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Some Actualities and Challenges in Sustainable Beef Cattle Breeding and Husbandry

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Beef cattle farming is an environmentally friendly food-producing animal husbandry sector that is based largely on pasture and arable by-product feedstuffs. It faces several problems that need to be addressed from a sustainability point of view. Population growth and growing food demand raise concerns about the environmental consequences of expanding beef production using current systems. Consequently, this condition underscores the importance of maintaining an equilibrium between these sustainability pillars and the necessity of adopting more sustainable models. This review article analyzes the most important, recent literary sources dealing with the sustainability of the sector. As a result of the literary synthesis, it has been established that most experts emphasize the two main pillars of sustainability, namely, economic and environmental aspects. The present work directs attention to the third and possible fourth point, the social as well as the cultural aspects of the sustainability of the beef cattle sector, which will be increasingly important to keep in mind in the future.

1. Introduction

Beef is the meat from cattle, which plays an important role in human nutrition. However, beef can be a twin product or by-product of milk production. The main advantage of specialized beef cattle husbandry, which can also be called suckler beef production, to intensive dairy cattle production is its low input possibility. Since the requirement of beef cows is much lower than that of dairy cows, beef production systems can be based on marginal lands, pastures, or byproducts of arable lands.

The importance of beef will surely increase in the future since international organizations (UNDESA, IBRD, SDGs) forecast that by 2050, the world's population could reach nearly 10 billion people, a 30 % growth compared to the year 2010.

The increased demand for beef, the adverse consequences of climate change, the lower productivity compared to other animal branches, and the environmental impact of greenhouse gas emissions pose significant challenges for the beef cattle industry.

Sustainable beef production is defined as the efficient production of safe, high-quality beef in a manner that protects and improves the natural environment, social and economic conditions of farmers, their employees, and local communities, and safeguards the health and welfare of beef cattle, according to the SAI Platform Beef Working Group (ERBS, 2013).

The aim of this review is to present the latest research findings addressing the limitations and challenges of the beef industry, which can contribute to making current models more sustainable. It offers insights to boost efficiency by enhancing reproductive performance, a critical factor for beef production profitability and minimizing the environmental impact per animal.

2. Some features and facts related to beef cattle production

With the global population growth, the increased demand for food poses greater pressure on the environment than ever before. At the same time, the beef cattle sector faces desertification, urban expansion, and soil degradation, which cause an annual loss of 24 Gt of soil every year (Bai et al., 2008). Since 1960, agricultural land use has decreased by 25 % in Europe and by 4 % in North America, while in developing countries, it has significantly increased: Africa by 46 %, Asia by 36 %, and South America by 83 % (Idel et al., 2014), the livestock

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sector, particularly the beef industry, faces significant challenges. Since that time, global beef production has been consistently increasing at an average annual rate of +1.59 %, while per capita beef consumption has decreased worldwide. The significantly lower productivity and longer production cycles of the beef cattle sector result in lower emissions per reproductive live weight of cattle compared to other livestock species. Improving reproductive and production efficiency is a prerequisite for economic and environmental sustainability (Pulina et al., 2021).

Increasing beef production using current unsustainable systems would have severe environmental consequences, increase greenhouse gas emissions, and directly harm global ecosystems (Richter et al., 2020). Beef production contributes to the economy, rural development, social life, culture, and gastronomy of European countries (Smith et al., 2018). In many areas of the world, beef production is a vital economic activity where few alternatives for other production exist. The future of the beef industry is linked to the reduction of ecological impacts, mainly by adopting agroecological mitigation practices and the simultaneous improvement of production performances and of product quality (Pulina et al., 2021).

Enhancing feed efficiency and reproductive traits in beef cattle by choosing an appropriate breed and genotype can improve profitability while simultaneously reducing the environmental impact of beef production. Genomic breeding value estimation and selection has become a practical approach for beef cattle, considered as global breeds, although its application is limited to certain traits (Szabó et al., 2017) however, it might improve the adaptation to climate change. Genomic selection could help better compliance with the sustainability requirement. The latest scientific advancements in genetics, nutrition, and husbandry techniques have enabled U.S. farmers and ranchers, as an example, to produce 20 % of the world's beef by only 6 % of the global cattle population. In 2017, they achieved the production of 26.2 Gt of beef with a 53 % smaller herd than would have been required in 1975 (Mateescu, 2020a).

3. Challenges of Sustainability

The three pillars of sustainability are attributed to the Brundtland Report, Agenda 21, and the 2002 World Summit on Sustainable Development (Moldan et al., 2012), and the possibility of integrating the cultural dimension as the fourth pillar is being examined (Axelsson et al., 2013). Social, environmental, and economic sustainability are closely interrelated and can be evaluated as a unified concept. It is necessary to establish a balance between them through innovation, the application of new technologies, and informing society. Consumer buying habits are influenced by information in the media, and the positive effects of the sector are overshadowed by the negative effects. The consequences of poor information can affect the sector in the short or long term (Hocquette et al., 2018). In developed regions, brands that do not address sustainability issues may lag behind due to consumer expectations.

3.1 Social Responsibility

The social sustainability of beef cattle farming and breeding encompasses human health and well-being, animal welfare, safe working conditions for employees, consumer expectations, social capital (public goods, cultural heritage, and employment), fairness, and social interactions. Sustainability's social pillar directly impacts individuals' quality of life and well-being, compared to environmental issues (Abd Rashid et al., 2021). According to the IPCC (2019) report, there are approximately two billion overweight adults, one billion undernourished individuals, and 30 % of the population suffering from anemia worldwide. The challenge lies not only in the growing population but also in the unequal distribution of food. According to the European Public Health Alliance (EPHA, 2021) report, high consumption of red and processed meat in the EU contributes to 2.7 % of all Disability-Adjusted Life Years (DALYs) and 3.8 % of premature deaths, whereas smoking, as a risk factor, contributes to 14 % of DALYs. Beef is an excellent source of high-quality protein, vitamins, minerals, and micronutrients.

The extensive use of antibiotics, which has facilitated intensive animal farming, is associated with the development of antibiotic resistance. Future beef production, which needs less antibiotics, must adhere to strict regulations regarding the use of drugs and hormones to minimize risks to human health. The European Commission (2020) Farm to Fork Strategy aims to reduce the use of antimicrobials in agriculture by 50 % by 2030. This concept is favorable for beef cattle farming because it is more natural than other livestock industries. From 2011 to 2018, antibiotic sales decreased by 34 % in the EU and the United Kingdom. Healthy and comfortable animals have higher production efficiencies and less impact on the environment (Broocks et al., 2017).

The sector faces significant challenges such as labor migration, an aging generation of beef cattle farmers, a lack of skilled workforce, and significant wage disparities across regions. EPHA (2021) research highlights the lack of young farming generation. In the EU27, farm managers are 55 y old or older, with only 10 % of farmers

being below 40 y of age. The proportion of young farmers under 35 y old decreased from 6.9 % to 5.1 % between 2005 and 2016.

The versatility of beef cattle farming brings numerous material and non-material benefits to society. In marginal areas where other sources of income are not feasible, it contributes to rural development, helps prevent the depopulation of villages, and supports the livelihoods of rural communities. Some of the ecosystem services and public goods provided by grass-based beef systems have clear economic values, but it is challenging to assign economic value to most of them despite people's dependence on them (FAO, 2016). In the United States, the economic value of ecosystem services derived from beef cattle farming, based on a recent study contracted by the Beef Checkoff using Census of Agriculture data, is approximately $\$24.5\times10^9$ \$/y. This highlights the importance of ecosystem services (Beef Research, 2021a).

According to data from REFED (2016), in the United States, 38 % of all food goes unsold or uneaten, which is equivalent to 149 billion meals annually, valued at $444 billion. This accounts for approximately 2% of the United States GDP, and its carbon footprint is equivalent to that of the entire U.S. aviation industry. An average American family wastes $2,500 worth of food annually, and according to the USDA, beef is the least wasted food (20 %). If beef waste were halved, the overall sustainability of the industry would improve by 10 % (Beef Research, 2021d).

3.2 Economic Viability

The economic sustainability of beef production and cattle farming aims to ensure long-term economic viability and well-being for both present and future generations while minimizing negative impacts on the environment and society. Studies have shown that economic sustainability is measured by factors such as profitability, liquidity, solvency, risk management, access to capital, succession planning, rural economic development, and consumer demand (Griffith et al., 2021). However, achieving long-term economic sustainability may have short-term negative effects on profitability.

According to Pulina et al. (2021), the average estimate of meat output (carcass produced per kg of body weight maintained) for cattle (0.181 kg/kg) is one order of magnitude lower than that of pigs and chickens (1.765 and 3.188). The main constraint in the beef industry is the lower reproductive output per unit of live weight, significantly lower productivity, and longer production cycles compared to other livestock species. According to Diskin and Kenny (2016), achieving good reproductive efficiency in beef herds is determined by several factors: maintaining a calving interval of 365 days, ensuring that less than 5 % of cows are culled annually as barren, having over 95 % of cows successfully calve and wean a calf, heifers calving at 24 months of age, compact calving with 80 % of cows calving within a 42-day period, and maintaining a replacement rate of 16-18 %. To sustain genetic improvement in these traits, it is necessary to closely align the calving date with the availability of pasture in the spring. In their study, Boyer et al. (2020) analyzed the impacts of reproductive failure on the profitability of raising replacement heifers in the U.S. beef cattle system. The results of the study indicate that to recover the investment cost for a dam, six weaned calves are needed, while in the case of losing one calf, nine calves are required, and in the case of losing two calves, ten calves are needed. The economic result, evaluated in terms of expected net present value, is positive when the heifer/cow does not lose a calf or loses only one calf in their productive career. However, if two calves are lost, the economic result becomes negative. These findings suggest that when a dam loses a calf, it may not be profitable for the farmer to continue breeding from it. Beef production systems around the world vary significantly, and maximizing production per unit of land while considering the available resources allows for optimal resource utilization. The efficiency of beef production in different regions can be measured by comparing the average cost of production to a benchmark value of 1 (efficiency of beef production in New Zealand). For North America the value is 1.3; Australia 1.2; South America 0.9 and the EU-27 average 1.5 (Márton, 2020).

Genomic breeding value estimation and selection enable the improvement of reproductive traits, feed efficiency, disease resistance, adaptability to environmental changes, and reduction of environmental impacts while increasing efficiency and profitability. Successful genetic improvement programs must strike a balance between health, environmental, and animal welfare considerations and price and production efficiency (Mateescu, 2020b).

Due to the increasing demand for grass-fed beef, Herron et al. (2021) examined the reduction of environmental impacts and optimization of performance in grass-based beef systems. They emphasized the importance of minimizing slaughter age and supplementing appropriate feeding practices. Finishing cattle at a younger slaughter age has numerous environmental benefits, but the optimum slaughtering age depends on the breed and cannot be applied universally.

The heterogeneity of the EU cattle sector at the regional level is substantial, with pronounced differences between western and eastern Member States and between northern and southern regions (Ihle et al., 2017). The average income per worker differs by a factor of 4.5 between the EU15 and EU13 countries. Previously joined Member States are more affected by changes in consumer habits, which may lead to the abandonment

of grazing in unfavorable areas. In the EU13, bovine meat production decreased substantially, while the suckler cow herd more than doubled. Suckler cow farming, often based on extensive production techniques, may present a competitive strategy in the EU13 countries.

The EU beef sector heavily relies on Common Agricultural Policy (CAP) payments for its income and is not competitive, making it vulnerable to global market changes. Enhancing efficiency, reducing dependence on subsidies, and improving profitability are crucial for the sector's viability. The Irish Cattle Breeding Federation (ICBF) has utilized performance, pedigree, and genomic data from 15 million beef cattle since 2011 (the world's largest beef cattle database) to develop the €uro-Star Replacement Index, which is a key sustainability indicator based on essential traits such as maternal milk, female fertility, cost of calving, cost of feed, and carcass growth rate. Initially, the impact of the index on maternal/cost of production traits was minimal due to the industry's focus on terminal traits such as growth and conformation. However, since 2015, the program has aimed to halt the negative trends in maternal/cost of production traits and ensure a balanced improvement in all traits associated with sustainable suckler beef production (ICBF, 2020)

3.3 Environmental Awareness

Environmental sustainability in the beef industry encompasses the protection of ecosystems and natural resources. It specifically focuses on biodiversity, carbon and water footprints, soil fertility, erosion prevention, and air quality. The types of beef production systems range from grazing to mixed systems, each with its own unique characteristics. Evaluating positive and negative sustainability impacts requires considering local conditions. The extent of greenhouse gas emissions depends on the production system. While it is not possible to eliminate methane emissions from cattle, proper management practices can significantly reduce them. Between 1961 and 2019, the U.S. beef industry reduced emissions per pound of beef produced by over 40 % and increased beef production by more than 67 % (Beef Research, 2021b). Currently, emissions from U.S. beef cattle account for less than 0.5 % of global greenhouse gas emissions (Beef Research, 2021c). Cattle convert 7 % of the residues generated from the processing of plant-based food into valuable protein, while municipal solid waste landfills account for 14 % of methane emissions in the U.S. (Beef Research, 2021e). Grazing regulates the quantity, height, and distribution of grasses and forage, preventing the proliferation of shrubs and weeds (Wiedinmyer and Neff, 2007).

According to the study by Snelling et al. (2022), the most sustainable cows observed in this study are those with low live weight and high cumulative weight of weaned calves, as they have lower resource requirements and lower rumen-dissolved methane emissions. Based on the results of the research, selection, mating decisions, breed utilization, heterosis effects, bases under runs of homozygosity (ROH), and increasing lifetime production can also contribute to decreasing emissions and improving sustainability. According to the above-mentioned ICBF result, the genetic progress has accelerated, and high-genetic-value animals have shown a 10 % lower daily methane emission compared to other individuals. It is projected that by 2030, the total methane output of a cow and calf will be reduced by 3 %, down to 3.3 t/y of methane. Simultaneously, the profitability of the same cow has increased by approximately 100 €/cow/y, highlighting the close relationship between profitability and sustainability in beef breeding (ICBF, 2020).

Water is another problem of sustainability. In 2016, four billion people faced severe water scarcity, a number expected to increase with population growth (Mosase et al., 2019). Reducing water footprint is an integral part of sustainable beef production. Water use is highest in feedlot systems, partly due to the grain fed to the cattle, lower in pasture systems, and lowest in semi-intensive silvopastoral systems. The highest usage is eight times greater than the lowest one (Broom, 2019). Ridout et al. (2019) examined the contribution of different foods to the water scarcity footprint of Australian adult daily diets. The study revealed that 25 % of the water scarcity footprint was derived from non-essential, discretionary food items, such as cakes, biscuits, sugar-sweetened drinks, and alcohol, which are not necessary for a healthy diet. The consumption of red meat (beef and lamb) contributed only 3.7 % of the total dietary water scarcity footprint.

Approximately 95 % of the water used in cattle production is for irrigating crops used for feeding cattle. The water cattle use for drinking represents around 1 % of the total water used in beef production, and in total, water used by beef represents only around 5 % of U.S. water withdrawals (Broocks et al., 2021). The U.S. beef industry reduced water usage by 3 % from 2005 to 2011 (Battagliese et al., 2013). In Australia, water stress decreased by 61 % between 1980 and 2015, with an 8.3 % decline in GHG emission intensity during the same period (Wiedemann et al., 2021).

When considering the climate and environmental impacts of agricultural production, it is crucial to consider not only emissions and water problems but also the potential of forestry and sustainable agriculture as the only economic activities capable of providing natural sink functions for carbon sequestration (Idel et al., 2014). Grass-based production systems can play a significant role in carbon sequestration, reducing feed, fertilizer, and fuel costs. These practices contribute to soil fertility, carbon sequestration, and the overall sustainability of beef cattle breeding and husbandry (HCS, 2021).

4. Conclusions

Based on the literature synthesis, it can be concluded that grass-based, properly implemented beef production systems, have a multifaceted role. Besides food production, they significantly contribute to improving biodiversity, carbon sequestration, soil fertility maintenance, erosion and forest fire prevention, the livelihoods of rural communities, and the preservation of traditions and cultural heritage. The enhancement of sustainability, from both economic and environmental perspectives, can be greatly facilitated through genomic selection, appropriate grazing, supplemental feeding, and professional management systems. The primary conclusion of this work is that the application of cutting-edge research technologies, consumer awareness, and sustainability-oriented decisions by participants in the beef industry can collectively reduce the environmental footprint and enhance beef production efficiency. What sets this review apart is its focus on leveraging local conditions and opportunities while emphasizing the growing importance of social and cultural aspects in the future sustainability of beef cattle farming. The role played by the latter two aspects is an important new factor in this field.

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