts such as chicken heads, intestines, and legs, which are often dressed off in developed countries, are readily consumed and considered delicacies in developing countries. Various animal products and how they are processed in Africa have been described by Mattiello et al. (2018).

After an animal is slaughtered, it provides a wide range of byproducts that can further be processed and used in other industries (Alao et al., 2017). These byproducts can further be utilized by humans as food or reprocessed as secondary byproducts for both agricultural and industrial uses (Liu, 2002). The nonedible animal byproducts are the ones that provide some of the nonfood roles directly, and these include products used as a raw material in the fabric, cosmetic, pharmaceutical, and animal feed industry. On the other hand, the condemned parts (gastrointestinal tract contents, trimmings, and fetus) may be used in biogas and fertilizer production industries (Figure 3).

**Nonfood Roles of Livestock**

Apart from food, livestock provide byproducts and nonfood roles that are often ignored, difficult to quantify, and are easily left out in evaluating the importance of livestock (Figure 2).
Animal byproducts

Apart from meat, pigs provide byproducts (water filters, rubber, antifreeze, certain plastics, floor waxes, crayons, chalk, adhesives, etc.). Cattle and other bovine animals provide tallow (fat), which is used in wax paper, crayons, margarines, paints, rubber, lubricants, candles, soaps, lipsticks, shaving creams, and other cosmetics. Poultry provide feathers that can be used as stuffing (down) in jackets and pillows. Furthermore, bees provide honey and wax that are used to make candles, lipstick, lotions, shoe polish, crayons, chewing gum, and floor polish.

Role of livestock in household income

Livestock play multiple roles in supporting household income (Herrero et al., 2012). Research has shown that 68% of households across the developing world earn income from livestock (Davis et al., 2007). For instance, the poultry industry contributes significantly in providing employment and supplementary income to the people and is an important instrument for socioeconomic improvement among the rural farmers. Mutami (2015) reported that, in Zimbabwe, backyard poultry production stimulates local economic development of urban centers and villages through the development of related micro-enterprises wholly or partly (Figure 4). Dairy production is another source of income in many developing countries. It is one of the enterprises that ensures a steady flow of income once animals start calving. The income is directly from product sales (milk, manure, and meat [after culling]) or indirectly as a source of employment for herdsmen or fodder suppliers. Other sources of income include hiring out animals for draft power and breeding services.

Sociocultural importance of livestock

Various livestock species play important sociocultural functions for rural households in developing countries (Bettencourt et al., 2014). The social roles of livestock include a set of rituals and social obligations, such as funerals, ritual slaughter, and bridewealth, which are provided formally or informally (Bettencourt et al., 2015). However, the sociocultural functions of livestock are underestimated in most of the communities. Poultry, compared with other livestock species, are socioculturally important with few religious taboos attached (Upton, 2004). For instance, some phenotypes of indigenous chickens (such as frizzled, black, or white plumage) in African countries are associated with customs such as being demanded to be used as fines or ritual slaughters. Similar beliefs extend to species such as goats and sheep in some cultures.

Importance of livestock in emergencies and disasters

Livestock are used as coping strategies to shocks in food security and emergency response, such as worsening economic conditions,
droughts, floods, and crop or livestock disease epidemics. These disasters affect rural livelihoods through loss of assets including livestock. Comparatively, complete loss of livestock as assets generally is not as acute as that of crops. Livestock tend to be more resilient than crops when disasters such as drought and floods strike. In Malawi, there is evidence that farmers owning animals such as goats are better able to cope with drought than those that rely on producing crops only as they can sell goats and buy food long after crops have wilted. However, most of the relief services do not consider livestock replacement in recovery programs as it is generally expensive. Relief items are usually in the form of processed food items or easy to grow food crops, thereby not replenishing livestock populations in communities affected by the disaster such as floods and droughts.

**Importance of livestock dung as mosquito repellent**

Studies have shown that animal dung can be used as an insect repellent (Mandavgane et al., 2005). In the ancient world, people used to burn animal dung as an insect repellent and even mixed with mud when building mud houses to control insects. But the modern world has ignored this indigenous knowledge and uses modern insect repellants, some of which are harmful to the environment as well as to human health. Researchers proved that pyrethroids used in repellents lead to hyperexcitation of the nervous system and prolong uses result in corneal damage, liver damage, and asthma. About 12% of users are seriously affected by the use of repellents (Mandavgane et al., 2005). In another study, the use of elephant dung as one of the main ingredients in the production of mosquito repellent proved to be eco-friendly organic herbal repellent with long-lasting protection and safe for human life, animal skin, and humans with no side effect and could be an alternative to commercially available synthetic chemical repellents (Ramy et al., 2019).

**Importance of livestock in weed control**

Weed control is another nonfood role of livestock, which remains untapped. It is established that livestock can be used in weed control such that the cost of weeding using human labor or herbicides is offset. They may be used to directly graze weeds or consume weeds that have been cut. Goats being browsers are useful in controlling shrubs and thistles. Sheep are considered as best for weed control as they graze close to the ground and easily control leafy plants, which in turn are nutritious to the animals. Sheep and geese are known to control grassy weeds in fields for legumes and other crops. There are recommended stocking densities of animals such as pigs, cattle, sheep, and goats in controlling perennial weeds between cropping seasons. Livestock can also be used in early grazing to prevent weed growth. They can also be used in clearing crop residues after harvest. In large plantations of trees such as rubber, livestock are used to control the overgrowth of cover crops. When they graze on mature weeds, they help destroy many weed seeds although not completely all. Ducks have also been used in integrated farming systems whereby their role is to control weeds and pests while supplying manure in the form of droppings (Figure 5). However, in many communities, grazing animals are used primarily for food or fiber, and their use for weed control is of secondary concern. Apparently, Integrated Weed Management has not been adopted as widely or as readily as Integrated Pest Management.

**Use of livestock manure in mixed farming systems**

Livestock play a vital role in nutrient recycling in the soil through the provision of manure. In most developing countries whose economies are agro-based, poverty has often been associated with poor soil fertility (Sanchez, 2002), and sensible use of organic resources (Chivenge et al., 2011) can improve the situation since few smallholders can afford enough mineral fertilizers for crop production. In this regard, livestock play a major role in land use system and facilitate soil fertility management and reduce costs associated with inorganic fertilizers. For instance, in Malawi, the use of manure from cattle feedlots have been attributed to increased sugarcane yield in sugar plantations while largely offsetting the use of inorganic fertilizers. Non-livestock owners are known to purchase manure to apply in their gardens. Manure has recently become an additional source of income to many livestock farmers, while, in the past, it used to be given out for free or sold at greatly reduced prices. Some farmers in Malawi further incorporate manure with inorganic fertilizers creating a mixture capable of achieving similar maize yields to fields with only inorganic fertilizer applied.

**Role of livestock in draught power**

Livestock provide nonhuman energy (animal power) to poor farmers for ploughing, drawing water, and transporting sick people and goods. Draught animal power provides an intermediate level of mechanization between human power and engine power (Figure 6). As such, it is attractive to smallholder farmers, who wish to improve their productivity within the availability of their limited livelihood assets, particularly in sub-Saharan Africa. Draught power is also used as a service in the community or hired out as an additional source of income. The species that are key in draught power are cattle, donkeys, mules, camels, and buffaloes.

**Use of livestock in biomedical research**

Biomedical research is another nonfood role of livestock. Often, when there are new techniques, products, or drugs to
be developed for humans, researchers use animals including livestock to test for safety and efficacy prior to making them available to human subjects (Beena, 2019). Though laboratory rodents have been used extensively, they have limitations in organ size, life span, breeding, physiology, metabolic, and behavior patterns (Polejaeva et al., 2016); hence, using livestock (cattle, sheep, goat, and pig) is better since they have common anatomy and physiology with humans. For instance, cattle are the best model for studies on reproductive immunology and placental biology since their reproductive cycles are similar to humans (Beena, 2019), whereas goats and sheep are the best models for studying cardiac and respiratory systems, respectively (Dosdall et al., 2013). Goats have also been developed as a model in orthopedic studies because their anatomy is similar to humans (Pearce et al., 2007). Using farm animals has advantages over smaller animals because livestock are larger in size, thereby easing the collection of larger volumes and more frequent samples for research (Hamernik, 2019).

Use of livestock in leisure

Many animals are bred and bought because people like to spend part of their free time with them (companion animals). Bettencourt et al. (2015) reported that animals play an important role in leisure, and, in some cultures, they are used for betting, racing, fighting, and hunting. For instance, in Timor-Leste, cockfighting is one of the older leisure activities preferred by many people whereby men take cocks as their precious animals ready for fighting. However, there might be concerns with animal welfare with such sport. Other sporting activities such as horse racing are important among the affluent in developing countries.

Challenges and opportunities

Despite the so many food and nonfood roles of livestock to humans, the sector is faced with several challenges, among which is the lack of data on nonfood roles of livestock. Where livestock are kept largely for social status, it becomes a challenge to justify the slaughter for home consumption, and, as a result, family members are denied access to the much-needed animal protein. However, literature shows that livestock play a significant role in rural livelihoods and the economies of developing countries. They are providers of complex functions including food and nonfood functions. Their relevance increases as human populations, disposable incomes, and urbanization rates increase as well as a change in eating habits. Therefore, there is a need for specific research aimed at a better understanding of the role of livestock, especially nonfood roles, which are mostly ignored, in the livelihoods of rural communities in the developing world.
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Conclusions

This article has highlighted the diversity of livestock contributions to smallholder farmer livelihoods in developing countries. The value of livestock as a food source, through milk, meat, and eggs, is well established. Further research and documentation of the nonfood contributions of livestock are critical to better quantify and evaluate the true value livestock contribute in these sectors. There is a need for more in-depth research on the nonfood roles of livestock in different communities in developing countries. This is necessary for a more accurate determination of how livestock contribute to the overall economic development, stability, and status in various contexts.

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Feature Article

The science behind the wool industry. The importance and value of wool production from sheep

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Introduction to Wool Production and Demand

Sheep and wool production occurs in a number of areas of the world. The production method, however, has been considered somewhat diverse. Wool production can collectively be the production of keratin fibers from a range of animals. This can include the production of cashmere, alpaca, mohair, angora, yak, elk, and camel fiber. Fiber characteristics from sheep wool can vary depending on the sheep breed, its age, the environmental grazing conditions, local market requirements, and export opportunities for the country of origin.

On an international scale, wool production is a small trade (Textile Exchange, 2019). The inception of manmade fibers in the 1880s has seen considerable shrinkage in the textile market share of wool. Wool production represents about 1% of the global supply of textile fibers (Table 1). Apparel wool from sheep contributes about half of that amount. The contribution of wool has fallen by about half over the past 20 yr as wool production has declined, and the production of manmade fibers has nearly doubled (IWTO, 2019).

Similarly, as wool production has decreased, there has been a reduction in demand for woolen fabrics in the last two decades (IWTO, 2019). Traditionally, apparel wool was used either as outer knitwear or as woven suiting attire. Research indicates that there is a trend away from these markets due to:

• Increasing casualization of the workforce;
• Limited trans-seasonal clothing options;
• Attitudes on discretionary spending during unfavorable economic conditions.

Casualization of workforce

Data show a consistent decreasing demand trend for woven suiting fabrics (IWTO, 2019). This is consistent with trend of the casualization of work wear and the importance of comfort and loungewear. This has been further compounded by recent requirements for employees to work from home due to recent COVID-19 pandemic restrictions.

Limited trans-seasonal clothing options

Traditional markets rely heavily on the autumn-winter months of countries in the northern hemisphere. Consumers in this environment provide demand based on the requirement of needing warmth from knitted outerwear. The high degree of seasonality to this market limits sales throughout the warmer months of the year (Cottle, 2010). Additionally, workplaces are now heated.

Implications

• This paper outlines the wool industry and highlights wool as a textile fibre. The wool industry has optimized the production of a niche product that has repositioned itself due to its inherent natural properties of being a natural, biodegradable product that offers consumer comfort and health benefits.
• Research into the breeding and management of sheep on-farm, has developed a raw product that is easier to process or has superior woolen attributes.
• Skin follicle formation and subsidiary glands affect wool production and quality. By understanding how wool follicle cells initiate and develop, producers are able to improve fibre quality.

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Table 1. World supply of textile fibers

| Fiber                | Million tonnes | Percentage of market |
|----------------------|----------------|----------------------|
| Polyester            | 55.1           | 51.5                 |
| Cotton               | 26.1           | 24.4                 |
| Cellulosic           | 6.7            | 6.2                  |
| Other plant fibers, including flax, hemp, jute, and coir | 6.1 | 5.7 |
| Polyamide            | 5.4            | 5.0                  |
| Other manmade        | 6.1            | 5.7                  |
| Wool sheep           | 1.1            | 1.0                  |
| Wool other animals   | 0.05           |                      |
| Silk                 | 0.16           | 0.1                  |
| Feathers, down       | 0.32           | 0.3                  |
| Total                | 107            | 99.9%*               |

Source: Textile Exchange (2019).
*The total may not be 100% due to rounding errors.

Attitudes on discretionary spending during unfavorable economic conditions

The woven suit industry and to a lesser extent outer knitwear are heavily reliant on positive economic conditions where wool consumption is related to the consumer’s “ability to pay rather than willingness to pay” (Rowe, 2010). As textile spending is classified as discretionary spending, there is generally a trend away from textile trading during tough economic conditions.

Future demand for wool

Future demand for wool will be determined by its ability to capitalize on new emerging markets. Due to diminishing returns in traditional markets, new markets such as the next-to-skin knitwear market (Rowe, 2010) offer an area of growth for wool. Wool marketing has focused on extending the use of wool into nontraditional markets. This includes the next-to-skin knitwear and athleisure market. These markets require wool to be worn as a base layer or as described as “next to skin”, which requires the fiber to have low fiber diameter (less than 18 µm) and capitalize on the unique fiber characteristics, such as breathability, resisting odor, and moisture-wicking capabilities. Additionally, the clean, green eco-positioning of wool according to the use of the life cycle assessment to quantify its sustainability position makes it attractive to the environmentally savvy consumer. The next-to-skin knitwear market does require certain specifications to suit this market. Wool must be soft to touch, also known as the handle of the fabric, and absent of considerable prickle predominately caused by coarse fibers (over 30 µm) to develop a level of consumer comfort (Naebe et al., 2015). Australia typically producers 95% of the world’s wool production that is finer than 19.6 µm (Cottle, 2010).

Limitations to the expansion of wool as a textile fabric

Wool is approximately four to seven times more expensive to produce and process compared with manmade fibers and other natural fibers such as cotton (Cottle, 2010). Naturally, to recover this cost, the selling price point of wool textiles needs to be significantly higher; therefore, wool needs to be marketed as a luxury niche product. Marketing has targeted the rising middle-class Asian consumers to purchase luxury wool items.

Economics of fiber production

The commercial significance of the physical properties of raw wool is summarized in Table 2. Mean fiber diameter is by far the most important physical property affecting processing performance, fabric properties, consumer evaluation, and price per kilogram. Some physical properties are of great importance in early and/or later stage processing, whereas others have lesser importance depending on the defined end use for which the fiber is destined. These physical properties directly affect the speed of processing, processing yield, quantity of waste products, yarn quality, dyeing performance, visual attributes, handle attributes, fabric properties, cost of product, and appeal to customer. Cottle and Baxter (2015) reviewed the testing requirements for important physical properties of wool.

Research has expanded the understanding of the effects of wool crimp (fiber curvature) on processing, knitted fabric requirements for important physical properties of wool, and wearer comfort (McGregor and Postle, 2009; McGregor et al., 2015a). The importance and influence of wool handle have been recently reviewed by Preston et al. (2016). The challenge for producers is to produce wool acceptable to the wool value chain in a variable environment. Inconsistent rainfall is a challenge to wool producers as pasture growth is limited by rainfall. Inconsistent pasture growth will lead to a decline in wool quality traits, such as staple strength, which is important for early stage processing. There are many on-farm factors that affect the physical properties of wool, including nutrition, reproduction, health, and management, and they are reviewed elsewhere (McGregor et al., 2016).

Influence of shearing on sheep management, wool production, and wool quality

In a sheep enterprise, lambing and shearing are two important husbandry practices that a producer can alter the timing of to improve productivity. The shearing event induces a cold response, which can result in an increased feed consumption and consequently metabolic rate. There is renewed interest in the implications of shearing to increase metabolic response, the benefits of an increased condition score post shearing, and thus improvements in reproduction rates from a strategic shearing event. An increased fertility rate potentially allows the producer to increase the reproduction rate and thus profitability.

The wool quality and production, such as staple strength, length, and fleece weights, are manipulated by the timing of the shearing event (McGuirk et al., 1996). Dust penetration will also affect the wool yield percentage and profitability of the wool production. Sheep with long wool during dusty summer conditions will have a higher dust penetration and increased...
contaminants in the wool. Dust penetration is also highly correlated with wool staple weathering (degradation by environment), which increases noil (waste or short fiber) losses during early stage processing and affects dying potential (Holt et al., 1994). Practices such as visually selecting for wool with additional wool grease content have shown to reduce the level of dust penetration along the staple length.

Fiber Production in the Skin

The development of the modern wool-producing sheep is a triumph of genetics and breeding over the past 200 yr from “primitive” sheep characterized by: fibers that were coarse (>30 to 120 µm); variably pigmented; highly variable in diameter and length (typically the animals had effectively two coats: an outer coarse coat and an inner finer coat); typically long, crimpless fibers; fibers that shed on a regular seasonal basis; and fibers that were medullated (contained an air core). The density of the fibers in the skin and the total fleece weights of such sheep were low. Indeed, this description defines “hair” in contrast to “wool,” which is characterized by: fine and ultrafine fibers (typically between 10 and 20 µm), high follicle density in the skin, high clean fleece weights, uniform fiber length and diameter (low coefficients of variation in both), high crimp frequency, regular crimp frequency, very white fibers, and almost continuous fiber production with little or no seasonal shedding. This transformation reflects strong selection pressure on the desired traits, many of which were apparent in the Merino sheep. This transformation reflects strong selection pressure on continuous fiber production with little or no seasonal shedding.

Table 2. The importance of wool attributes to wool processing

| Characteristics                  | Processing significance                                                                 | Importance to scouring and topmaking | Importance to yarn and cloth manufacturing |
|----------------------------------|----------------------------------------------------------------------------------------|--------------------------------------|--------------------------------------------|
| Mean fiber diameter              | Affects hauteur, spinning limits for yarn, fabric mass per unit area, fabric prickliness, and softness | ****                                 | ****                                      |
| Length                           | Major contributor to hauteur and yarn quality                                          | ***                                  | ***                                        |
| Washing yield                    | Measures quantity of clean fiber                                                       | ****                                 |                                            |
| Vegetable matter amount and type | Impact carding and combing yield and contributes to hauteur and fabric quality         | ***                                  | **                                         |
| Strength                         | Major contributor to hauteur                                                          | ***                                  |                                            |
| Crimp (fiber curvature)          | Affects hauteur, yarn evenness, fabric properties, and handle                          | **                                   | **                                         |
| Clean fiber color                | Affects dying ability                                                                  | *                                    |                                            |
| Suint/moisture content           | Affects wool color                                                                     | *                                    |                                            |
| Handle                           | Affects softness of fabrics                                                           | *                                    | **                                         |
| Weathering                       | Affects hauteur and dying ability                                                      | *                                    |                                            |

Source adapted from Anon (1973), Aitken et al. (1994), and Cottle (2010). Hauteur is defined as fiber length after early stage processing.

****Most important; ***major; **secondary; and *minor.

Production of wool fibers in a follicle

The wool follicle has three major regions of fiber production: the follicle bulb or germinative region, the zone of keratinization, and the zone of final hardening. Cells multiply rapidly in the follicle bulb and the daughter cells or transient amplifying cells migrate distally up the follicle. During this migration, they are rapidly synthesizing keratin, the high-sulfur
amino acid fiber protein. Keratin is synthesized from amino acids derived from the surrounding blood vessels and delivered to the cells by amino acid transport systems (Thomas et al., 2007). Wool proteins are then formed by the normal gene transcription/translation mechanisms of mammalian cells (Fratini et al., 1994). The inner root sheath, which surrounds the fiber cells, is also produced by the cells produced in the follicle bulb. In fact, most of the cells produced in the bulb produce this sheath and not the actual fiber (Hynd, 1989). The root sheath hardens before the fiber cells and produces a “dye” through which the wool cells are cast and shaped. As the cells approach the end of the keratinization zone, the sheath cells are resorbed and the fiber cells dehydrate and hardens. The hardening is a result of the production of disulfide bonds between sulfur atoms on the cysteine residues in the keratin protein.

Wool fibers contain two major cell types: the cortical cells, which form the bulk of the fiber and which are thin, elongated cells (approximately 5 µm wide and 100 µm long) (Hynd, 1989), and the cuticle cells, which are thin (1 µm) flat cells that surround the fiber and overlap with each other to produce the typical scale pattern seen on animal fibers (Meyer et al., 2002). The cortical cells are of two types: the paracortical cells, which are typically high in sulfur-containing amino acids, and the orthocortical cells, which are characterized by lower-sulfur proteins (Fratini et al., 1994). Wool fibers are characterized by regular repetitions of crimping or curling of the fiber. The higher the frequency of crimping, generally the finer the diameter of the fiber, although the relationship is far from perfect. The crimp in wool is a result of a combination of differential hardening of cells on one side of the fiber relative to the other, which is associated with differential rates of cell production on either side of the dermal papilla, the small tongue of tissue that invaginates the follicle bulb (Hynd et al., 2009).

Effects of genetics and nutrition on wool growth and quality

The effects of genotype and nutrition on wool growth and wool quality are evident through changes in the skin follicle population described above and through the rates of cell production, keratinization, and elongation. From a genetic viewpoint, the main trait affecting wool “quality” and quantity is follicle density. Generally, sheep with high mean fiber diameter have higher clean fleece weights but there are significant genetic deviations from unity allowing producers to select animals that have genetically not only low mean fiber diameter but also high clean fleece weight. The linking trait is follicle density; high follicle density is associated with both low mean fiber diameter and high fleece weight. Higher follicle density is associated with both lower fiber diameter, but lower fiber diameter is associated with lower clean fleece weight on average. Importantly, however, the relationship between mean fiber diameter and clean fleece weight is highly variable and that means there is substantial opportunity to identify genotypes of sheep, which have not only a low fiber diameter but also a relatively high clean fleece weight. These animals have more total wool follicles because of higher follicle density (number per unit area of skin) and greater total skin area (because the animals are larger and may have greater skin surface area/body weight). The latter is due to

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**Figure 1.** Transverse section of sheep skin (Merino) showing the typical pattern of three primary follicles (with associated sweat or suint glands and large sebaceous glands) and secondary follicles (with sebaceous glands only).

**Figure 2.** Transverse section of the skin of a Merino sheep at day 135 of gestation (A) and at birth (B) showing primary follicles (P), immature secondary follicles (Si), and mature secondary follicles (Sm). Immature secondary follicles are not yet producing a fully formed fiber.
greater wrinkling of the skin (i.e., skinfold), which can be detrimental for other reasons (blowfly attractiveness and difficulty shearing). Again, however, high fleece weight and low fiber diameter are achievable without increasing wrinkle because the relationship between wrinkle and those traits are genetically highly variable.

Nutrition has strong effects on the rate of wool production and most of the quality traits. Nutrition during pregnancy influences the initiation of follicles in the skin of the fetus as described earlier. Poor ewe nutrition during follicle initiation reduces the number of follicles initiated, with permanent negative effects on lifetime wool production (reduced fleece weights) and fiber diameter (increased diameter) (Schinckel and Short, 1961). Postnatal nutrition affects wool growth as shown in Figure 3.

The rate-limiting component of the feed for wool growth is protein and specifically the sulfur-containing amino acids cyst(e)ine and methionine (Reis and Schinckel, 1963). In general, however, on most of the feeds, the supply of limiting amino acids is reflected best by the total dry matter intake and hence the strong relationship as shown in Figure 3. Note, the nature of the relationship between feed intake and wool growth is one of diminishing returns, which means that the “efficiency” of wool growth declines as the intake increases. The rate of this decline depends on the genotype of the animal such that genetically high-producing sheep are more efficient at all intake levels but particularly at high intake rates. This has important implications for stock management in that sheep at high stocking rates will produce more wool per hectare than sheep at low stocking rates even if all feed on offer is consumed under both scenarios. Importantly too, the sheep at higher stocking rates will produce fleeces that are lower in mean fiber diameter, which has additional economic benefits.

**Wool Characteristics and Processing**

The greasy wool physical properties present at shearing have a direct impact on the processing performance of wool into yarn and fabrics. Table 2 describes the wool characteristics that will have an impact on yarn quality.

![Figure 3. Relationship between digestible dry matter intake (g/day) and clean wool growth rate for sheep with a high or low genetic propensity for wool growth rate (after Hynd, 2019).](https://academic.oup.com/af/article/11/2/NP/6276808 by guest on 18 May 2021)

**Fiber diameter**

Fiber diameter describes the mean diameter of the wool fiber, measured in micrometers (µm) of the greasy wool, and impacts on the yarn thickness and fabric mass per unit area (Martindale, 1945). The fiber diameter is the most important wool trait, which affects the price of greasy and clean wool and will impact on the processing performance (the finer the wool fiber the more expensive, but slower the processing), level of entanglement during the scouring process (finer wools have higher entanglement), and fiber breakage (finer wools have higher breakage). Fiber diameter can influence fiber length (hauteur) and also the amount of wool waste (Romaine) during topmaking (AWTA, 2004). The wool fabric wearer comfort and prickle response are directly correlated with fiber diameter (McGregor et al., 2013) as well as fabric handle (McGregor et al., 2015b; Preston et al., 2016).

**Staple length and strength**

Staple length and staple strength will be discussed here, due to both impacting early stage processing. Staple length and staple strength are measured using the ATLAS (Automatic Tester of Length and Strength) machine. Staple length is a measure of the length of the wool staple (measured in millimeters). Staple length is important in predicting hauteur, which is an estimate of fiber length after topmaking (AWTA, 2004). Staple length is, therefore, measured prior to sale in its greasy raw wool form. Discounts are applied to short and long staple length (approximately <60 and >100 mm). More recently, it is not uncommon for producers to manage staple length by shearing at intervals less than 12 mo. As previously mentioned, there can be additional sheep production benefits with this.

Staple strength is the measure of the force (Newtons) required to break a given thickness of wool staple or bundle (ktex). Staple strength will estimate the level of fiber breakage during topmaking, which will influence hauteur. Wool that is weak or “tender” is discounted (<32 N/ktex) and expected not to be able to sustain the rigors of carding and combing processes and produce a higher level of Romaine (wool loss at combing; AWTA, 2004). The position of break of the wool staple is important, as breaks in the middle of the staple will result in shorter hauteur, which will affect potential end use.

**Yield**

Yield is the estimation of wool remaining after the removal of contaminants in greasy wool. Contaminants may include vegetable matter, wax, suint, and dust. The price of wool is provided as a clean price (price on actual weight of wool). Therefore, yield is measured prior to the sale of raw wool.

**Vegetable matter**

Vegetable matter refers not only to the type of cellulose contaminant in the wool but also to the amount present in the
wool. Vegetable matter type and amount will not only affect the speed but also the degree of processing required. Both factors will, therefore, influence the level of price discounts received by producers. Additional carbonization may be required when there is a high vegetable matter percentage or when there is a high level of hardheads (plant seeds that have a hard seed coating). Carbonizing removes the vegetable matter by applying a known concentration of sulfuric acid to carbonize the cellulose material, which is then pulverized through a crushing and dedusting process (Teasdale, 1996). Vegetable matter, such as burrs, shive, and seed, can be removed in small volumes during carding and combing.

Wool garment comfort, prickle, and moisture

Knitted woolen fabrics are more commonly used in casual wear, which is more popular and has superior comfort than the traditional woven wool fabrics. Knitted woolen fabrics were once worn as heavy outerwear, but now fine knitwear has been used in next-to-skin garments. Therefore, the pre-conceive association that wool can have prickle and an itch sensation requires attention. Garnsworthy et al. (1988) established that the physiological basis of the prickle sensation was the number of protruding fibers capable of exerting a force of ~0.74 mN against the skin. Wearer trials identified mean fiber diameter as the predominant measurement for prickle response (McGregor et al., 2013).

Prickle responses can also be influenced by skin moisture, such that moist skin evokes more neutral discharge from fabric, compared with dry skin (Garnsworthy et al., 1988). Single jersey wool fabrics showed that mean fiber diameter accounted for 53% and 56% of the variance in damp and sweaty sensations, respectively, with finer fibers associated with lower sensation scores (McGregor et al., 2015c).

Wool ComfortMeter and Wool HandleMeter

Two instruments, the Wool ComfortMeter and HandleMeter, were developed to objectively measure the comfort and handle of woolen fabrics. These instruments were calibrated to wearer trials. The Wool ComfortMeter reading is strongly correlated with the prickle rating assigned by wearers (McGregor et al., 2013, 2015b; Naebe et al., 2015). The Wool HandleMeter measures the handle parameters of knitted single jersey wool fabric, using eight objective parameters to predict handle attributes (IWTO DTM-67, 2014).

The Future of Animal Fiber Production: Sustainability and Skin Health

The attributes of wool to improve skin health and environmental sustainability profile of wool are two areas of considerable interest to research funding bodies (Figure 4). Recent work has seen the opportunities for wool to further promote itself with these credentials. The following chapter will highlight some of the recent work.

Microparticles and pollution

Fiber content of textiles is often not the source of consumer attraction, particularly in fast fashion. Consumers do not consider or are aware that they are wearing “plastic,” when purchasing polyester garments, and textile engineering often manufactures synthetics to feel like organic fibers at a reduced cost. However, polyester fibers will pill, break, and wear down creating the same pollution issues as plastic bags.

Currently, two-thirds of all textile items are synthetic, petroleum, based polymers, and consideration is being made on including a metric for microplastic pollution in the environmental assessment of textile sustainability (Henry et al., 2019).

Figure 4. An overview of fiber advocacy for current wool research.
The emerging issue of microfiber pollution in our waterways and the impact on the ecosystem puts natural fibers in the spotlight as a more sustainable fiber for apparel use.

Microplastics pollution caused by washing synthetic textiles is one of the main sources of pollution found in oceans, waterways, on land, and in the air. Synthetic clothes contribute to about 35% of global microplastics in the world oceans. A study investigating the washing process of synthetic clothing showed that between 124 and 308 mg of microfibers for each kilogram of washed fabric is filtered from wastewater. The length and diameter of the microfibers indicate dimensions that would pass through wastewater treatment and pose a threat to marine organisms (De Falco et al., 2019). The annual microfiber pollution from apparel into the marine environment is estimated at 0.2 million tonnes annually (Sherrington, 2016).

The textile industry is not certain of the environmental impact of these synthetic fibers, but the recent analysis of biodegradation in seawater was measured using the percentage of material converted to carbon dioxide over a 90-d test period. The synthetic fibers, polyester, nylon, and polypropylene were compared with Merino wool knit fleece and wool carpet pile. Commercial wool products degraded between 20% and 23% in 3 mo, an even greater degradation than the cellulose control material (10% degradation). The synthetic products had either no degradation (polypropylene) or up to 1%. The authors concluded that wool fibers readily biodegrade in seawater and would only persist for a period of months, compared with synthetic fibers existing for many years or decades (Collie et al., 2019). A concerning report of microfibers in the Hudson River and entering the Atlantic ocean showed that 50% of microfibers are plastic in origin (Miller et al., 2017).

**Skin health**

Individuals with sensitive skin or atop dermatitis would not naturally recognize wool as a fiber choice to wear next to skin. However, sensitive skin loses the ability to regulate moisture, and wool has the highest moisture-absorbing capacity of all apparel fibers. Wool fiber has the ability to transfer moisture between the body and the environment, which achieves thermal comfort and a stable microclimate between the skin and fabric (Li et al., 1992). A recent study evaluated the effects of quality of life and physiological measures of adults and children with atopic dermatitis while wearing 17.5 µm fine Merino wool for 6 wk compared with standard clothing for 6 wk. The Merino wool clothing provided improvements in mean eczema area and severity index scores and dermatology life quality index scores, compared with standard clothing (Fowler et al., 2019).

The use of superfine wool has also been examined in infantile eczema in patients between 4 wk and 3 yr of age. The crossover study compared 100% superfine wool clothing with 100% cotton clothing, with each fiber being worn for a period of 6 wk. The superfine wool clothing reduced SCORing Atopic Dermatitis index, severity index, Infants Dermatitis quality of life index, and topical steroid use, while changing from wool to cotton resulted in an increase of these scores. The conclusions made by the authors suggested that superfine Merino wool can be used to manage childhood atop dermatitis (Su et al., 2017).

The use of wool to improve other health conditions has also been investigated using woolen underwear, bed coverings, mattresses, and woolen cushions. Patients with fibromyalgia, which is a debilitating disease causing chronic pain and tender points (Burkham and Harris, 2005), require a multidisciplinary approach to treatment that may include the use of wool. Patients using wool for a period of 20 wk showed significant improvements in pain score, tender points count, and sleep quality index, compared with a baseline assessment of 7 wk without wool products (Kiyak et al., 2009).

**Conclusions**

The following review has provided an overview of the level of scientific understanding that is incorporated into sheep and wool production. In terms of global market share, wool is considered a small niche product, but it has successfully positioned itself as a superior product in terms of its eco credentials and advantages to human health and well-being. Like all agricultural products, wool continues to aim to achieve greater efficiencies in production and quality. These efficiencies may stem from improved on-farm management, continued genetic improvement in wool production, and quality or reduced cost of production through innovation and technology. This approach will continue to maintain the competitiveness of the wool fiber.

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How agricultural rendering supports sustainability and assists livestock’s ability to contribute more than just food

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Feature Article

Implications

- Consumers are widely unaware of how agriculture and livestock produce more than just food and rendering prevents waste in animal production systems by utilizing nearly all by-products from the production of meat.
- Rendering is highly sustainable; “Rendering is Recycling/Upcycling” and supports the three pillars of sustainability (Environmental, Social, Economic).
- Rendering is essential in producing sustainable animal feed ingredients and pet food as well as many nonfood products consumers use every day.
- Extending the utilization of rendered products in animal food would improve sustainability across the board.
- Rendering directly supports environmental sustainability by utilizing by-products that would otherwise be treated as food waste, thus diverting it from landfills and even less desirable disposal options.

Key words: animal feed ingredients, biofuels, pet food, rendering, sustainability, upcycling

What Is (Agricultural) Rendering?

For clarity, agricultural rendering will be referred to as “rendering” throughout this article.

Render, from the French verb rendre, meaning “to give back,” is the act of processing and cooking undesired, or uneaten livestock and poultry meat (and used cooking oil [UCO]) that remains after a meat animal has been slaughtered and the meat used for consumption has been harvested. Rendering then safely and hygienically processes it to create new products so nothing is wasted. Renderers upcycle that unused material (fat, protein, feathers, bone, etc.) for new, secondary uses (Meeker and Hamilton, 2006; Figure 1).

Rendering has existed for centuries and is one of the oldest “recycling” practices. That is why it is often said rendering is “recycling” as the rendering process “gives back” in the form of new, high value, rendered goods (Meeker, 2020), while additionally returning resources to the environment in the form of water recovery and reclamation, saved landfill space and reduced greenhouse gas (GHG) emissions.

At its start, rendering was used primarily for soap and candle making, mostly done in a kettle over an open fire. Further developments to the rendering process came in the 19th century enabling family owned, small renderers and packers to produce both edible and inedible products (Meeker, 2020).

Many meat eaters in North America consider roughly 50% of a meat animal to be “inedible,” leaving a large amount of material left over (NARA, 2020). Rendering reclains this otherwise wasted food (protein, bone, fat, etc.), as well as UCO from restaurants, and transforms it into ingredients for countless new goods-upcycling most of this unwanted meat from slaughter and processing into things like animal feed ingredients, safe and nutritious pet food, beauty, household and industrial products, biofuels, and many more useful and common goods.

Instead of wasting these leftovers through other disposal methods, renderers in the United States and Canada recycle the materials into 15.7 million tons of fat, oil, and protein products annually (NARA, 2020). Doing this not only creates alternative, sustainable fuels to power trucks, trains, water vessels, and other vehicles but also nutritious pet food, beauty, household and industrial products, biofuels, and many more useful and common goods.

As a result, huge volumes of meat leftovers and UCO are kept out of landfills, resulting in a net reduction of carbon emissions, a substantial GHG reduction, reduced food waste and saved landfill space. Renderers and those in the rendering industry play an important role in reducing food waste, sustainably recycling valuable agricultural resources, and positively...
contributing to local, state, national, and international economies (NARA, 2020).

Safety and Regulation

Safety practices in the processing of rendered material are of utmost importance. Renderers have quality and safety control systems in place with voluntary programs such as the Rendering Industry Code of Practice (NARA, 2017) designed to foresee hazards that could occur, and prevent them. Each rendering plant develops its own feed safety plan based on the raw materials processed and the end products manufactured. These control systems assure that cooking temperatures are high enough to kill bacteria and control pathogenic microbial contamination.

Additional programs also address plant and transport cleaning, and other biosecurity measures such as traffic control. Stringent testing protocols are used to verify that rendering processes are accurately managed and operated. Testing programs include training and strict record keeping, as well as spot checks and follow-up by independent third-party auditors to ensure plants are following all plan instruction and protocol to the letter to ensure product safety. These voluntary programs have been followed for years and prepared the industry well for compliance, the programs were implemented long before Food Safety Modernization Act (FSMA) regulations even became mandatory.

FSMA legislation and regulations are the most comprehensive overhaul of the FDA food safety regulations in over 70 years. Legislation was passed by Congress on December 21, 2010 and signed into law by President Obama on January 4, 2011. FDA finalized, and published regulations in consultation with industry over several years, and effective dates began in 2015. FSMA is broken into seven different rules, with the intent to protect the U.S. food supply at all points.

The intent is to transform the nation’s food safety system by shifting the focus from responding to foodborne illness to preventing it. FSMA does not cover meat and poultry slaughter already covered by USDA inspection, but does regulate all animal food and ingredients with few exceptions (FDA, 2020).

FSMA requires hazard analyses by all feed and ingredient manufacturers and preventive controls such as validated and monitored cooking operations must be implemented for all significant hazards. Current good manufacturing practices are required throughout plants for training, sanitation, operations, equipment, and other areas to ensure safe production. Rendering plants are among the most scrutinized and most inspected animal food ingredient producers in the world, and the rendering industry is highly compliant with FSMA regulations.

More Than Just Food—Rendered Products Surround Us Every Day

Renderers often discuss the “Big 4” rendered product markets: pet food/animal feed, fuel, oleochemical products, and fertilizer. However, other rendered products not mentioned as often include gel bone (rendered bone chips) used to create gel caps used for vitamins, supplements, and drugs, cosmetics (like lotions and soaps made from rendered fats), and even tires.

Rendered fat alone is utilized for production of many nonfood and nonanimal feed applications such as candles, detergents, fabric softener, deodorant, shaving cream, perfume, cosmetics, lotions, crayons, paint, lubricant, biodiesel, plastic, waterproofing materials, cement, ceramics, chalk, matches, antifreeze, insulation, linoleum, rubber, textiles, medicines, soap, and crayons (Iowa State University Extension, 2020; Figures 2–4).

Most rendered fats are derived from beef animals for tallow, swine for lard, and poultry as poultry grease or poultry fat. Minor percentages of total fats are derived from other species, such as sheep for mutton tallow and fish. Rendered fats specifically have many additional industrial uses with over 70% of those requiring processes like refining, filtration, bleaching, hydrogenation, trans-esterification, and drying before they can be made into new products. All these processes for fats fall under the category called oleochemistry.

Soap can be used as a historical example of a product made from rendered fat: harder fats produce firm soaps, whereas softer fats produce soft soaps with harder fats resisting oxidation so firmer soaps do not go rancid as fast (as softer soaps). Free fatty acids provide a measure of the amount of hydrolysis that has taken place within the fat molecule. Time, temperature, and the presence of moisture all favor the hydrolysis of fat into free fatty acids and glycerol needed for the final product. Refined and bleached (R&B) color is a factor that is determined by the degree of damage done to the fat. As the soap-making industry grew and became more refined, the quality standards and specifications for animal fat became more precise to meet the soap industry’s needs. The specifications and terminology from the soap industry formed the basis for the quality standards and characteristics used today.

Industrial uses of different fats depend on their characteristics as determined by analyses such as titer, fatty acid profile, free fatty acid content (or sometimes acid value), saponification
value, R&B color, peroxide value, and the absence of impurities, like moisture and unsaponifiable matter. Rendered fats may be further processed by refining, bleaching, and deodorizing, and used as raw materials in hydrogenation, hydrolysis to fatty acids, and trans-esterification to fatty esters. Many factors affect the suitability of rendered fats for such use including the types and blends of animal byproducts to be rendered, storage conditions of the animal raw material byproducts before processing, storage conditions of the rendered fats after processing, and the methods and procedures of the rendering process used.

Whiteness, or lack of color indicates the fat was rendered from high-quality raw materials and good rendering techniques which is important for finished soap quality. Moisture, impurities (such as soil or metals), and unsaponifiables (plant sterols and pigments from plant sterols originating from the gut contents [forages, grains] of rendered offal) are important determinants of fat quality and indicated by the abbreviation MIU. Excess MIU will cause deterioration of the fat during storage (Meeker, 2020).

Biodiesel fuel is an important subcategory made possible by using rendered materials including fats and proteins. A considerable percentage of America’s biodiesel and renewable diesel is made from recycled cooking oil, also known as UCO, such as that used in fryers, with a large amount also coming from animal fats. According to the U.S. Energy Information Administration (EIA, 2018) 1.86 billion gallons of biodiesel were produced in 2018. Of that total, 9.2% of the feedstock (644,000 tons) were classified as animal fats and 13.2% of the feedstocks (918,000 tons) were classified as recycled yellow grease or other, with UCO included in the recycling category. Because of their chemical composition, fats release concentrated amounts of energy when burned which can be used as a biofuel (Panwar et al., 2011).

Materials such as organs, hair, hooves, and blood also contribute to other products in addition to foodstuffs. Examples can be found below.

- Blood components are used for dyes and inks, adhesives, medicines, and laboratory materials.
- Hides are utilized in the production of gelatin, sheetrock, adhesives, and medicines.
- Hooves and horns are also used for adhesives, as well as plastics, plant food, photo film, shampoo, lamination, wallpaper, and plywood.
- Hair can be used for air filters, brushes, felt, insulation, plaster, and textiles.
• The brain and internal organs are utilized to produce antiaging creams, medicines, musical instrument strings, tennis racquet strings, hormones, enzymes, and vitamins.
• Bone is used for charcoal, fertilizer, and glass.
• All rendered proteins including meat and bone meal and blood meal are rich in nitrogen and phosphorus and can be used to produce natural fertilizers (Jatana et al., 2020).

Many items made with rendered products, including biodiesel, may be a surprise to consumers and the general public, whereas other processed goods from proteins and fats (like protein meals used in animal feed) are more widely known and come in a variety of different forms with unique attributes. Descriptions of each material are in the definitions below.

### Protein Meals

Protein meals manufactured from animal products provide essential protein for the dietary needs of livestock and other animals. The meals are used for pet food, poultry, livestock, fish, and crustaceans. The Association of American Feed Control Officials (AAFCO) defines the identity and composition of these feed ingredients (AAFCO, 2020), those definitions are paraphrased here:

- **Blood meal**: Produced from clean, fresh animal blood free from all extraneous materials including hair, stomach contents, and urine.
- **Hydrolyzed poultry feathers**: The product resulting from the treatment, under pressure, of clean, undecomposed feathers from slaughtered poultry, free of additives or accelerators.
- **Meat and bone meal**: Rendered product from mammalian tissues, including bone. Not to contain added blood, hair, hoof, horn, hide trimmings, manure, stomach, and rumen contents.
- **Meat meal**: Similar to meat and bone meal, meat meal is the rendered product produced from mammalian tissues, exclusive of any added blood, hair, hoof, horn, hide trimmings, manure, stomach, and rumen contents.
- **Poultry byproduct meal**: Rendered and clean parts of poultry carcasses, such as necks, feet, and whole carcasses, exclusive of added feathers.
- **Poultry meal**: Dry rendered product derived from the parts of whole carcasses of poultry or a combination of clean flesh and skin with or without accompanying bone, free of feathers, heads, feet, and entrails. Suitable for use in animal food.
- **Fish meal**: Clean, dried, ground tissue of either or both whole fish or fish cuttings, with or without the extraction of portions of the oil.

### Fats

The AAFCO defines a number of animal fats suitable for animal food, including the ones paraphrased below.

- **Animal fat**: Fat obtained from mammals or poultry tissues in the commercial processes of rendering or extraction. It consists predominantly of glyceride esters of fatty acids and contains no additions of free fatty acids or other materials obtained from fats.
- **Hydrolyzed fat or oil, feed grade**: Obtained through the fat processing procedures commonly used in edible fat processing or soap making.
- **Yellow grease, feed grade**: The rendered product from the tissues of mammals and/or poultry blended with used cooking or frying oil from human food preparation, consisting of animal and/or vegetable fats or oils.
- **Used cooking oil, feed grade**: The product of used cooking or frying oil from human food preparation, consisting of animal and/or vegetable fats or oils, collected from commercial human food facilities, then heated (Figure 5).

### A Sustainable Contribution

The sustainability benefits of rendering can be accurately tracked and are more highly valued as our environment faces threats of climate change and reduced landfill space. Additionally, consumers seem ever more aware of their sustainability practices when making purchases due to this information and education on sustainability being widely available across media platforms. Specific areas of rendering’s sustainable contributions include reduced food waste, water reclamation, and sustainable pet food; each detailed below.

Rendering reduces the environmental impacts of animal agriculture by sequestering five times more GHGs than are produced (Gooding and Meeker, 2016). By reclaiming otherwise discarded meat leftovers, renderers make our food production footprint smaller (Figure 6).

### Reduced food waste

Sixty-two billion pounds of raw materials are cooked and rendered to result in approximately 31.4 billion pounds of raw materials.
rendered products produced annually from in the United States and Canada. As a result, these huge volumes of meat leftovers and UCO are kept out of landfills, resulting in a net reduction of carbon emissions (NARA, 2020). In fact, if all renderable products were sent to landfills, all available landfills would be full in approximately four years.
Preventing food waste in the first place is an important first step in saving landfill space, and one that comes before rendering (as expressed in the food recovery hierarchy shown here) (Figure 7; EPA, 2020). Although all livestock food animals generate byproducts as they are transformed for human diets, reduced restaurant and personal food waste can be eliminated before it becomes a problem by following the levels of the hierarchy starting with “source reduction.” Renderers pick up UCO from restaurants which helps reduce food waste from that sector, but plate waste is not well utilized because of lack of infrastructure and the high cost of logistics to collect and cook waste food for animal feed; additionally no system exists to collect either UCO or other food waste from households.

Grocery store leftovers would also be a contributor to food waste, but because renderers pick up those meat leftovers (in the form of trimmings, fat and bone) from butcher shops, grocers, and small slaughtering operations, grocery store waste has a much smaller footprint. Renderers also recycle billions of pounds of UCO from restaurants used to cook fried food items like French fries, and transforms that oil and fat into biodiesel, renewable diesel, and ingredients for pet food and animal feed (Figure 8).

**Water reclamation**

Rendering reclaims and cleans valuable water that would otherwise contribute to the decay of byproducts and cause contamination in the environment. The rendering process evaporates the moisture from the raw materials and processes all runoff and wash water through water treatment that meets regulatory standards. Annually, 3.7 billion gallons of water are reclaimed during the rendering process and naturally released back into the environment through evaporation or returned as clean water to streams and rivers (NARA, 2020)—that is enough water to fill 5,604 Olympic swimming pools. All this water meets federal, state, and local safety standards when returned to rivers and streams.

Additionally, renderer pickup of used cooking grease and oil from restaurants saves municipal sewer and wastewater systems from becoming clogged. This helps prevent millions of dollars in damage, repairs and contaminated water quality from broken sewer lines and sewage back up.

**Sustainable pet food**

Protein and fat ingredients obtained from rendering are used to manufacture pet foods. These rendered ingredients are not only sustainable, but also safe due to the enforcement of strict safety guidelines including the use of high heat in the rendering process to destroy bacteria and harmful pathogens. The resulting products are also handled, stored, and distributed under controlled conditions to minimize contamination. All rendering plants are required to be in compliance with FDA’s animal food regulations under FSMA, which ensures safe processing occurs. In addition, renderers have voluntary quality and safety control systems in place via formal programs such as the Rendering Industry Code of Practice (Meeker and Meisinger, 2015).

The rendering industry adds value to animal parts not normally used for human consumption (organs, bones, cartilage, and fat) by processing this material for pet food ingredients. These rendered end products provide essential fat, protein, vitamins, and minerals to enhance pet health and nutrition (Meeker and Meisinger, 2015). Use of rendered products in pet food also significantly reduces the carbon footprint of the food we feed our dogs, cats, and other pets by repurposing byproducts that might otherwise be wasted (Meeker and Meisinger, 2015). With many pet parents’ growing interest in the sustainability and carbon footprint of their pets’ food, renderers highlight the rendered protein ingredients in their pets’ food is not only nutritious but is also helping to reduce food waste.
Supporting the Three Pillars of Sustainability

Rendering also represents all three pillars of sustainability—Environmental, Economic, and Social. These three pillars are sometimes depicted visually as architectural pillars and other times as a three circle Venn diagram. The concept of sustainability has been discussed publicly as early as the 1980s and the three pillars have been presented as a “common view” of sustainable development in media since as early as 2001 (Purvis et al., 2019; Figure 9).

Pillar 1—Environmental

- Rendering’s environmental support pillar is a strong one. More than 62 billion pounds of renderable materials are produced in the United States and Canada each year. By reclaiming otherwise discarded meat leftovers, renderers make our food production footprint smaller, save landfill space, and help minimize the environmental impacts of animal agriculture such as climate change, as rendering assists greatly in the reduction of food waste, reduced GHG and water consumption.

Figure 8. “From fries to fuel” infographic.
**Pillar 3—Economic**

There is some expected overlap in the Social and Economic pillars in reference to the rendering industry as the economic stability of the industry directly affects the stability of careers, therefore leading to rendering’s high job retention and financial ability to contribute to their communities.

- The rendering industry is sustainable and financially stable with an economic contribution of $10 billion, annually.
- An average rendering plant provides nearly 100 stable jobs that offer competitive pay and benefits (NARA, 2020).

**New Data**

Renderers play an important role in reducing food waste, sustainably recycling valuable agricultural resources and positively contributing to local, state, national, and international economies. Quantification data were collected by the North American Renderers Association and published in 2020 (NARA, 2020).

This report is not available publicly, but the executive summary and all key takeaways are included here:

- From powering passenger vehicles and trucks, trains and inland and ocean-going water vessels to feeding cattle, hogs, turkeys, chickens, and other animals, the nation’s renderers play an important role in positively contributing to local, state, and national economies, while also sustainably using these valuable resources. The findings from this research will allow the industry to better communicate its value, identify opportunities and plan for a strong future.

This research consisted of understanding the total supply of renderable products, estimates of total rendered products, conducting a three-part survey of rendering companies in new products, rendering helps customers and consumers to be more sustainable while providing thousands of full-time and stable jobs supporting families and local communities from coast to coast in America and Canada, many in rural areas. Adding to the stability of work in the rendering industry, these positions cannot be exported due to the raw and perishable nature of the material the rendering industry reclaims.

- Rendering workers are highly skilled and competitively compensated, and renderers contribute to their local communities and organizations.
- The average North American rendering plant employs 94 employees and does not run a swing shift. Paid time off starts after 2 weeks and 70% or more of the employees’ health insurance premium is covered by the company (NARA, 2020).
- Disability insurance, job-related certification, education and a 401(k) program with a company match is also provided. Renderers and plant owners also invest considerably in improvements and enhancements to sustainability efforts, in addition to supporting their local communities both financially and socially (NARA, 2020).

**Pillar 2—Social**

- Rendering is a financially sound and community focused industry. With employee retention rates high, renderers offer career stability and contributions to local communities.
- By reclaiming and converting animal leftovers and UCO into
Figure 10. “What if there was no rendering” infographic.
the United States and Canada, and studying consumer and industry-driven market trends. Highlights from the research are outlined below.

More than 62 billion pounds of renderable raw materials are produced in the United States and Canada each year from farms, feedlots, and slaughter facilities working with cattle, hogs, sheep, chickens, and turkey. These materials are highly perishable byproducts of meat and poultry produced for human consumption—offal, bones, blood, feathers, and animals that die on farms or in transit to slaughterhouses.

This figure includes organ meats and meat and poultry byproducts that move directly from slaughter to pet food processors. It does not include UCO. Although there are 213 companies classified as rendering and meat byproduct processing companies in the United States, there are 34 primary rendering companies in the United States and 3 primary rendering companies in Canada, making the total employment for the rendering industry in the United States estimated at 8,916 people and 1,803 in Canada (NAICS, 2019).

Approximately 15.7 million tons of rendered products are produced from beef, pork, turkey, and broiler processing plants annually. This is 57% protein meals, 40% fats, and 3% plasma meal. In 2018, the equivalent of 11.1 million acres of soybeans (protein equivalent) and 2.6 million acres of corn (energy equivalent) were averted (not planted). This is due to:

- 6.1 million tons of protein from 8.9 million tons of protein meals being recovered by rendering plants.
- 52 trillion kcal of energy from 6.3 million tons of fats being recovered by rendering plants.

Rendered products have a substantially positive environmental impact in that it keeps those products from ending up in landfills by redirecting them to higher valued, more sustainable markets such as feed, fuel, and fertilizer. An additional sustainability benefit of rendering is the reclamation and return of clean water to the environment. 3.7 billion gallons of water from the products that are rendered are either released as water vapor (evaporation) or through treated wastewater discharge.

Approximately, 289,037 tons of animal and poultry fats, and 501,413 tons of fresh and frozen meat and poultry byproducts and organ meats that come from a combination of direct slaughter and rendering plants are used by pet food manufacturers, and roughly 1,543,129 tons of rendered protein meal from byproducts of meat, poultry, and fish are included in pet food diets. In addition, 1,333,248 tons of meat and poultry are most likely sourced directly from slaughter plants for pet foods.

Survey respondents report they reclaimed and repurposed approximately 800,000 tons of UCO in the 1-year study period, which represents about half of all UCO. Repurposing a large amount of this material averts what would otherwise go to other less-sustainable destinations.

According to the U.S. Energy Information Administration (EIA) 1.86 billion gallons of biodiesel were produced in 2018. Of that total, 9.2% of the feedstock (644,000 tons) were classified as animal fats and 13.2% of the feedstocks (918,000 tons) were classified as recycled yellow grease or other. UCO is included in the recycled category.

Renderers are substantial employers who offer competitive benefits to their employees, including paid time off, contributions to 401(k) (and other retirement funds that help ensure their employees are taken care in retirement), paid health insurance premiums, disability insurance, and education assistance for job-related skills and certificates.

In addition to upcycling materials that would otherwise end up in landfills, renderers are investing millions of dollars in environmental improvement efforts resulting in a total of $165.5 million spent on all environmental improvement efforts over the last 5 years (2015 to 2019) and $188 million planned to be spent on all environmental improvement efforts over the next 5 years (2020 to 2024).

Looking Forward

The rendering industry is dynamic and ever changing. New focus and initiatives continue to occur in the areas of environmental issues, governmental regulations, raw material, and market conditions.

Large amounts of energy are used during the rendering process, in the cooking process, and by the fleet of trucks needed to haul the raw and finished material to the plant or customers. Renderers continue to seek to solve these evolving issues by finding more efficient solutions and economical rendering equipment.

Updates in consumer preference of food will also continue to change. Reduced waste is a factor front-of-mind for many consumers, as is sustainability. The rendering industry continues to educate the public on the many sustainability benefits of upcycling rendered material into new goods.

Looking ahead the rendering industry has these large-scale issues to keep in mind, as well as more focused key items to consider as it prepares for the future. The rendering industry and markets for rendered products should expand to match the predicted growth of meat production and services needed by a growing U.S. and Canadian population. Continued investments in research such as that by the Fats and Proteins Research Foundation (FPRF) are also needed to fund research that can enhance product safety, improve rendering efficiency, support use in animal nutrition, and find new uses and markets for these byproducts.

African Swine Fever continues to spread across southeastern Asia, as such, the animal feeding and rendering industries need to remain cognizant and ready to combat nonscientific animal health and feed safety concerns regarding porcine-derived products with knowledge of existing research.

In simple terms, swine producers and veterinarians often think use of rendered products pose a risk of spreading virus. Scientific data does not support this assumption.

Trends continue to evolve in the pet food sector as well, the latest of which relates to the use of animal byproducts in dog and cat foods that are not rendered but rather purchased raw or frozen and then extruded as a complete pet food. Another trend emerging in the poultry industry is to eliminate animal
byproducts in poultry rations. The rendering industry must continue to use new and existing research data to prove that animal byproducts can provide a nutrient rich diet for poultry. The rendering industry also continues to research new methods and processes to meet needs of evolving customers.

Conclusion

The rendering business is profitable and sustainable. It is also essential to making a meat animal more sustainable than it would be if byproducts were not rendered and used for the highest possible purpose.

By making numerous new products with the unused meat and byproducts derived from livestock, rendering and renderers provide local jobs, support their communities, and contribute to significantly reduced food waste, saved landfill space, reduced GHG emissions, production of nutritious and sustainable animal food, and clean water reclamation.

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Feature Article

From trucks to tips—examples of peripheral ways by which the meat industry impacts the U.S. workforce and economy

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Introduction

The meat supply chain impacts far more than just the nourishment of those consuming the product. In the United States, it was estimated that, in 2018, Americans would have had annual access to over 100 kg of red meat and poultry per capita on a retail basis (Jones et al., 2018). Yet, often overlooked is the immense and complex system that is in place to ensure that the wholesome, nutritious, and satisfying food that is meat makes it to the tables in homes and restaurants. From trucking, to processing, to packaging and merchandising, animals, and the resulting meat, pass through many hands and, along the way, a number of industries and lives will be positively affected as a result of meat animal agriculture.

As the system of meat animal agriculture is so vast, it is the intent of this article to compose a small survey of some of those important parts that are integral to keeping the meat industry moving and people consuming meat. This article will provide an economic and personnel employment perspective from that of a meat scientist who, over many years, has had the opportunity to see the inner workings of the meat animal community from gate to plate. The article is constructed to provide broad observations of specific steps in the meat animal agriculture system to help provide context and stimulate discussion on how important of a role meat plays beyond its contribution as food. In this piece, there will be a wide look at how the transportation network for live animals to the packing facilities plays a role in the overall economy of the United States. There will also be an assessment of the labor force needed to keep the meat packing and processing sector operating. Finally, the article will culminate with how meat is an integral part in the restaurant and dining industry using a case study approach, demonstrating how it is ultimately a value-added contributor to those in that service-oriented profession.

Live Animal Transportation

For anyone who has had the opportunity to observe the large-scale operation of commercial animal harvesting facilities, the immense capacity for transportation that is required to deliver the live animal to the harvest facility and subsequently deliver the finished product to the consumer is quite apparent, even from the first encounter. Although the evaluation of a large-scale commercial packing plant in North America could lead to a lengthy study in its own right, in order to draw a conclusion as to the immensity of the meat production system, an estimation of the live animal transportation requirements to the packing house can begin to establish a baseline for how impactful the meat production chain is to the transportation industry.

Implications

- Finished meat animal livestock delivery to packers and processors account for an estimated 2.9 million transportation delivery event opportunities providing jobs for those in trucking and associated industries.
- Average production worker earnings in a meat processing facility are over twice the 2020 U.S. federal hourly minimum wage. Not only are those positions earning respectable wages for entry-level positions, but the added worker employment benefits in the meat production and processing industry can enhance the value of the job to the employee.
- A meat entrée on a restaurant menu is typically a higher value-added proposition for the restaurant business and waitstaff than that of a nonmeat dish.
- Meat animal production societal impact is far greater than simply nourishment; it is a system that provides powerful employment and economic opportunities directly and indirectly tied to the system itself.

Key words: livestock transportation, meat, packing facility, restaurant industry
In 2019, the United States slaughtered 26,116,700 young fed beef (steers and heifers), 125,844,300 commercial hogs (barrows and gilts), 2,020,400 sheep and lambs, and 9,224,243,000 broiler chickens under federal inspection (U.S. Department of Agriculture National Agricultural Statistics Service, 2020).

According to the U.S. Department of Agriculture Ag Data Commons Animal Transportation Database for Beef Cattle (U.S. Department of Agriculture Ag Data Commons, 2019), a 16.15-m-long livestock tractor trailer with multideck trailer capacity Figure 1 can safely accommodate 38 head of beef cattle with an average live weight of 636 kg. A standard size livestock tractor trailer has an inside trailer compartment dimension of 16.15 by 2.51 m for a floor area of 40.54 m². Many of the commercially operated livestock transporters using the above-mentioned tractor trailer have two layers in the trailer compartment, thereby effectively doubling the floor area capacity available for smaller livestock species, such as hogs and sheep. The Transport Quality Assurance publication recommends 0.45 m²/head for hogs with live weights averaging 136 kg each (Transport Quality Assurance, 2019). Therefore, based on those standards, a livestock tractor trailer, as mentioned, would be able to accommodate 180 head of finished hogs per transportation delivery event. Furthermore, using the same size and format of trailer, the recommended density for full-fleece sheep with live weights of 55 kg would be 0.4 m² (Williams, 2000), resulting in approximately 202 finished sheep per delivery event. It is estimated that approximately 6,000 finished broiler chickens can be loaded on a commercial tractor trailer using standard size packing modules stacked 2 high (U.S. Department of Agriculture Animal and Plant Health Inspection Service VS, 2013). Based on the estimated livestock transportation calculations, if one were to use the conservative estimate of a traditional 16.15-m-long livestock tractor trailer with two layers, the annual number of truck delivery events to move the finished beef, hogs, sheep, and poultry to the processing facility would exceed 2.9 million (Table 1).

The aforementioned estimation of trucking delivery events of finished live animals for operation of the U.S. meat processing facilities in 2019 is likely a conservative assessment. The annual total number of transportation events necessary for the harvesting of livestock in the United States is likely larger than the estimated 2.9 million due to a few additional industry dynamic considerations, one in particular would be vehicle size. In the case of processing facilities that harvest older livestock (e.g., cull cows, sows and mutton), the transport of those animals is often done using a pickup truck and smaller trailer, which has much less capacity and would greatly add to the number of transportation events in total for the operation of meat processing facilities in the United States. Regardless of the exact number of trucking delivery events, meat animal agriculture clearly supports a tremendous amount of jobs, directly or indirectly, tied to the transportation industry. Consideration far beyond what could be included in this paper would be related to the economic connection of maintaining the transport vehicles used to deliver the animals to the packing facilities, the fueling network necessary to operate the trucks, the dispatch personnel needed for scheduling the vehicles, and the impact of even the amount of tires sold over time that will require replacement during the lifetime of the transport equipment. Furthermore, consideration could also be made for all of the shipping events and transportation necessities of the finished goods from the meat processing facilities to the final point of purchase. Even though it is only a small snapshot in time, transport of the finished live animal to the processing facility is a significant and necessary economic and employment contributor to the overall food production chain in the United States.

### Packing House Personnel and Material

In 2019, the U.S. Bureau of Labor and Statistics identified that there were 527,460 jobs related to animal slaughter and processing reported (BLS-ASP, 2019). Frontline production workers made up 61.39% of the total number of personnel employed (BLS-ASP, 2019). Support occupations helping to make up the remaining total include but are not limited to transport and material handling, maintenance and repair, office and administrative services, sales, finance specialists, marketing personnel, and technology managers. The majority of those employed at a meat packing or processing facility, however, are skilled technicians who are essential contributors to food production, the economy, and the security of the United States.

A large-scale commercial packing house in North America somewhat resembles a small city at times. Many locations of greater size are far more than a food production facility or

### Table 1. Estimated number of total livestock delivery events in 2019 of finished beef, hogs, sheep, and broilers to a packing facility using a 16.15-m-long tractor trailer

| Species* | Number of animals slaughtered under federal inspection in 2019* | No. of animals per 16.15-m-long livestock tractor trailer | Total estimated number of truck delivery events |
|----------|---------------------------------------------------------------|----------------------------------------------------------|-----------------------------------------------|
| Beef²    | 26,116,700                                                    | 38                                                       | 687,282                                       |
| Hogs³    | 125,844,300                                                  | 180                                                      | 699,135                                       |
| Sheep⁴   | 2,020,400                                                    | 202                                                      | 10,002                                        |
| Broilers⁵ | 9,224,243,000                                               | 6,000                                                    | 1,537,374                                     |
| Total    |                                                              |                                                          | 2,933,793                                     |

*Young fed beef steers and heifers, average 636 kg live weight.
²Barrows and gilts, average 136 kg live weight.
³Full-fleece sheep, average 55 kg live weight.
⁴U.S. Department of Agriculture National Agricultural Statistics Service (2020).
place of employment. Meat processing plants are often a place that offers meals, health benefits, and, in most cases, a culture of team spirit that shows just how much can be accomplished when a large group of people work together for a common objective.

Nearly all large-scale packing houses have a cafeteria or dining option on premises that consistently provide hot and cold meals and beverages to employees at very affordable prices. If a packing house is large enough, it may also provide onsite basic medical services to help maintain worker health and provide for rapid response in the case of a workplace injury incident. Because of the availability of relatively high-paying entry-level positions, the meat production industry has been a destination for many people who are looking for the opportunity of employment, in this case, a trade-based career. With little or no experience, a person working at a packing house can expect to obtain a wage much higher than the 2020 U.S. federal minimum of $7.25/h. (Department of Labor, 2020). In 2019, the mean hourly wage of all meat plant production employees in the United States was $15.20, whereas once an employee advanced through the ranks to a supervisor in production, they could nearly double their hourly wage. The mean wage of meat processing facility production supervisors in 2019 was $27.94/h. (BLS-ASP, 2019).

In addition to wages earned, many large-size packing companies offer additional employment benefits, such as health insurance, continuing education classes, discounts on meat products, and valued-worker incentive programs. Considering an hourly plant production worker could begin employment in the United States with no documented education or degree and, in some cases, little to no understanding of the English language, the packing and processing of meat offers a respectable starting career for those interested, willing, capable, and ready to be a part of the food production system workforce.

The packing and processing segment of the meat industry also contributes to other manufacturing industries that supply the necessary tools and consumable products in those facilities. For one example, as reported by the National Beef packing company, a 23.5- × 40- × 60-cm corrugated cardboard box of beef boneless lip-on ribeye subprimals (North American Meat Institute #112A; North American Meat Institute, 2014) would be able to accommodate five subprimals for each case unit (National Beef, 2020). A midsize beef packing house harvesting 3,500 head of cattle per day would use 1,400 boxes of corrugated cardboard to pack the ribeye product alone. Furthermore, the overwhelming majority of fresh meat in the United States, and other developed nations, is vacuum packaged in a synthetic pouch often made of polypropylene, nylon, polyester film, polyvinylidene chloride, ethyl vinyl acetate, or a composite combination of these materials (U.S. Packaging and Wrapping, 2020; Zhou et al., 2010). Subprimals and cuts, either individually or in combination with others, are vacuum packaged and then subsequently stored and shipped in the corrugated cardboard boxes as mentioned. Packaging materials will make up a large portion of the consumable items in a packing house, which are essential for maintaining food safety, product quality, and overall product yield. Packaging manufacturing companies play an important role in supplying the materials needed to continue to safely and effectively store and distribute meat products to the consuming public; therefore, the meat industry is supporting additional career opportunity in the packaging manufacturing industry beyond those that work directly in a meat processing facility.

Additional resources necessary for equipping the many operational team members in a meat packing and processing establishment include linens (e.g., frocks, aprons, and knit gloves), personal protective equipment (e.g., hard hats, cooler coats, chain mesh gloves and aprons, cut-resistant gloves and sleeves, and hearing and eye protection), and tools of the trade (e.g., knives, scabbards, steels, and saws). Moreover, many of the large packing and processing plants have teams that help to maintain equipment, assist with electronic technology upkeep, manage water treatment and conservation, and have onsite rendering capabilities to utilize the animal and its byproducts.

Figure 1. Livestock tractor trailer being loaded with beef cattle (Image credit: Kerner Cattle Company).
to the utmost potential. The economic and employment impact of the overall meat packing and processing community alone is immense in the United States and would be hard to quantify fully considering the complexity of how the industry is formed, as well as how many roles, jobs, and resources it touches.

Restaurant Dining Industry Impact

The total number of restaurants in the United States in 2018 was surveyed at 660,755 with a total sales estimate of over $800 billion (Miller and Washington, 2020). As an industry, the restaurant business is clearly a large economic contributor and employer; the U.S. Bureau of Labor Statistics reported 10.8 million occupations related to the restaurant industry in 2019 in the United States (BLS-ROEP, 2019). Employment opportunities abound in the restaurant community. Food preparation specialists (chefs and cooks) make up a large part of the worker population in the restaurant industry; however, other positions include servers/waitstaff, dish washers, dining room attendants, food prep workers, and in-house butchers. Moreover, the restaurant business, like many industries, employ a large network of support staff who help to ensure product flow and customer satisfaction; examples of those support positions would include marketing specialists, finance and accounting experts, inventory control managers, market researchers, and customer service personnel, as well as computer and technology technicians. Finally, there is the entire infrastructure that is in place servicing the restaurant community itself that includes distribution specialists, logistics managers, wholesale food and supplies account representatives, and, once again, transportation workers.

Since at least 2010, the National Restaurant Association has ranked, at minimum, one meat-focused category in the top 10 food trends of the year. Eight of those years, the meat category was ranked number 1 and, five of those years, there were two meat categories in the top 10 food trend rankings, indicating that meat cuisine continues to be a major focus for the restaurant community (National Restaurant Association, 2020).

According to Technomic (2018), research into the foodservice protein category found that, in the United States,
there were 3.75 billion kg of chicken, 3.65 billion kg of beef and 2.49 billion kg of pork sold at foodservice. Interestingly, in the same study, there was nearly 99% adoption of beef being sold at restaurants (Technomic, 2018). A case study assessment for this article looking at the top 50 independent restaurants in the United States ranked by annual gross income (Miller and Washington, 2020), and the averaged results of their reported online menu pricing for select menu items, is displayed in Table 2.

Results of the case study found that all of the top 50 restaurants evaluated had at least more than one meat entrée on their menu (data not shown). All of the meat entrees generated greater gross profit than that of the salad entrée items when the ingredient cost was the commonly assumed 30% of the listed menu price (BC Book Articulation Committee, 2015; Table 2). All of the meat entrees, with the exception of the beef burger, generated greater average gross profit for the restaurant than the nonmeat pasta entrée example (Table 2). Furthermore, if a meat entrée is purchased because the average menu value is consistently higher than that of the nonmeat options, a waitstaff employee could expect a larger tip as tipping in the United States is often based on 15–20% of the total bill (Lynn, 2006). Mean hourly wage for a waitstaff employee in the United States was reported in 2019 as $12.70/h. Tips at a restaurant for a waitstaff employee can be a considerable addition to one’s take-home earnings. A 20% tip for a job well done based on the average beef or lamb entrée menu price reported in Table 2 would be $8.92 or $11.12, respectively. When compared with that of the salad entrée price at 20% tip equaling $3.14, the incentive to serve the higher valued meat options is over 100% to 200% greater. The ability for meat to generate additional income for the restaurant and waitstaff, as well as provide a tasty meal for the dining customer, demonstrates that its value potential far exceeds that of a vegetable-based option. Meat is a tremendous value-added economic driver in the restaurant industry, which not only generates more profit for the restaurant producing the meal but also allows for additional income potential for employees waiting the tables in those restaurants. Furthermore, meat is considered to have very desirable palatability and aesthetic (Figure 2) characteristics that consumers appreciate, which may help with return business to those restaurants offering a satisfying eating experience. Although the value potential for all restaurants cannot be fully extrapolated from the small exercise demonstrated in Table 2, it could still be assumed that, relatively speaking, a meat entrée will continue to be a greater take-home finance generator for a restaurant business than a nonmeat meal.

### Summary

The meat animal industry is an immense network of workers and resources (Figure 3). From the point of delivery of a live finished animal to the packing facility to the point of consumption at the home or restaurant, the meat industry as a whole impacts millions of jobs. If one were to consider the greater immensity of the meat animal sector and backtrack to the farmers and ranchers raising the animals for food production, it would increase that number even further. The meat animal itself is an incredible value-adding entity in that, in most cases, it converts either low-value or, in the case of ruminants, indigestible, vegetable material into nutritious and palatable protein products that continue to be in great demand in both the United States and beyond.

There continues to be tremendous pressures by a number of groups that tout the virtues of limited meat consumption or even suggesting the curtailing and harvesting of all animals for meat. It is important to realize the immense human benefit of meat animal production and how many jobs, people and processes it is tied to, not to mention the value-added economic impact it supplies. Furthermore, meat provides a satisfactory addition to a meal that enhances the human experience for those who are able to consume it for whatever reason. Meat animal agriculture and meat production provide far more than nutrition for a growing U.S. and global population. Although this article focused on the U.S. meat animal model, many of the

### Table 2. Analysis of the average online menu pricing of select item categories from the top 50 independent restaurants in the United States ranked by annual gross revenue in 2019

| Menu item | Number of menus with those items sold as an entrée (out of 50) | Average menu price of each menu item | $ Gross profit at a 30% menu cost | % Difference from average price of pasta dish | % Difference from average price of salad dish |
|-----------|---------------------------------------------------------------|--------------------------------------|-----------------------------------|---------------------------------------------|---------------------------------------------|
| Beef      | 39                                                            | $44.59                               | $31.22                            | 111                                         | 184                                         |
| Pork      | 20                                                            | $29.20                               | $20.44                            | 38                                          | 86                                          |
| Lamb      | 14                                                            | $55.60                               | $38.95                            | 163                                         | 254                                         |
| Chicken   | 38                                                            | $27.66                               | $19.36                            | 31                                          | 76                                          |
| Burger    | 15                                                            | $19.51                               | $13.66                            | −8                                          | 24                                          |
| Pasta     | 41                                                            | $15.70                               | $10.99                            | −26                                         | −                                           |

* Miller and Washington, 2020.

†Specifically selected as filet mignon/tenderloin steak.

‡Ground beef.

§No meat included.
major players in the group of industrialized nations also have processes in place similar to that of the United States and, as a result, meat will continue to be a hub in a very large network.

Conflict of interest statement. None declared.

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BLS-ROEP. 2019. United States Bureau of Labor Statistics NAICS 722500—restaurants and other eating places. [accessed September 15, 2020]. https://www.bls.gov/oes/2019/may/naics4_722500.htm.
Smallholder dairy farming contributes to household resilience, food, and nutrition security besides income in rural households

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Keywords: assets, dairy cattle, food, income, resilience, smallholder farmer

Introduction

Smallholder dairy production is important in supporting rural livelihoods. Dairying generates income and contributes to food and nutrition security (Chand et al., 2015). The Malawi Government through the Department of Animal Health and Livestock Development recognizes smallholder dairying as one of the key enterprises to support rural development and implements various programs supporting dairy production. Nongovernmental organizations (NGOs) and other development partners consider smallholder dairying as a tool to enhance livelihood of rural poor households and as a tool in climate change adaptation and resilience (Chagunda et al., 2016). Bryan et al. (2013) reported that there are various benefits that can be derived from dairy production if appropriate and holistic strategies are put in place. Improving household food and nutrition security is linked to increased access to and control of income and women participation in decision-making of household expenditure at household level (FAO, 2011). Enterprises such as dairy production, which provide a regular source of income, provide the ability to increase diversity of food and household need purchases. In comparison to crop enterprises, contribution of dairy farming to household income manifests in various ways. A household can get income from milk sales, animal sales, manure sales, and use of manure as fertilizer. Dairy farmers use the income from milk to purchase other food items such as rice, meat, maize, fish, vegetables, cooking oil, beans, sugar, and salt (Kalumikiza, 2012), nonfood items as well as pay for hospital bills, school fees, and other services. As a component of Capacity Building for Management of Climate Change program, a case study was undertaken in Mayani and Linthipe Extension Planning Areas (EPAs) in Dedza District to determine the contribution of dairying to smallholder household incomes, food availability, and assets in comparison with nondairy farmers.

Data collected in 2014 and 2018 were used in the analyses. A semistructured questionnaire was administered to 273 sampled households of which 46% were dairy farmers and 54% nondairy farmers in 2014 while 199 households (dairy [52%] and nondairy [48%]) were involved in 2018. Selection of farmers utilized a stratified random sampling procedure. Five villages with farmers keeping dairy cattle were systematically selected and thereafter households of dairy and nondairy farmers were randomly sampled. Data collected included household demography, land ownership, land use, income, and household food availability. These were assessed and compared between dairy and nondairy farming households. Descriptive statistics, crosstabs, and t-tests were used to analyze the data.

Implications

• Smallholder dairying contributes more than income to rural livelihoods.
• Although total land ownership is similar between dairy and nondairy farmers, land allocation to food crop, cash crop, and other uses is different. Dairy farmers allocate more land for food crop and pasture production while nondairy farmers allocate land to additional cash crops.
• Dairy farmers have far higher food crop yields and annual incomes, more diversified sources of income, and are more resilient to food insecurity than nondairy farmers.
• Dairy farmers own high number of live assets and hence seem to be better placed to improve their socioeconomic status than nondairy farmers.

Demographic characteristics of farmers

Smallholder dairy farmers are generally few in Linthipe EPA, making less than 1% of the population. The high cost of
investment associated with dairy production restricts resource-poor households to participate in dairy farming. Most dairy farmers use support from NGOs or the Government to access dairy animals on loans which they repay by either passing on a heifer offspring to the next beneficiary or cash in agreed installments and period. The demographic characteristics in terms of household size, marital status, gender, and educational level of the household heads were generally similar for both dairy and nondairy farmers in 2014 and 2018. The average household size was around five while marital status was dominated by monogamous marriages (75%) with a few polygamous marriages and individuals that were widowed, divorced, or single. Most household heads were male (about 80%), and about 67% of them had attended primary education while about 18% had attained secondary education. Only a few of the household heads had attained tertiary education (1.5%) and rest did not have any formal education. These characteristics are in line with those reported in National Statistical Office (2017) for Malawi in general. This shows that dairy farmers are not substantially different in terms of their demographic characteristics except that they have an interest in dairy and have access to capital needed.

The age of the participating dairy and nondairy farmers in this study was numerically different. The dairy farmers were relatively older (50 ± 12 yr) compared to nondairy farmers (44 ± 13 yr) in 2014 while in 2018 the ages were 51 ± 15 and 47 ± 16 yr, respectively. There were few young farmers involved in dairy and this could be due to lack of start-up capital and the high labor demand associated with the cut and carry dairy feeding systems that are used. Quddus (2012) and Dehinenet et al. (2014) reported that adoption of dairy farming is negatively correlated to age of head of household in Bangladesh and Ethiopia. However, the farmers in the area of focus in Malawi have been in dairy farming for 8 yr on average which shows that the farmers started dairy farming at relatively younger age. This may indicate that dairy farming has relatively few new entrants potentially due to high capital requirements. This could be an indication of the need for deliberate mechanisms to stimulate more entrants into dairy farming and hence avert dwindling of the farmers started dairy farming at relatively younger age. This may indicate that dairy farming has relatively few new entrants potentially due to high capital requirements. This could be an indication of the need for deliberate mechanisms to stimulate more entrants into dairy farming and hence avert dwindling of number of farmers in dairy farming over time. For instance, tailor-made training for older dairy farmers to improve technical efficiency since technical efficiency of dairy farmers reduces with age where farmers below 40 tend to be better than those above 40 yr (Masunda and Chiweshe, 2015). Such strategies can build on existing pass-on scheme programs widely implemented by NGOs and political will which have proven to substantially contribute to dramatic increase in number of dairy farmers and animals in developing countries.

Type of dwelling units

Dwelling units were generally made of a variety of construction materials that reflect the socioeconomic status of farmers in both 2014 and 2018. Most farmers had dwelling houses with walls made from burnt bricks (58%), earthen floors (69%), and roofs made of iron sheets (55%). Dwelling houses were different between dairy and nondairy farmers. The walls of the dwelling houses were more likely to be made of mud and poles in the homes of nondairy farmers than dairy farmers. Also, a high percentage of nondairy farmers had houses with earthen floors (76%) and grass-thatched roofs (28%) than dairy farmers (60% and 10%, respectively). On the other hand, significantly more dairy farmers had dwelling houses with cement floors and iron sheet roofs than nondairy farmers. Use of burnt bricks, cement floors, and iron sheet roofs are associated with improved socioeconomic status. This suggests that dairy farmers have greater access to more valuable building materials compared to nondairy farmers. This could be attributed to ability to generate income and access to loans and other services available to dairy farmers that enable them to improve their dwelling houses. Dairy farmers are organized into milk bulking groups (MBGs) where they have a milk collection and cooling center where milk buyers collect milk from. The MBGs leadership is well trained and manages milk sales and access to various services offered by milk buyers (processors) and other stakeholders. Among other things milk buyers offer farmers loans to buy farm inputs and deduct the loan repayment from the payments for the milk sold to them. Such arrangements give dairy farmers access to greater resources than nondairy farmers.

Land ownership and allocation to crops

Total land owned and agricultural land sizes were generally similar between dairy farmers and nondairy farmers, at around 1.7 and 0.5 ha in 2014, respectively. In 2018 dairy farmers owned significantly more total land and agricultural land (1.23 ± 0.94 and 1.06 ± 0.88 ha) than nondairy farmers (0.70 ± 0.59 and 0.64 ± 0.49 ha), respectively. The bigger size of agricultural land for dairy farmers could be attributed to availability of more income or resources that enabled access to more land. The land was either an upland or wetland (dimba) and was generally used for crop and pasture production. Dairy farmers tended to allocate more land to maize (0.8 ha) and pasture (0.1 ha) than nondairy farmers (0.6 and 0.03 ha), respectively. Maize is the staple food and more land allocation to maize may reflect ability to purchase inputs which most nondairy farmers cannot afford. Inorganic fertilizer is the key input in maize production. Dairy farmers tend to combine use of both organic manures from their farms and inorganic fertilizers. This seems to work well for dairy farmers and enables to increase land size and productivity. Other farmers have developed formulae of combining organic manure and inorganic fertilizer to produce enough fertilizers to apply in maize production. This combination of organic and inorganic fertilizers works well as part of integrated soil fertility management and mitigation of climate change challenges. It not only improves soil fertility but also soil texture and water holding capacity and hence raises the potential for high productivity.

Nondairy farmers also allocated wetlands to cash crop farming while dairy farmers used wetlands more for pasture production. Wetlands enable farmers to produce crops or pastures even after the rainy season. This implies that nondairy farmers supplement their incomes with cash crops.
this is at a very small scale and may not support the farmers throughout the year.

Crops grown

Farmers normally grow more than one crop and regardless, maize was the major staple crop grown by 99% of households followed by Irish potatoes at about 24% in 2014 while in 2018 the same crops were grown by 97% and 31%, respectively. In general, farmers produced a variety of crops grown in both rain fed and irrigated systems. The major cash crops were beans, groundnuts and soya beans which were grown by 78%, 56% and 49% of the respondents in 2014, respectively. The same cash crops dominated in 2018 with relatively lower proportions of respondents involved at 53%, 26% and 27%, respectively. The notable variation in proportions of farmers growing cash crops was probably due to variations in the demand for the cash crops. Decisions to produce cash crops are usually driven by demand and pricing of the cash crops. Interestingly, it was also observed that some nondairy farmers were involved in pasture production which could be used by other livestock but also as a means for income generation if the pastures were sold to dairy farmers. Production of pastures by nondairy farmers can also be a means to increase pasture availability where land size is a constraint for dairy farmers and hence a business opportunity for the nondairy farmers.

Livestock ownership

Most farmers (83.3%) that were interviewed owned at least one species of livestock. Tropical livestock units (TLUs), defined as one local mature cattle equating to 1 TLU, per household was about 3.5 ± 2.94 for dairy farmers and 1.3 ± 1.87 for nondairy farmers (Table 1) in 2014 while it was 3.40 ± 2.61 and 1.59 ± 2.27 in 2018.

The high standard deviations show that there is a wide variation in livestock ownership which depicts inequitable distribution of livestock. Cattle, goats, pigs, chickens, and ducks were the most widely kept species. As expected, dairy farmers had, on average, significantly higher overall TLUs (3.5 and 3.4) than nondairy farmers (1.3 and 1.6) in both years. This means dairy farmers own an equivalent of 3–4 cattle as opposed to 1–2 by nondairy farmers. This gives an indication that dairy farmers own higher numbers of live assets when compared to nondairy farmers.

Dairy cattle accounted for an average of about 57% of the TLUs of the livestock owned by dairy farmers. This shows that dairy and nondairy farmers generally owned similar numbers of the other livestock. Although only a few nondairy farmers (about 5%) owned local cattle, the average TLUs from local cattle was similar between dairy and nondairy farmers meaning that the average local cattle herd sizes were similar between dairy and nondairy farmers. This implies that dairy cattle ownership is over and above the routine enterprises that smallholder farmers produce. Dairy farmers are therefore much more diversified in terms of livestock species kept and crops grown such that they are likely to be much more resilient to shocks that negatively affect livelihoods in rural areas. Figure 1 shows dairy cattle in a typical smallholder farm in Malawi.

Food availability

Food availability in households was variable with differences between dairy and nondairy farmers. In 2014, overall, about 62% households reported that they did not face food shortage throughout the year. From these, 35% were dairy farmers and 27% nondairy farmers. Within groups, 75% of dairy farmers indicated that they did not face food shortage as opposed to 51% of nondairy farmers. Further, by November 2014, about 85% of dairy farmers indicated that they still had staple food reserves available in the household vs. 73% of nondairy farmers. Crop harvest in Malawi is generally in April and in 2014 some nondairy farmers indicated that they had run out of staple food reserves as early as July 2014 while dairy farmers indicated staple food reserves starting to run out in October 2014. A similar trend was observed in 2018 where 58% of the respondents indicated that they never ran out of staple food and 38% of these were dairy farmers which accounted for 72% of all dairy farmers. This suggests that dairy farmers mostly have prolonged food availability compared to nondairy farmers. This is likely due to increased crop outputs from gardens of dairy farmers compared to nondairy farmers. The availability of cash from milk sales also enables dairy farmers to purchase staple food thereby increasing their resilience to challenges that

| Species          | Farmer status | N  | % Keeping | Herd size |
|------------------|---------------|----|-----------|-----------|
|                  |               |    |           | Mean      | SD        |
| Cattle           | Dairy farmer  | 229| 99.60     | 3.06      | 3.11      |
|                  | Nondairy farmer | 17 | 7.00      | 3.71      | 2.37      |
| Goats            | Dairy farmer  | 146| 63.50     | 4.45      | 2.88      |
|                  | Nondairy farmer | 108| 44.60     | 3.87      | 2.63      |
| Sheep            | Dairy farmer  | 3  | 1.30      | 3.33      | 2.52      |
|                  | Nondairy farmer | 6  | 2.50      | 2.33      | 1.97      |
| Pigs             | Dairy farmer  | 81 | 35.20     | 4.56      | 3.72      |
|                  | Nondairy farmer | 67 | 27.70     | 3.48      | 3.15      |
| Chickens         | Dairy farmer  | 177| 77.00     | 13.53     | 11.79     |
|                  | Nondairy farmer | 127| 52.50     | 10.18     | 9.08      |
| Ducks            | Dairy farmer  | 11 | 4.80      | 6.09      | 4.09      |
|                  | Nondairy farmer | 7  | 2.90      | 8.14      | 8.28      |
| Rabbits          | Dairy farmer  | 8  | 3.50      | 4.50      | 2.88      |
|                  | Nondairy farmer | 2  | 0.80      | 4.00      | 2.83      |
| Guinea fowls     | Dairy farmer  | 8  | 3.50      | 2.88      | 1.96      |
|                  | Nondairy farmer | 9  | 3.70      | 6.00      | 4.82      |
| Pigeons          | Dairy farmer  | 13 | 5.70      | 10.23     | 8.12      |
|                  | Nondairy farmer | 11 | 4.50      | 53.09     | 96.61     |
| Total TLUs*      | Dairy farmer  | 229| 99.60     | 3.51      | 2.94      |
|                  | Nondairy farmer | 188| 77.70     | 1.28      | 1.87      |

*TLUs = tropical livestock units defined as one local mature cattle equating to 1 TLU.

Table 1. Livestock ownership and herd sizes by dairy and nondairy farmers in Mayani and Linthipe EPAs in 2014 (n = 273)
might result from natural shocks including those related to climate change and variability.

**Household income**

Household income was variable and significantly ($P < 0.05$) higher among dairy (MK302,638.89) than nondairy farmers (MK123,951.45), 1 USD = MK720.00. The overall proportion of the income was dominated by crops (maize, groundnuts, and a few from tobacco) and nonfarm sources such as businesses, daily paid labor, and sales of natural resources (Figure 2).

Apart from remittances, significant differences ($P < 0.05$) were noted on other sources of incomes between dairy and nondairy farmers. Dairy farmers had higher overall household income and income from livestock and crops than nondairy farmers. This may imply that dairy farmers were more dependent on farming as their business than nondairy farmers. The higher interest in business could be facilitated by better access to inputs and markets compared to nondairy farmers. Better access to inputs and other services is often facilitated by dairy processors (milk buyers) who offer dairy farmers loans to access both crop and livestock inputs. Dairy farmers had a higher degree of mixed or integrated farming systems meaning that they capitalized on biological synergies that exist in integrated farm systems such as nutrient recycling where by-products from one system are inputs in another.

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**Figure 1.** Dairy cattle in smallholder farms in Malawi.

**Figure 2.** Contribution of household income from different sources among dairy and nondairy farmers in Linthipe and Mayani EPAs in Malawi in 2014 and 2018 ($n = 273,472$; error bars show standard error of the mean).
system. For instance, use of animal manure as organic fertilizers and use of crop residues as feed.

Nondairy farmers had higher percentage of income from nonfarm sources including remittances than dairy farmers (Figure 2). Usually such means of income are likely nondesirable coping mechanisms to inadequate crop yields (Mavhura et al., 2015).

**Household assets**

Grouping assets according to Njuki et al. (2011) showed that farmers have transport, domestic, farm, and livestock assets. Overall dairy farmers had more assets in each of the categories than nondairy farmers. Dairy farmers also had a higher diversity of assets compared to nondairy farmers with an overall average value of MK231,751 vs. MK86,427 (exchange rate: 1 USD = MK762) per household, respectively. This is an important aspect as Ellis (2000) reported that diversification among poor communities has a positive attribute on livelihoods security. The asset ownership further confirms that dairy farmers are better placed to be more resilient to diverse shocks such as weather, economic and social factors, and political unrest than nondairy farmers.

The results on food availability, household income, and asset ownership generally show that dairy cattle play an important role in the socioeconomic status of rural households. Chagunda et al. (2016), using examples from Kenya, Malawi, Mozambique, Tanzania, and Zambia, similarly demonstrated that dairy farming is an important agricultural enterprise that supports food and nutrition security as well as household income for poor households. Smallholder dairy enterprises do not only serve individual households but also supply the bulk of the milk in the dairy value chain in developing countries and a considerable contribution to national gross domestic product (Chagunda et al., 2016; Odero-Waititu, 2017). Kabunga et al. (2017) associated less child stunting and improved income with dairy ownership in Uganda while Yasmin and Ikemoto (2015) associated dairy farming with substantial reduction in poverty among women in Bangladesh. Similar contributions from dairy are reported in other developing countries (Olwande et al., 2015; Chagwiza et al., 2016; Kebebe, 2017). Generally, the findings of our study confirm previous reports on the importance of smallholder dairy farming and provide more evidence in terms of specific benefits from the enterprise.

**Conclusion**

Findings show that dairy farmers were relatively better in terms of food security, household income, and assets. There is strong signal that dairy farmers are more resilient to food shortage with high likelihood of improvement of their socioeconomic status as reflected by having less dependence on nonfarm income, having better dwelling houses, and owning more assets, among other factors. Smallholder dairy farming is not only a source of household income, but also a major contributing factor to household resilience, food, and nutrition security. It is therefore important that dairy development programs should consider the important role that dairy farming plays in livelihoods of smallholder farmers and hence support to the dairy sector to be done with a much wider lens than is currently the case.
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Feature Article

Horse meat production in northern Spain: ecosystem services and sustainability in High Nature Value farmland

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Key words: ecosystem services, extensive livestock systems, horse rearing, meat production, valorization and promotion strategies

Introduction

The natural environment provides many benefits to humans, which are assessed in terms of ecosystem services. In most mountain regions of Europe, the rural exodus and the abandonment of the traditional practices have led to deep changes in the landscape, decreasing the characteristic mosaic and the diversity of inherited ecosystems (Martínez-Fernández et al., 2015; Muñoz-Ulecia et al., 2021). As a consequence, many ecosystem services are being affected, such as the biodiversity, the carbon sequestration, and the provisioning value of food for herbivores, among others (Durán et al., 2020; Oggioni et al., 2020). In addition, the current situation of climate change seriously aggravates the problem of land abandonment, especially in areas of high plant productivity. Forest expansion and shrub encroachment are leading to a loss of open spaces, a homogenization of the landscape and an accumulation of fuels that, in a situation of high temperatures and drought, entail high environmental risks.

Europe, as other regions of the world, has undergone in the last decades profound changes in their fire regime, and extreme wildfires are becoming increasingly frequent due to fuel accumulations and to drier and hotter climatic conditions than decades before (Krawchuk et al., 2009; Leys and Carcaillet, 2016). As a consequence, extreme wildfires are one of the most important threats Europeans face nowadays, due to its destructive capacity and its affliction on both human lives and the natural environment (San-Miguel-Ayanz et al., 2013). Until recently, fire policies have mostly focused and invested on fire suppression and have assigned a minor role to fire prevention and to fuel management techniques. However, the high costs of preventing fuel buildups through periodic mechanical clearings of biomass cannot be accomplished with the limited budgets of the public administrations, and a social engagement and an active landscape management are necessary (Sande et al., 2010; Otero and Nielsen, 2017). It is in this context that the role of domestic herbivores and their associated extensive livestock systems become crucial. The capacity of herbivores to ingest high amounts of biomass may constitute an effective tool for reducing vegetation fuels in critical areas of the landscape (Canals, 2019).

Implications

- Pasture-based, extensive livestock systems play an important role in the preservation of the rural landscape, and the many ecosystem services associated.
- Spain is the major horse meat producer at EU level, based on traditional extensive systems and a subsequent fattening outside the origin region.
- The movement of animals from raising to fattening areas entails a loss of added value in the regions of origin, which decreases farm profitability.
- The social recognition of the environmental role of extensive rearing systems based on native breeds and the local production and valorization of the horse meat are crucial objectives that need to be addressed and developed in the following years.

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Equine farms play an important socioeconomical role in the sustainable development of mountain areas in many regions of southern Europe, and they play a key role as preservers of landscapes. Of the range of domestic herbivores suitable for environmental grazing, horses have several important advantages. Despite being monogastric, they can digest cellulose efficiently, the main organic component of plants, and their big frame size and rapid digestion process ensure a high intake capacity. Their digestive tract is designed to take in small and frequent meals of forage, and they exert a selective pressure on grasslands that results in a characteristic “lawn and rough” pattern according to their dietary preferences (Williams et al., 2020). Horses are estimated to spend about 75% of the daytime and 50% of the nighttime grazing (or a total of 60% of a 24-hr day. Fleurance et al., 2001). In addition, thanks to their size and heavy complexion, they can also gain a control on lignified vegetation through the trampling (personal observation).

Regarding the environment, equines adapt very satisfactorily to extreme climates (cold temperatures, high rainfall, snowfall events) and to rough landscapes, particularly when native breeds are used (Canals, 2019). In the current situation of climate change and the priority to reduce greenhouse gas emissions, horses also have an important advantage over ruminants due to their particular digestive physiology that reduces the production of methane. The emission factor for methane (kg CH₄ per head) coming from enteric fermentation is significantly much lower in equines than in ruminants (14 kg CH₄ per head of equine vs 48 kg CH₄ per head of cattle; FAO, 2020). Similarly, the energy losses in horses due to CH₄ production average 3.5% of the feed digestible energy compared to 10% to 13% in adult ruminants (Vermorel, 1997).

### Horse Meat Production in Spain

Worldwide, horse meat production (741,003 tonnes and 4,803,585 carcasses) is currently far below the rest of meat-producing species (0.25% of the total, even below goat and rabbit meats), whereas pork (36%), poultry (34%), and bovine (21%) are the most produced and consumed meats.

Spain stands out as the major horse meat producer in the EU (17%), followed closely by Italy (16%), Romania (14%), Poland (11%), and France (8.2%; FAO, 2020). According to the national statistics, the current horse censuses account for 630,703 heads (MAPA, 2020a), distributed in 189,452 farms (Figure 1b), which are mostly concentrated in southern and western Spanish regions such as Andalusia (34%), Extremadura (6.4%), Castile and Leon (12%), Galicia (6.4%), and Asturias (6.2%) (Figure 1a).

Among the national registered horses, most animals are raised for leisure activities and only 6.1% are focused on meat production. The latter corresponds to 38,200 animals slaughtered in 2019, which means 0.4% of the total Spanish livestock production and a value worth of 78M€ (MAPA, 2020a). From the total registered equine farms, 15.3% horses are bred for meat production, and most of them (88%) are located in the north-western regions of Spain (Asturias, Castile and Leon, Galicia, Basque Country, and Cantabria; Figure 2a).

In the last decade, horse meat production has increased in the country by 51%, and over 73% of the meat produced goes to European markets. National economical balance for international trade is positive for equine meat (MAPA, 2020b), with higher exports (27M€ and 7,074 tonnes) than imports (0.51M€ and 302 tonnes). The level of local consumption is low (average supply per capita below 0.10 kg; Belaunzaran et al., 2015), but it is increasing in the last years. All these data indicate the potential of this product for both exportation and local consumption.

The traditional meat production system is based on the raising of native breeds, which were used as draft animals in the past and that were reoriented for meat production after farm mechanization. For decades, equine breeding innovation depended on the weight, which established genetic improvement programs, artificial insemination, etc. When these activities were transferred to the regional governments, the development and promotion of the horse breeds displayed a high variability among regions. As a consequence, a great breed variability can be found nowadays, which is mainly linked to geographical areas: heavy horse breeds (mare live weight > 650 kg) such as Hispano-Bretón (Castille and Leon; Cantabria; and Huesca), Burguete (Navarre), Basque Mountain Horse (Basque Country), and Catalan Pyrenean Horse (Catalonia); medium-frame breeds (351–650 kg) such as Jaca Navarra (Navarre) and crossbred animals; and small-frame breeds (<350 kg) such as Galician Mountain Horse (Galicia), Asturcón (Asturias), and Romanov (Castile and Leon).

**Figure 1.** Spanish animal census (a) and equine farms (b) distribution. Source: MAPA (2020a).
concentrates and forage until slaughter. Commonly, animals after weaning and a short adaptation period, foals are fed on butchers. In these units, 20–25 native animals are reared, and mally small-size family farms or farms directly owned by local rate 92% of the Spanish horse feedlots (MAPA, 2020c).

With Castile and Leon (13%), Basque Country (11%), Navarre (9.2%), Aragon (9.2%), and La Rioja (5.6%) regions, concen-

The movement of foals from the north-western to the fattening and slaughtering areas in the north-eastern regions involves a loss of added value in their regions of origin. The finishing of foals in their original regions, besides an opportunity gain for the rural economy, will also ensure an optimal and complete use of the natural resources, and the traceability and highest quality for the final product, the meat. As a consequence, any action that helps and gives support to the local production and valorization of the final product would be beneficial for the producers and for the rural economy.

Nutritional Composition of Horse Meat

Horse meat, as any other meat, is a nutritionally valuable foodstuff. It constitutes a significant source of high-value proteins, iron, zinc, B type vitamins, and selenium with a greater bioavailability compared with that found in other foods (Lorenzo et al., 2014). However, in contrast to other more consumed meat species (i.e., bovine, poultry, or pig), few scientific studies have focused on horse meat quality although it has been recognized as a healthy meat (Lorenzo, 2013; Belaunzaran et al., 2015).
Horse meat has a low-fat content and a significant proportion of n-3 polyunsaturated fatty acids (PUFA), such as linolenic (18:3n-3) and other long-chain n-3 fatty acids (FA), that have been reported to have beneficial properties for preventing chronic diseases (Weylandt, 2016). In horses, considering their digestive track, dietary FA are absorbed before the anaerobic microbial hydrogenation occurring in the hindgut (cecum and colon). Thus, the postgastric localization of digestive chambers allows them for an efficient absorption and deposition of n-3 PUFAs coming primarily from pastures. In addition, even though the horse is a nonruminant herbivore, due to a light microbial fermentation taking place in the hindgut, the formation and accumulation of several trans-18:1 and conjugated linoleic acid isomers have been reported (Clauss et al., 2009). The low trans-FA level in horse tissues is not surprising since the formation of nonindustrial trans-FA normally occurs in ruminant species through biohydrogenation processes in the rumen (see review by Aldai et al., 2013).

The aforementioned considerable n-3 PUFA transfer efficiency from pasture to muscle tissue in horses was described in the 1950s (Gupta and Hilditch, 1951), and more recently, several studies have brought up new peculiarities of these animals. Even though horses do not have a gall bladder, the continuous secretion of biliary salts, together with lipase-rich pancreatic juices, provides them the ability to efficiently digest high amounts of dietary lipids in the small intestine. In this regard, a specific pancreatic lipase (pancreatic lipase related to protein 2) that is absent in pigs, turkeys, or ruminants has been described in horses, and has been linked to its capacity to hydrolyze the linolenic acid (18:3n-3) esterified in galactolipids of plants (see recent review by Sahaka et al., 2020). In this line, several studies have pointed out that horse tissues constitute

![Figure 3. Scheme of the Spanish horse meat production system.](https://academic.oup.com/af/article/11/2/NP/6276808/62)
a valuable source of energy and PUFA in the diet of humans in the Paleolithic and the Neolithic, when plants and marine foods were scarce due to recurrent glaciations (Guil-Guerrero et al., 2013), and this could be directly related to the preferential deposition of 18:3n-3 in neutral compared to polar lipids (i.e., subcutaneous fat; Belaunzaran et al., 2017).

**Valorization of Horse Meat Production Systems**

The concept of High Nature Value (HVN) farming in Europe constitutes a recognition of the fact that the conservation of biodiversity depends on the continuation of low-intensity farming systems and the environmental services and positive externalities they provide. But, for its maintenance, these systems need to be profitable to farmers and rural development is necessary (González-Díaz et al., 2019). Existing support mechanisms such as the agri-environment measures have helped to slow down the loss of these systems, but they are insufficient to make HVN farms commercially viable and ensure its survival in the rural economic structure (Rodríguez-Ortega et al., 2018).

The recognition and valuation of the ecosystem services provided by extensive farming systems is necessary to raise social awareness and design effective communication strategies that contribute to improve the market value of the animal-derived products (Faccioni et al., 2019). That is why new efforts are being carried out to valorize and promote the extensive production system itself, as well as the final product (horse meat), based on its important role in the sustainable development of mountain areas at economic, environmental, and social levels (i.e., the European project Open2preserve, https://open2preserve.eu/en/). Anyway, giving a monetary value to these externalities is a challenge, and many attempts of measurable criteria for the valuation of the ecosystem services provided by pasture-based farming systems are being developed in the last years to that purpose (Bernués et al., 2014; Rodríguez-Ortega et al., 2014; Maldonado et al., 2019; Durán et al., 2020).

In the same line, the Payments for Environmental Services can be a suitable arrangement to remunerate producers for the positive externalities associated to the environmental grazing and to compensate farmers for the complexity of the management and/or the potential decrease in productivity (Sattler et al., 2013; Varela et al., 2018). In the south of Spain, there is a long-lived and successful example of the implementation of payments to shepherds for practicing an extensive and targeted grazing for the maintenance of firebreaks areas. The Red de Áreas Pasto-Cortafuegos de Andalucía (RAPCA) program rewards extensive breeders for their biomass control services in fuel breaks located in public forests. The payments received depend on the size, location, and difficulty of grazing of the area assigned to each shepherd, as well as the degree of accomplishment of the task. The political will, the stable commitment from the public administrations, and the well-designed system of biomass monitoring have been crucial for the success of the program (Varela et al., 2018).

**Conclusions**

In a scenario of climate change, the preservation of resilient landscapes that encompass as many ecosystem services as possible is necessary, and low-intensity farming systems are to play a key role in them. Pasture-based, extensive equine breeding produces a traceable and remarkable high-quality meat, while offering many positive externalities such as the preservation of mosaic landscapes and its associated biodiversity, the reduction of fuels for wildfire prevention, the recovery of endangered breeds, the maintenance of a primary activity that fixes population, and the low-water and -carbon footprint linked to pasture-based livestock productions with a low-methane emission. From now on, an important work to promote the local production of horse meat and the investment in effective diffusion and communication tools that raise social awareness and contribute to improve the consumption and the market value of these animal-derived products is necessary.

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**Figure 4.** Distribution of the horse meat production (a) and average carcass weights (b) in Spain. Source: MAPA (2020b).
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Utilization of by-products and food waste in livestock production systems: a Canadian perspective

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Key words: food waste, by-product utilization, livestock

Introduction

Increasing demand for food coupled with higher environmental standards is shaping agricultural activities toward ecologically sustainable and efficient systems (McGuire, 2015). However, food waste remains a global dilemma, with negative environmental, social, and economic consequences (Spang et al., 2019) associated with estimated annual losses of approximately one-third of all edible food (1.3 billion metric tonnes, MMT) across the supply chain (FAO, 2011). More recently, the FAO (2019) has defined food waste using two indices: food lost in production or in the supply chain before it reaches the retail level (Food Loss Index) or food that is subsequently wasted by consumers or retailers (Food Waste Index). Fourteen percent of the world’s food is lost before it reaches the retail level, but the contribution associated with the Food Waste Index is still being explored (FAO, 2019). In the United States alone, food loss streams have been estimated at 35.9 MMT from production/processing of vegetables, fruit, and meat/poultry/fish, whereas total retail and consumer waste are estimated at 19.5 MMT and 40.8 MMT, respectively (Dou et al., 2016). In Canada, total annual loss and waste along the food value chain equates to 35.5 MMT, of which 11.2 MMT (32%) is avoidable, valued at $49.5 billion, and representing 51.8% of the food dollars spent in retail stores in 2016 (Gooch et al., 2019).

As described above, food loss is typically associated with loss of quality or low-quality by-products during the production, processing, and distribution stages of the supply chain, whereas food waste or surplus food is defined as food that is not consumed at the retail, food service, and consumer stages of the food supply chain and is related to consumer behavior (Dou et al., 2016). By-products include a wide range of feedstuffs obtained from 1) cereal grain and oilseed cleaning, milling or extraction; 2) brewery, distillery, or ethanol production; 3) vegetable, fruit, and sugar processing; and 4) livestock processing. Often, a collective term, “food loss and waste,” refers to both indices (Gooch et al., 2019). The term surplus, although perhaps more socially acceptable, was purposefully avoided as it implies that producers and the associated food supply chain are using land and resources in excess of demand. Furthermore, it mitigates the shared responsibility to address loss and waste across the supply chain, from the producer to the consumer.

 Estimates of food loss and waste are dictated by methodology, with potential overestimates because 1) food redirected for less productive uses, such as fertilizer and animal feed, is deemed as lost; 2) farm losses are monetized at retail-level prices (Bellemare et al., 2017); and/or 3) an inability to accurately determine consumer waste, which can be impacted by many factors including consumer affluence (van den Bos Verma et al., 2020).
Minimizing food loss is an important avenue to improve global food security and improve management of land, water, and energy resources in food production systems. Indeed, it has become a global priority formalized by the United Nations (UN) 2030 goal to “...halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses” (UN, 2015).

Options to reduce food loss and waste have been described using a “hierarchy of recovery” (Figure 1) which include 1) reduction at source, 2) recovery/redistribution to address hunger, including utilization in animal diets, 3) recycling into pharmaceuticals, cosmetics, fertilizers/compost, as well as biodiesel or natural gas production through anaerobic digestion, and finally, 4) disposal in landfills or via incineration (ECCC, 2019). These options, however, vary broadly by country according to technological development, regulations restricting rendering of animal products into animal feed, as well as consumption. Although countries with higher per capita consumption have higher food waste production (van den Bos Verma et al., 2020), many also have efficient livestock production systems based on emissions per unit of commodity (Gerber et al., 2011). Canada, for example, has highly efficient livestock production systems, but produced 961 kg of waste per capita in 2014 at a cost of $85/capita for nonhazardous waste management (Richter et al., 2018). Many Canadian communities utilize landfills for disposal as a consequence of the availability of significant tracts of undeveloped land (Bruce et al., 2016).

Therefore, diverting food loss and waste toward livestock and poultry feed is a logical solution to reduce use of landfills as a strategy for disposal. Numerous studies have addressed food loss and waste in terms of food security, food safety, public health, and the environment, but there are a limited number of North American reviews (Dou et al., 2018), examining conversion to feed for food-producing animals. Modeling efforts have demonstrated that if livestock were removed from the landscape in the United States, $43.2 \times 10^9$ kg of human-inedible food and fiber by-products would no longer be converted into human-edible food, pet food, or industrial products (White and Hall, 2017), highlighting the importance of food loss and waste utilization as an ecosystem service associated with livestock production. Unusable by-products present a liability and their disposal has an associated environmental footprint.

### Food loss and waste streams available for inclusion in livestock diets

Utilizing food loss and waste in animal diets addresses waste management, food security, resource and environmental challenges. Livestock as “up-cyclers” play a critical role in the solution to reducing food loss and waste (Figure 2), with the potential to convert inedible foods into high-quality protein in the form of meat, eggs, and milk, while addressing waste management, food security, resource and environmental challenges (Dou et al., 2018). More specifically, the presence of a myriad of microorganisms in the rumen, and to a lesser extent, the

![Figure 1. Hierarchy of solutions to address food loss and waste (adapted from ECCC, 2019).](https://academic.oup.com/af/article/11/2/NP/6276808/12/NEF78788/18 May 2021)
large intestine, has the potential to effectively degrade fiber present in human-inedible plants and plant by-products to enable the ruminant host to generate high-quality protein including essential amino acids and fatty acids (Matthews et al., 2019). Animal protein is also an important source of B vitamins, with B12 obtained exclusively from animal sources, as well as A, D, and K2 (organ meats) and various minerals (i.e., zinc, selenium, iron) that are often more available in animal than plant-based foods (Leroy and Cofnas, 2020).

Currently, a large portion of the feed utilized in North American livestock production consists of grains, pulses, and oilseeds, as well as other commodities including potatoes that fail to reach the quality grade required for human consumption. This can be the result of harvest failures, crop pests, poor growing conditions due to early frosts, floods or drought, or excess production exceeding storage capacity. For example, in Canada, malt barley commands a price that is 51% greater than feed barley, but over 75% of malt barley fails to meet the criteria necessary for beer-making (Ribeiro and McAllister, 2016) due to factors including sprouting damage or low protein content which interfere with the malting process. However, barley that is rejected for malt production is acceptable as livestock feed. Furthermore, cereal grains and pulses are cleaned of contaminants prior to shipping, generating “grain screenings” consisting of mixtures of broken grains, chaff, weed seeds, and dust. The chemical composition of grain screenings can vary substantially depending on the parental material from which they were derived and their origin during the cleaning process. Screenings that are captured in dust collection systems are often high in minerals and fiber, suitable only as a low-quality feed for ruminants. To improve nutrient consistency and quality, screenings are often blended and pelleted prior to feeding.

In addition to on-farm or near farm losses, as much as 30% of global agriculture production results in biomass waste (Ajila et al., 2012) from food and industrial processing, including alcohol and biofuel production, oilseed processing, fruit and vegetable processing, sugar production, root and tuber processing, and herb, spice and tree processing (Salami et al., 2019). Increased production of biofuels in Canada (approximately 1.8 billion liters in 2019; GAIN, 2019a) has generated Figure 2. Food waste arises from food processors, restaurants, households, and food markets. Some food waste can go directly to livestock farms as feed, whereas others require secondary processing where they are separated from waste, subject to further processing. Streams that are suitable as feed are used on livestock farms, those designated as unsuitable may be directed toward composting or biodigestion. Unrecyclable packaging may be directed toward landfill. Plants that produce bioethanol and vegetable oils produce distillers grains and oilseed meals, which can be used directly by livestock as an important source of energy and protein.
dried distillers grains, which are rich in energy, protein, and minerals. This by-product can constitute up to 50% of the diet dry matter (DM) for confined cattle (Leupp et al., 2009) and up to 15% and 10% of the diet dry matter for pigs (Beltranena and Zijlstra, 2011) and poultry (Salim et al., 2010), respectively.

Expansion of oilseed production in Canada has also resulted in increased availability of oilseed meals. Canola (19 MMT annually) and soybean (6 MMT annually) were the principal oilseeds produced in Canada in 2019 (GAIN, 2019b). Soybean and canola meal are the principal protein sources used in livestock diets, with the fiber being higher and protein content lower in canola than soybean meal. Sunflower, flax, corn, and safflower are also sources of oilseed meals in Canada, but account for less than 1% of meal production.

A number of feed sources resulting from the regional processing of crops are often substituted for a portion of the cereal grain in animal diets, many of which have been characterized by Lardy et al. (2015). Milling of wheat to flour produces bran and germ or a mixture of by-products that can be offered to livestock as wheat middlings. Similarly, the hulls of primary crops such as oats, soybeans, and sunflowers may be removed during processing and are frequently used as a fiber source in ruminant diets. Processing by-products of fruits and vegetables including potatoes are also available for utilization in livestock diets. However, their high moisture necessitates immediate use or further treatment (e.g., ensiling) to prevent spoilage. As fractionation of commodities for inclusion in foodstuffs expands due to increased demand for novel products including meat substitutes, the diversity and volume of by-products in livestock diets is expected to increase. For example, pea processing in western Canada has expanded significantly to provide pea isolates used in dairy and meat substitutes (Acheson, 2016; https://www.roquette.com/media-center/news/2020-09-29-roquette-world-largest-pea-protein-plant-portage-canada).

Japan and South Korea have been leaders in recycling food waste into animal feed, where as much as 60% of daily municipal food waste is redirected to animal feed (Nguyen et al., 2017). An opportunity for further inclusion of food waste in livestock diets in Canada exists, given that of the 61.12 MMT consisting of dairy and eggs, field crops, produce, meat and poultry, marine, and sugar/syrup entering the Canadian food system in 2016, only 25.58 MMT (41.9%) were consumed, with 31.4% of the remainder deemed as avoidable food waste. The largest volume and value arose from manufacturing, followed by households, and the processing sector (Gooch et al., 2019).

**Challenges**

Despite the abundance of by-products and food waste available, there are a number of challenges regarding their use in livestock production.

**Economic viability**

Logistics associated with collection, transport, and handling of by-products and food waste may be too cost-prohibitive for use in livestock diets, particularly when considering high-moisture by-products and food waste. In Canada, some food processing by-products, such as whey and waste vegetables, may be provided at little to no cost to livestock farms, provided that the farms pay transportation costs and ensure timely pick-up. For livestock farms located in close proximity to source, these by-products can reduce feed costs significantly. Even for more “main-stream” by-products such as distillers grains, reduced costs compared with cereal grains and protein supplements promote increased inclusion in livestock diets.

Several Canadian food producers (including Maple Leaf Foods, McCain Foods, Kraft Heinz Canada, Unilever Canada, General Mills, Nestlé and Kellogg’s) have made public commitments to reduce food waste including diverting surplus food for human consumption or reusing food as livestock feed, compost, or to generate alternative energy (ECCC, 2019). Identifying industries with significant loss and waste along the food supply chain, quantifying food waste and by-product availability, as well as effective communication and coordination (Gooch et al., 2019), are necessary steps to leverage strategies for large-scale diversion of food loss and waste to livestock feed. To date, economic costs have limited the number of animal feed processors and distributors in Canada that have converted human-inedible food waste to animal feed (MacRae et al., 2016). Economic assessments of food waste recycling scenarios using indicators such as return-on-investment are needed to assess their economic feasibility at a commercial scale. Incentives are considered necessary to ensure the economic feasibility of recovering and recycling materials from food loss and waste, especially in the retailing, manufacturing, and processing sectors (Caldeira et al., 2020). Improving the economic efficiency of recycling by-products and food waste, combined with tax incentives, could create demand for these products within the animal feed industry.

**Collection and distribution logistics**

Efficient and cost-effective collection and distribution of consumer food waste is a global challenge, with disposal in landfills often deemed as the most economically viable option (Dou et al., 2018). In Canada, urban centers are widely dispersed, with rural areas characterized by small communities and isolated farmsteads (NZWC, 2018). Consequently, transportation of waste commodities over long distances creates logistical challenges. Although consumers prefer to purchase locally produced food, options to reduce food waste at a local scale may be limited with the exception of its use as a substrate for biogas or composting. A systematic approach to food waste accounting is essential to design efficient and effective policies that result in reduced food loss and waste along the food supply chain. Fortunately, estimating the volume of food loss generated by production and processing is easier compared with estimation for the household and food service sectors as a consequence of standardized practices that generate by-products of known quantity. Defining the myriad of food wastes that arise from households, retail, and food service sectors is far
more challenging due to the diversity of purchasing and consumption behaviors by consumers (Caldeira et al., 2019).

### Regulatory restrictions

Inclusion of by-products and food waste in animal diets is also limited by regulatory policy as feedstuffs must be included in the Feeds Act governed by the Canadian Food Inspection Agency (CFIA). The Feed Acts in Canada permits the use of several processing by-products and bakery wastes as feed (CFIA, 2015), but there are many low volume and novel by-products associated with new processing technologies and changes in consumer demand that are not currently included. For example, by-products resulting from the extraction of oil from hemp include meal (32% crude protein) and hulls, which are valuable protein and fiber resources, but are not currently included in the list of permitted feeds. Increased consumer demand for newer products, such as quinoa, have resulted in by-product and wastes that have suitable nutritional profiles to allow displacement of cereal grains, but often these are not approved for use in animal diets. In other cases, existing regulations prevent or restrict use. For example, the Enhanced Feed Ban is a stringent regulation, which restricts the recycling of meat and bone meal to prevent the introduction of prions responsible for bovine spongiform encephalopathy that may be present in specified risk materials into the food chain. An examination of regulatory policy supported by research has the potential to address economic viability and sustainability of food production through safe expansion of by-product use commensurate with expanded commodity production and availability of food loss and waste at the processing, retail, and consumer levels.

### Feed safety

Any effort to divert food that does not meet quality standards for humans or is recovered prior to disposal in landfills must ensure that animal, human, and environmental health is uncompromised. A wide range of potential contaminants can be found in by-products and food waste, such as mycotoxins, herbicides, fungicides, pesticide residues, pathogens, antinutritional factors (glycoalkaloids, tannins), and heavy metals (aluminum, arsenic, cadmium, and lead), as well as glass, metal, and plastic packaging (CFIA, 2019). The high moisture content of many fruit and vegetable by-products and food waste creates an ideal environment for the growth of bacteria and fungi that may produce toxins during decomposition. It is important to note that sensitivity to feedstuffs containing antinutritional factors such as fungal metabolites differs between species. For example, cattle and poultry are less sensitive than pigs to vomitoxin, a fungal metabolite that may be found in Fusarium-infected cereals (Trenholm et al., 1985).

Commercial composting plants employ a variety of processes to remove plastic, glass, metal, and stone contaminants including density separation with water or air, vacuum, and manual removal (Levis et al., 2010). Therefore, to divert food waste to animal feed, labor, and advanced equipment are required to separate usable food waste from packaging and foreign contaminants (Truong et al., 2019).

A number of preservation techniques: 1) heat sterilization, 2) heat sterilization plus drying to 80% to 95% DM, 3) ensiling alone or after heat treatment with or without addition of fermentation aides (bacteria, enzymes, or acids), and 4) enzymatic treatment have been employed to stabilize food wastes (Dou et al., 2018). However, these processes can add significant cost to their utilization (Sugiura et al., 2009) and typically occur at a centralized industrial scale, making it challenging for small stakeholders to undertake. In Japan, specialized plants have successfully manufactured feed from by-products and food waste utilizing processes ranging from drying to ensiling with lactic acid bacteria (Sugiura et al., 2009). For several high-moisture commodities, such as potatoes, ensiling is essential for preservation and to suppress pathogens causing diseases such as cysticercosis (Buttar et al., 2013). In the European Union, advanced low-cost low-energy processing technologies based on physicochemical and biotechnological processes (Petrusan et al., 2016) have been developed to treat fruit, vegetables, tubers, cereals, and dairy wastes to produce bulk feed, as well as specialized functional feed additives including 1) protein hydrolysates; 2) functional immune-stimulating protein hydrolysates; 3) fiber with prebiotic properties; and 4) antioxidants to enhance oxidative status. More recently, enzymatically treated wastes from supermarket food including fruit, vegetable, meat, and dairy products were fed to growing pigs in California (Jinno et al., 2018). These wastes provided a level of nutrition comparable to that of a standard corn-soybean diet, but the pigs gained less weight due to reduced intake as a consequence of the high water content of the feed. Consequently, to be adopted, these food wastes must be priced to ensure cost of gain remains comparable or lower than standard diets.

### Assessment of nutrient quality

The heterogeneity of by-products and food waste creates challenges as their nutrient composition may vary considerably within and between lots, making it difficult to balance diets to meet livestock requirements. Screenings, for example, are frequently marketed on the basis of bulk density, making it difficult to gauge their nutritional value. Consequently, the nutrient composition of these products must be measured frequently and diets reformulated as necessary. One solution with on-farm application is the use of near-infrared spectroscopy (NIRS) for rapid assessment of feed value, and the detection of mycotoxins and pesticides in food waste (Shahin and Symons, 2011). However, prior to on-farm use, robust calibration equations must be developed for each by-product by comparing NIRS spectra to traditional laboratory evaluation of the feeds. Other rapid screening technologies, such as flow-injection mass spectrometry, could also be used to detect contaminants, but would only be suited to centralized food waste/by-product processing distribution centers due to operational complexity and equipment costs. Nonetheless, rapid and accurate assessment to determine the nutritional value of by-products and food waste is
essential if these products are to be utilized in precision feeding livestock operations (Dou et al., 2018).

**Environmental impact**

Over the last decade, several life cycle assessments (LCAs) have been conducted to determine the environmental implications of traditional disposal streams for food loss and waste (anaerobic digestion, landfill, and composting) compared with their use as livestock feed. However, inclusion of end point affects without consideration of “up-stream” impacts along the food chain, including energy, fertilizer, water, and land use as well as greenhouse gas (GHG) and ammonia emissions, has been identified as one of the shortcomings associated with several of these assessments (Dou et al., 2018). Recently, Salemdeeb et al. (2017) conducted a hybridized LCA that used 14 environmental and health indicators associated with four food waste disposal strategies. Converting municipal waste to feed for pig production lowered the environmental impact compared with anaerobic digestion and composting, with wet-processing superior to dry processing for all environmental indicators. These evaluations often involve assessment of trade-offs in food waste management practices. For example, in South Korea, it requires energy to dry and process food waste in centralized facilities, but once produced it can be economically transported longer distances and is less likely to spoil due to its low water content. In contrast, wet food waste is much more expensive to transport and spoils rapidly, but if used locally does not produce the GHGs associated with drying and long distance transportation.

Over the last decade, Canada Sheep and Lamb Farms Ltd have successfully included bread, beet pulp, pea, lentil, and dried bean screenings in formulated rations to 60,000 ewes. Use of by-products will continue as they expand their operation from Canada into Russia. Bakery products are being used successfully by some Canadian cattle and sheep farms. Bread packaged in plastic bags for retail sale is received by the feedlot where it is chopped, plastic removed by airflow and included in total mixed rations. The bread is an ideal substitute for cereal grains as it contains 16% crude protein and is high in energy.

**Conclusions**

Global and Canadian assessments of food loss and waste as a percentage of food grown are substantial, but there is no standardization as to how these assessments should be conducted. This hampers progress in our collective battle against food loss and waste by delaying public policy change and the creation of accountability metrics that can be applied across the food supply chain. Nonetheless, it is evident that redirection of food waste from landfills is necessary to improve global food security and resource sustainability issues. It is also logical that livestock, with their capacity to “up-cycle” relatively low-quality feedstuffs into high-quality protein, are an essential element of this solution. Canadian livestock producers are recognized globally for the animal care standards, milk, meat and egg quality and efficiency of production. Furthermore, Canadian farmers have demonstrated interest, ingenuity, and investment to replace traditional feeds with by-products and even food waste.

Today’s diversity of by-products and urban setting for much of our food waste requires a diversity of solutions. Disincentives to waste food will be influenced by food prices and costs for food disposal. Producer and processor incentives to recover more food and to redirect by-products away from landfill and nonfood recycling efforts will require investment to improve infrastructure, creating market
opportunities. Furthermore, revised policy and regulation are essential to fully implement the spectrum of solutions. Research to facilitate safe incorporation of by-products and food waste into animal feed is a critical step toward changes in policy and regulation.

Canada has some unique challenges. The large geographic area, with much of food processing and food waste occurring in large urban centers means that by-product and food waste sources are often large distances from the livestock and poultry farms. As a major food commodity exporter, Canada’s food supply chain is heavily intertwined with multinational food processors and retailers affecting transportation costs. These companies will need incentives or regulation to shift current practices at the local or national level. As one of the world’s most northerly food producers, Canada may have an advantage by using cold weather to reduce spoilage of by-products or food waste in storage for a part of the year to reduce storage and processing costs. Furthermore, comprehensive LCA-type assessments to examine environmental benefits of treatment options including replacement of feed grains with by-products or food waste will provide much-needed information regarding the impact on the environment including GHG and ammonia emissions as well as land and water. Finally, a coordinated approach requiring input from producers, feed suppliers, researchers, policy makers, and retailers is critical for the development of successful strategies for inclusion of food loss and waste in livestock diets.

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Youth livestock programs provide intangible benefits through life skill development

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Since the early 1900s, livestock shows have been held throughout the United States for adults and youth to compare the quality of their animals. These shows have been held at the local, county, district, state, regional, and national level. In the early days, one of the most famous shows was the “International” held at the stockyards in Chicago, IL. Exhibiting a champion animal at the International was considered the pinnacle of achievements in the livestock industry. The former Dr. O’Dell G. Daniel said, “There will be livestock shows as long as there are youngsters who have parents and grandparents. Let’s not confuse the issue by saying we have steer shows, barrow shows, lambs shows, etc. We have kid shows where it is necessary to have an animal to be admitted through the gate” (Daniel, 1986). For youth exhibitors, the “rewards” for raising and showing animals are more than monetary awards. The former Dr. O’Dell G. Daniel said, “Junior Livestock Projects are educational. They are the greatest teaching project known to man” (Daniel, 1986). If you ask youth what they gain from raising and showing animals, they will respond with a laundry list of what are now referred to as “life skills” (Hendricks, 1998). The Targeting Life Skills wheel was developed by P.A. Hendricks at Iowa State University and published in 1998. Working from the Head, Heart, Hands, and Health included in the 4-H motto, Hendricks listed 35 life skills on the “Targeting Life Skills” wheel (Figure 1). Many of these “life skills” can be attributed to the virtues of raising and showing livestock projects. Regardless of whether the youth is a member of 4-H, FFA or simply raising animals on their family’s farm or ranch, the valuable skills developed from raising animal projects are numerous.

In recent years, we have seen an increase in the number of children with special needs participating in youth livestock shows. We attribute part of this increase to Agricultural Engineers who have modified wheelchairs to include a head

Implications

• Raising and showing livestock results in the acquisition of numerous life skills by youth. Some of these skills include responsibility, time management, and animal husbandry skills like feeding, breeding, vaccinating, treating animals for sickness, treating animals for lameness, and training animals for the showering.
• Youth who show animals also learn about ownership deadlines, entry deadlines, making travel plans, and teamwork learned from working together as a family.
• Youth who compete on judging teams learn to evaluate dairy cattle, horses, meat, or livestock such as beef cattle, goats, sheep, and swine.
• Youth who compete on dairy cattle, horse, meat, or livestock judging teams learn leadership development skills like critical thinking, decision making, and public speaking.
• The leadership skills gained by youth who compete on judging teams will give these youth an advantage later in life, especially when they are interviewing for jobs.

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pie for sheep and goats that is attachment on the side of the wheel chair and allows a youth exhibitor to bring their sheep or goat to the showering and compete side by side with their fellow exhibitors. Wheelchairs have also been modified to allow swine exhibitors with special needs to compete in the show ring with their contemporaries. We applaud these changes that have increased the number of youth who are able benefit from raising and showing animal projects.

In addition to livestock shows, judging contests (dairy, horses, livestock and meat) for 4-H, FFA and collegiate youth have been held since the early 1900s. In the United States, judging contests have served as an effective means of measuring a team’s or individual’s ability to evaluate dairy cattle, horses, livestock, and meat. Judging competitions are enjoyable as well as educational. They evaluate contestants’ ability to make logical decisions, in a fixed amount of time, with a given scenario and a selected group of animals or cuts of meat. First, students must learn to evaluate the desirable and undesirable points of conformation and performance of four animals, four carcasses, or four cuts of meat per class. The student must utilize his/her senses to perceive the differences in structural correctness, muscularity, and fat deposition. After weighing the placing factors, the student must persuasively present (in oral or written form) a set of reasons explaining the factors that influenced their class placing. Points are awarded to the contestant for accuracy, organization, and speaking/writing ability. A judging contest, therefore, builds character and instills self-confidence. Both traits are important in helping students develop leadership potential, a basic long-term goal of the activity.

Coaches across the country invest a large amount of time each year developing their students’ general livestock and meat knowledge and leadership potential with extensive decision-making and speaking/writing experiences. Many hours of practice are required to teach students to consistently and correctly place animals, carcasses, or cuts of meat in the same order as the official judges, as well as to deliver a persuasive, truthful, and organized set of reasons.

Boys and girls and young men and women are entitled to the kind of training and experience that will enable them to enjoy life to the fullest and to meet with eagerness, assurance, and satisfaction their social and economic responsibilities of both the present and the future. The training and experience required for living this full life through youth and adulthood may be secured in large measure in 4-H, FFA, and FHA activities and the necessary supporting subject matter instruction (Smith and Kirkpatrick, 1990, p. 7). The initial purpose of the livestock judging activity was to encourage the critical evaluation of livestock for the improvement of beef cattle, swine, and sheep. The activity is centered around the evaluation of a class of four animals and the determination of a placing, using a standard set forth by livestock experts from the university and the livestock industry. Livestock are assessed on their value as either a market or breeding animal. The evaluation of livestock exercises the participant’s problem solving and decision-making skills to determine the most logical order in which the animals should be placed.

McCann and McCann (1992) said the livestock judging activity provides youth who have an interest in the livestock industry with the opportunity to develop necessary life skills for
their futures and their careers. They also stated that through the training process before competition, livestock judging participants develop the most skills (compared with the amount of skills they learn during the actual judging competition). They learn to develop a thought process through the assimilation of concepts identified with proper evaluation practices. Through active preparation for the contest situation, called “work-out” sessions, participants become associated with and learn to adjust to pressure situations (Figures 2–6; Pictures taken during the 2000 Indiana State 4-H/FFA Livestock Judging Contest at Purdue University).

An important component of the activity is the participant’s delivery of a set of oral reasons, which describes the contestant’s thought process in placing the livestock and defends their decision in a structured manner that is logical and professional. In the early years of the judging program, reasons were written by the participant to justify and defend his or her placing. Through the years, reasons have evolved into an oral presentation to an official judge. Oral reasons allow participants to become more proficient in defending their decisions using public speaking skills (Purdue University Cooperative Extension Service, 1998).

Development of important life skills such as communication, problem solving, and understanding one’s self has been taught through experiential learning throughout the history of 4-H youth programming (Boyd et al., 1992). Throughout the development of the 4-H Livestock Judging Program, residual benefits, such as life skills development, have enhanced the validity of maintaining the activity. Livestock judging has been associated with developing a variety of employer preferred life skills in its participants (Smith, 1989). Judging livestock uses skills which involve the comparison of differences (Hunsley and Beeson, 1988).

Livestock judging participants learn to evaluate the desirable and undesirable points of conformation in a class of four animals (McCann, 1988). When one learns the process of evaluation through the livestock judging activity, these same skills can be integrated into other real-life situations. The judging activity is a widely practiced art in the livestock industry because success in business depends on the producer’s ability to select animals that are of correct type and have economic usefulness to both the producer and the consumer (Eversole, 1990). The livestock judging contestant must be able to visually perceive differences in muscle, fat, and structural correctness (McCann, 1988). Participation on livestock judging teams is credited with improved critical thinking skills; improved organization, delivery, and accuracy of written and oral communication processes” (p. 30).

In 2000, Mr. Chad Martin and Dr. Clint Rusk conducted a study to determine the impact of the Indiana 4-H Livestock Judging Program from a retrospective account of former participants. The participants in the study were to indicate their demographic information such as age, gender, college education, gross annual income, if they had been a 4-H volunteer, current career status, if their children have been involved in the 4-H Livestock Judging Program, and livestock judging and coaching experience. Participants were also to rate the influence the 4-H livestock judging activity had on the development of specified life skills. The range of the scale was from, “not influential at all,” to “almost essential to my ultimate development of that attribute.” The life skills indicated are often associated with workforce preparedness (SCANS, 1991). Participants were asked to give qualitative accounts as to how the Indiana 4-H Livestock Judging Program influenced their personal growth.

Fifty percent of respondents participated in the Indiana 4-H Livestock Judging Program as a contestant between 1986 and 1999. Approximately 60% of respondents were between the ages of 26 and 40. The reported distribution show that over 90% (N = 172) of the former participants pursued an education beyond the secondary level. Just over half (55.6%) of the respondents indicated they attended Purdue University. Those who attended a junior college before going to Purdue University were only 2.3% of the population. Just over 10% of respondents stated they attended a junior college known for its livestock judging team excellence, before attending another agricultural university besides Purdue University. Just over half (52.8%) of respondents indicated a bachelor’s degree was the
Approximately one-fourth obtained a master’s degree, whereas 1% received a PhD, 1% earned a Doctor of Veterinary Medicine, and 0.5% received an MBA. Of the respondents with at least some form of postsecondary education, 83.6% received a bachelor’s degree or higher. Over half (55.4%) of respondents stated their participation in the Indiana 4-H Livestock Judging Program affected their choice of colleges. 52.7% of respondents indicated they had judged a county fair livestock show after completing the Indiana 4-H Program. Approximately one-fourth, or 23.7%, of the respondents had judged a state livestock show, 15% had experience judging a regional livestock show, one-tenth had judged a national livestock show, and 2% had served as an international livestock judge.

Respondents were asked to indicate the level of influence the 4-H Livestock Judging Program had on developing specific life skills associated with workforce preparedness. These skills included the following: oral communication skills using proper
terminology, self-confidence, problem-solving ability, decision making, ability to verbally defend a decision with accuracy, self-motivation, organizational skills, self-discipline, teamwork, and livestock industry knowledge. Former participants were asked to rank each life skill according to the level of influence the 4-H Livestock Judging Program had on developing that skill, using the following scale: (1) not influential at all, (2) mildly influential, (3) moderately influential, (4) highly influential, and (5) almost essential to my ultimate development of that attribute. The 4-H livestock judging activity was highly influential in the development of the following skills: the ability to verbally defend a decision, livestock industry knowledge, oral communication, and decision making. All other life skills were determined to be moderately influential (Table 1).

Former participants in the Indiana 4-H Livestock Judging Program were asked an open-ended question regarding their accounts of how the judging program influenced their personal growth. Over 75% (132 of 171) of respondents indicated...
participation in the Indiana 4-H Livestock Judging Program influenced their personal life in a positive manner. Examples of these responses include the following: “The Indiana Livestock Judging Program was the single most important experience of my life. In terms of personal growth, the judging program opened doors and led me down a very successful path. I know I wouldn’t be where I am today without it.” Another respondent stated: “The 4-H livestock program helped develop skills I will carry with me for the rest of my life. It opened doors and introduced me to people in the livestock industry that could only be obtained through my judging career.”

The responses that identified preparation for the workforce as being positively influenced by participation in the Indiana 4-H Livestock Judging Program totaled 131 or 76.6% of those who responded. Examples of these responses include the following: “It helped my communication skills which are essential in day-to-day operations in my career. It became the foundation of all other skills needed in life.” “I am responsible for running meetings and supervising people. My judging experience taught me to speak in public, while at the same time evaluate situations.” “The program has given me a sense of self-confidence and has taught me how to voice my opinion. In my job, I communicate with all types of people, from high government officials to farmers. Being involved in judging programs helped.”

Table 1. Distribution of former participants in the Indiana 4-H Livestock Judging Program: rating the influence the program had on developing specific life skills associated with workforce preparedness

| Life skill                          | N   | Mean | SD  | Frequency of responses |
|------------------------------------|-----|------|-----|------------------------|
| Verbal presentation                 | 185 | 4.20 | 0.81| 2 6 16 90 70           |
| Livestock industry knowledge       | 185 | 4.15 | 0.86| 2 6 26 80 71           |
| Oral communication                 | 185 | 4.07 | 0.81| 2 6 25 97 55           |
| Decision making                    | 185 | 4.04 | 0.80| 3 6 20 108 48          |
| Self-confidence                    | 185 | 3.93 | 0.80| 3 8 25 97 55           |
| Problem solving                    | 185 | 3.68 | 0.90| 6 11 44 99 25          |
| Teamwork                           | 185 | 3.56 | 0.97| 5 22 49 83 26          |
| Self-motivation                    | 185 | 3.46 | 1.00| 10 16 61 75 25         |
| Self-discipline                    | 185 | 3.45 | 0.98| 9 18 61 76 21          |
| Organizational skills              | 185 | 3.35 | 0.95| 8 20 75 64 18          |

*Scale: 1 = not influential at all, 2 = mildly influential, 3 = moderately influential, 4 = highly influential, 5 = almost essential to my ultimate development of this attribute.*

A total of 39 respondents (22.8%) reported the personal contacts and friendships gained from participating in the 4-H Livestock Judging Program were another important value. “My involvement in 4-H and Collegiate judging activities created lifelong contacts within the pork industry.” “It was a great experience to go and meet people around Indiana.” “It gave me the opportunity to interact with a wonderful group of young people.” “4-H livestock judging was a tremendous positive influence in my youth and into my adult life. I received many great rewards, but most importantly, met many great friends through my activities and involvement in livestock judging. Now, I feel it is more important to give back and volunteer my time and help other people.” “I gained the respect, friendship, and collective knowledge of a number of people around the state.” “I think it made me a more well-rounded individual, not only in terms of livestock evaluation, but also in terms of public speaking. The greatest influence in my opinion was the opportunity to have contact with some of the most influential people in the livestock industry; not to mention all of the friends I met with a common interest.”

Sixteen respondents said development of livestock knowledge was a positive influence of the Indiana 4-H Livestock Judging Program. Following are two representative responses: “The program has helped me have better judgement and make better decisions to help improve my cow/calf operation.” “As a seedstock swine producer, being able to evaluate swine is extremely important to my success.”

Twelve respondents, or 7.0% of those responding, stated the Indiana 4-H Livestock Judging Program was influential in helping them achieve academic success. Example responses in this category include the following: “The 4-H Livestock Judging Program kept me in school and helped me in my current occupation.” “The 4-H Livestock Judging Program and 4-H in general were the main reasons I chose to attend Purdue University and study Agriculture.” “Being on the livestock judging team helped me become more responsible. I had to get my schoolwork done so I could stay on the team.” “It helped me to think on my feet and articulate my thoughts verbally.” “The 4-H Livestock Judging Program allowed me to make better and quicker decisions by forcing me to think on my feet.”

Table 2 reflects the frequency and percentages of responses in each category of qualitative responses to the question of how the Indiana 4-H Livestock Judging Program influenced the personal growth of former participants. Almost 99% of respondents indicated the Indiana 4-H Livestock Judging Program had a positive influence on their personal growth. Three quarters of respondents included remarks stating the Indiana 4-H Livestock Judging Program positively influenced their personal life and their preparation for the workforce.
Participants with experience as a 4-H volunteer in one or more areas. This indicates that the 4-H livestock judging activity was valuable enough to its former participants to encourage them to become active in the program after completing judging team participation. Over half of the participants in this study, with children of eligible age, have involved their boys and girls in the Indiana 4-H Livestock Judging Program. Those who participated in livestock judging as a youth and then provided the same opportunity for their children have favorably assessed the value of the experience.

Several participants in this study indicated that they had experience as a livestock judging coach at various levels. Coaching a livestock judging team allows former participants to pass along their acquired knowledge to those who are coming through the ranks. Those who competed on a junior college livestock judging team may have had an opportunity to assist their collegiate coach following their year of eligibility. Animal Science graduate students have an opportunity to coach livestock judging teams at the collegiate level following their year of eligibility. Most of the former participants in the Indiana 4-H Livestock Judging Program have judged a county livestock show. This indicates that the program provides a proper foundation for those who wish to continue in a livestock judging career. The program also inspires its participants to utilize the knowledge they gain, beyond their 4-H livestock judging experience.

The purpose of this study was to determine the impact of the Indiana 4-H Livestock Judging Program on past participants’ development of life skills associated with workforce preparedness. The first objective of the study was to describe the demographics of former participants in the Indiana 4-H Livestock Judging Program. The criteria selected to determine the demographics were age, gender, college education information, income, occupation, history of 4-H volunteer involvement, livestock judging team coaching experience, and level of livestock show judging experience. The typical former participant in the Indiana 4-H Livestock Judging Program was a 31- to 40-yr-old male with a bachelor's degree or higher from Purdue University, who indicated the program affected their choice of colleges. The typical former participant was employed in the agriculture industry, earned $45,001–$55,000 annually, had experience volunteering in 4-H programs, and had judged at least one county livestock show. Former participants with children have involved their boys and girls in the 4-H Livestock Judging Program. Most respondents received a bachelor's degree from Purdue University. Those who participate may be more apt to attend college because of their scholastic aptitude. The agriculture industry is developing and evolving at a fast pace. It is important that 4-H programming offer opportunities for youth to become more aware of the industry. As indicated by this study, the typical former participant of the 4-H Livestock Judging Program is employed in agriculture and earns between $45,001 and $55,000. Former participants may have anticipated an agriculture career before their participation in livestock judging, therefore, further developing their skills and knowledge. As agriculture is becoming more diverse, with an increasing pool of employees from nonagricultural backgrounds, 4-H programs like livestock judging provide an opportunity for people to become more accustomed to the fundamentals of agriculture and the ability to become more knowledgeable about livestock, without the requirement of growing up on a farm. Because 4-H programs rely heavily on volunteerism to be successful, it is encouraging to see most former participants with experience as a 4-H volunteer in one or more areas. This indicates that the 4-H livestock judging activity was valuable enough to its former participants to encourage them to become active in the program after completing judging team participation. Over half of the participants in this study, with children of eligible age, have involved their boys and girls in the Indiana 4-H Livestock Judging Program. Those who participated in livestock judging as a youth and then provided the same opportunity for their children have favorably assessed the value of the experience.

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The second objective of this study was to collect qualitative perspectives of how the Indiana 4-H Livestock Judging Program influenced the personal growth of former participants. There were several responses showing a high level of favor toward the program in more than one manner. These responses showed the 4-H Livestock Judging Program developed workforce preparation skills as well as social, academic, personal, and livestock skills. Several individuals indicated the program was valuable in developing their communication skills. Because of the participants’ experience in oral reasons, they also developed the confidence to speak publicly. Former participants indicated they learned how to make proper decisions. A phrase commonly made by respondents to describe their 4-H livestock judging team experience was “the program helped me learn to think on my feet.” This concurs with the SCANS (1991) report which specifically stated one of the important skills employers look for in their employees, is the ability to stand on their own two feet and make decisions. The third objective was to determine the influence of the Indiana 4-H Livestock Judging Program on developing necessary life skills. The typical respondent indicated the 4-H Livestock Judging Program was moderately to highly influential in developing specific life skills associated with workforce preparation. The ability to verbally defend a decision with accuracy was the skill most influenced by participation in the program. This concurs with McCann’s (1992) findings on the development of necessary life skills. The ability to verbally defend a decision is developed by the exercise of presenting oral reasons multiple times to effectively describe the thought process used by the participant in placing the class of livestock. Those who excel in oral reasons learn to more effectively use the English language to get their point across.

**Conclusions**

The purpose of this study was to determine the impact of the Indiana 4-H Livestock Judging Program on past participants’ development of life skills associated with workforce preparedness. The first objective of the study was to describe the demographics of former participants in the Indiana 4-H Livestock Judging Program. The criteria selected to determine the demographics were age, gender, college education information, income, occupation, history of 4-H volunteer involvement, livestock judging team coaching experience, and level of livestock show judging experience. The typical former participant in the Indiana 4-H Livestock Judging Program was a 31- to 40-yr-old male with a bachelor’s degree or higher from Purdue University, who indicated the program affected their choice of colleges. The typical former participant was employed in the agriculture industry, earned $45,001–$55,000 annually, had experience volunteering in 4-H programs, and had judged at least one county livestock show. Former participants with children have involved their boys and girls in the 4-H Livestock Judging Program. Most respondents received a bachelor’s degree from Purdue University. Those who participate may be more apt to attend college because of their scholastic aptitude. The agriculture industry is developing and evolving at a fast pace. It is important that 4-H programming offer opportunities for youth to become more aware of the industry. As indicated by this study, the typical former participant of the 4-H Livestock Judging Program is employed in agriculture and earns between $45,001 and $55,000. Former participants may have anticipated an agriculture career before their participation in livestock judging, therefore, further developing their skills and knowledge. As agriculture is becoming more diverse, with an increasing pool of employees from nonagricultural backgrounds, 4-H programs like livestock judging provide an opportunity for people to become more accustomed to the fundamentals of agriculture and the ability to become more knowledgeable about livestock, without the requirement of growing up on a farm. Because 4-H programs rely heavily on volunteerism to be successful, it is encouraging to see most former participants with experience as a 4-H volunteer in one or more areas. This indicates that the 4-H livestock judging activity was valuable enough to its former participants to encourage them to become active in the program after completing judging team participation. Over half of the participants in this study, with children of eligible age, have involved their boys and girls in the Indiana 4-H Livestock Judging Program. Those who participated in livestock judging as a youth and then provided the same opportunity for their children have favorably assessed the value of the experience.

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**Table 2. Distribution of qualitative responses from former participants in the Indiana 4-H Livestock Judging Program on the ways the program influenced their personal growth**

| Response category                      | N*     | Percentage |
|--------------------------------------|--------|------------|
| Positive influence                   | 169    | 98.8       |
| Personal life influence              | 132    | 77.2       |
| Workforce preparation influence      | 131    | 76.6       |
| Personal contact influence           | 39     | 22.8       |
| Livestock knowledge influence        | 16     | 9.4        |
| Academic success influence           | 12     | 7.0        |
| Think on your feet influence         | 8      | 4.7        |
| Negative influence                   | 2      | 1.2        |

*One hundred seventy-one respondents gave qualitative comments.
The fact several former participants have established a career and official judges. The process of giving multiple sets of oral reasons during work outs and in competition allows the participant to develop a proficiency in this important skill needed to be successful in today’s workforce.

Livestock industry knowledge was the second most influenced skill acquired as a result of participation in the program. The fact several former participants have established a career in the agriculture industry may have resulted in such a high rating of this skill. Participants are learning how to identify important aspects of the livestock industry in order to become more aware of the business. Oral communication is used daily and is a necessary skill in the workforce (SCANS, 1991). Through oral reasons competition, students are given the opportunity to develop their own unique communication style. The successful oral reasons presenter uses proper annunciation and articulation to portray their thoughts. Self-confidence is essential to successfully present a set of oral reasons. Oral communication and self-confidence are “selling one’s self” in the workforce. The ability to make good decisions relies on the opportunity to practice developing thought processes. Participants in the 4-H Livestock Judging Program indicated that the program was highly influential in the development of this important life skill. By repeatedly making decisions in the livestock judging activity, 4-H youth are getting a head start in developing decision-making skills. These skills are not only essential in the workforce, but they are also an important tool for generating decisions in the adult life. Former participants will be better able to communicate, have more self-confidence, and increase their problem-solving ability as a result of participation in the 4-H Livestock Judging Program. Without question, the Indiana 4-H Livestock Judging Program has been beneficial in the development of important life skills in past participants and should continue to be highly influential in the new era of 4-H Youth Development programming.

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International Congress on Farm Animal Endocrinology

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Despite this unprecedented Covid-19 pandemic, animal scientists in Canada and around the world are working diligently to maintain high quality animal research. The Canadian Society of Animal Science is pleased to introduce two symposia that are being organized in collaboration with the American Society of Animal Science for the 2021 ASAS-CSAS-SSASAS Annual Meeting & Trade Show that will be held in Louisville, Kentucky, USA, July 14–18. Symposium 1: Prospects for Exploiting Epigenetic Effects in Livestock Production and Symposium 2: Livestock resilience and climate change (see details below). In addition, the CSAS is working on the November issue of Animal Frontiers, showcasing more than 10 articles giving an insight on how epigenetics will impact livestock production in the future with contributions from authors that will provide a global perspective.

We hope these events and publications will contribute to the scientific community and animal production stakeholders.

Best wishes,

Flavio S. Schenkel (President), on behalf of the Canadian Society of Animal Science Executive

### Oncoming CSAS Symposia

**Symposium 1: Perspectives for exploiting epigenetic effects in livestock production**

**Description:** Epigenetics is currently an expanding area of research in livestock genetics and breeding, which started to be translated to practical applications in breeding and animal management and nutrition. This symposium will discuss the prospects for exploiting epigenetic effects to improve livestock production.

**Thursday (PM), July 15, 2021**

| Speaker                    | Country   | Title                                                                 |
|---------------------------|-----------|----------------------------------------------------------------------|
| Dr. Marcio Duarte         | Brazil    | Fetal programming and meat quality                                   |
| Dr. Marc-Andre Sirard     | Canada    | DNA methylation across generation in bovine                         |
| Dr. Luiz F. Brito         | USA       | Transgenerational effects of heat stress in pigs: an epigenomic perspective |
| Dr. Ying Yu               | China     | Analyses of inter-individual variations of sperm DNA methylation and their potential implications in cattle and pigs |
| Dr. Aleksandra Dunislawska| Poland    | Epigenetic changes in chicken induced by an early microbiome reprogramming via bioactive substances |

**Symposium 2: Livestock resilience and climate change**

**Description:** Global climate change will affect livestock production while the demand for livestock products is expected to increase by mid of the 21st century. A look into the interaction of livestock resilience and climate change will be discussed in this Symposium.

**Friday (AM), July 16, 2021**

| Speaker                    | Country   | Title                                                                 |
|---------------------------|-----------|----------------------------------------------------------------------|
| Dr. Christine Baes        | Canada    | Dairy Resilience: Canada’s path forward                              |
| Dr. John Basarab          | Canada    | Use of genomic tools to improve production efficiency, health resilience and carbon footprint of beef production |
| Dr. Roland Kröbel         | Canada    | Estimating the environmental impact of livestock operations using a Canadian whole-farm model developed for Canadian producers |
| Dr. Frank Mitloehner      | USA       | Rethinking Methane: Livestock’s Path to Climate Neutrality          |
| Dr. Adriana Rivera Huerta / Dr. Maria Salud Lozano | Mexico | Impacts on biodiversity, environment and society of beef production in the Mexican tropics: A Life Cycle Assessment approach |
EAAP is the international Federation of Animal Science for Europe and the Mediterranean area. Join EAAP and become member of the most exciting international animal science network and then have access to many services that are indispensable for every animal scientist worldwide.

**THE 72nd EAAP ANNUAL MEETING WILL BE HELD IN DAVOS (SWITZERLAND)**

EAAP and the Swiss Local Organizing Committee for the 2021 EAAP Annual Meeting wish to inform you that, despite the trouble caused by the Covid-19 pandemic, the 2021 Annual Meeting will be held from August 30th to September 3rd, as originally planned. The structure of the meeting depends on future pandemic developments and the related governmental restrictions. The option that we are currently considering is to hold a hybrid meeting, that is to have an on-site meeting in Davos with selected sessions offered virtually. The Theme of the conference will be: “Scientific solutions to different demands on the livestock sector”.

The Annual Meeting will host scientists and experts from all disciplines of animal science, not only from Europe but also from other countries around the world. The EAAP Meeting provides a platform for scientists and industry experts to meet and acquire new knowledge and to exchange their experiences on the latest research results from many areas of animal science. The many sessions, plenary session, poster presentations and discussions about scientific achievements in livestock production during the Annual Meeting all provide an opportunity to put new ideas into practice. More information can be found at [www.eaap.org](http://www.eaap.org) and [www.eaap2021.org](http://www.eaap2021.org)

Congress website: [www.eaap2021.org](http://www.eaap2021.org); e-mail: info@eaap2021.org; the venue: Davos Congress CH-7270 Davos Platz

**NEW EAAP WEBINAR SERIES!**

We are excited to announce the EAAP series of upcoming webinars designed to disseminate and to share information on animal science and livestock industry. Webinars typically will take place in the afternoon of the second Tuesday of every month. Each month, EAAP offers three hour-long webinars on topics of key interest. We are inviting top scientists, policymakers, experts, etc. to bring new ideas and thinking to anyone who would like to know more in animal science and livestock industry. Check on our website ([www.eaap.org](http://www.eaap.org)) for more updated information.

**INDIVIDUAL MEMBERSHIP OF EAAP**

The EAAP membership is open to all scientists. It is a great opportunity to be update on the latest publications and other relevant information in the animal sector.

We have more than 4000 members already!

Join us at [https://www.eaap.org/individual-members/](https://www.eaap.org/individual-members/)

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