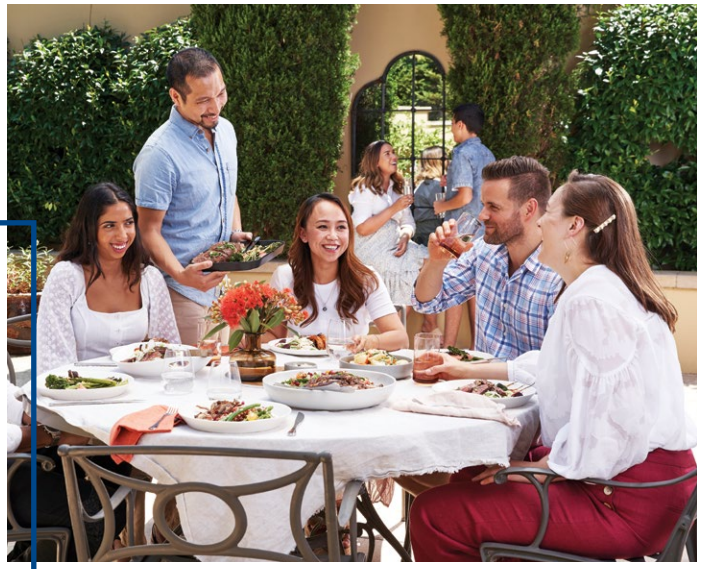
Animal Frontiers Paper 1

Executive summary



The societal role of meat – what the science says

Peer Ederer and Frédéric Leroy

Eating meat has been a feature of a nutritious meal in cultures across the globe for as long as there have been written records, and likely as far back as the earliest days of human life. Likewise, the debate about the virtues, or otherwise, of eating meat, has a long and rich history, and can be seen in the writings of the Ancient Greeks, from the vegetarianism of Pythagoras to the declaration from Aristotle that "if nature does nothing in vain" then animals were fit for consumption.

Every generation must confront this issue, but they must consider it using the best and most recent scientific evidence. This Special Issue of Animal Frontiers aims to provide that evidence, drawing together 36 authors and many more researchers to examine meat's impact and importance with respect to nutrition, health, environmental sustainability and economic affordability, as well as ethical considerations.

As part of our overall effort, we formulated **The Dublin Declaration of Scientists**[1] and invite all scientists around the world to support the Declaration by signing it digitally, and give our science a voice that is too often silenced.

To assist the reader of this Special Issue, we have provided executive summaries of the research, but we encourage taking the time to digest the following papers in full.

The role of meat in the human diet: evolutionary aspects and nutritional value

How meat contributes to the global supply of nutrients and what risks may be created by a large reduction in meat consumption.

Non-communicable disease risk associated with red and processed meat consumption – magnitude, certainty, and contextuality of risk?

An examination of evidence that purports to show a relationship between red and processed meat with non-communicable diseases and the implications for recommended intake levels of red meat.

Ecosystem management using livestock: embracing diversity and respecting ecological principles

How livestock can contribute to restoring soil carbon and improving ecosystem function showing adaptive grazing and environmental protection are not mutually exclusive.

Challenges for the balanced attribution of livestock's environmental impacts

The limitations accounting systems currently used to measure and describe livestock impact have in terms of estimations of emissions and appropriate recognition of social and environmental benefits.

Affordability of meat for global consumers and the need to sustain investment capacity for livestock farmers

Exploring whether there is a protein gap in world supply, the affordability of meat, and how to increase investment without impacting price or smallholders, particularly in low-income countries.

[1] www.dublin-declaration.org

Is meat eating morally defensible? Contemporary ethical considerations

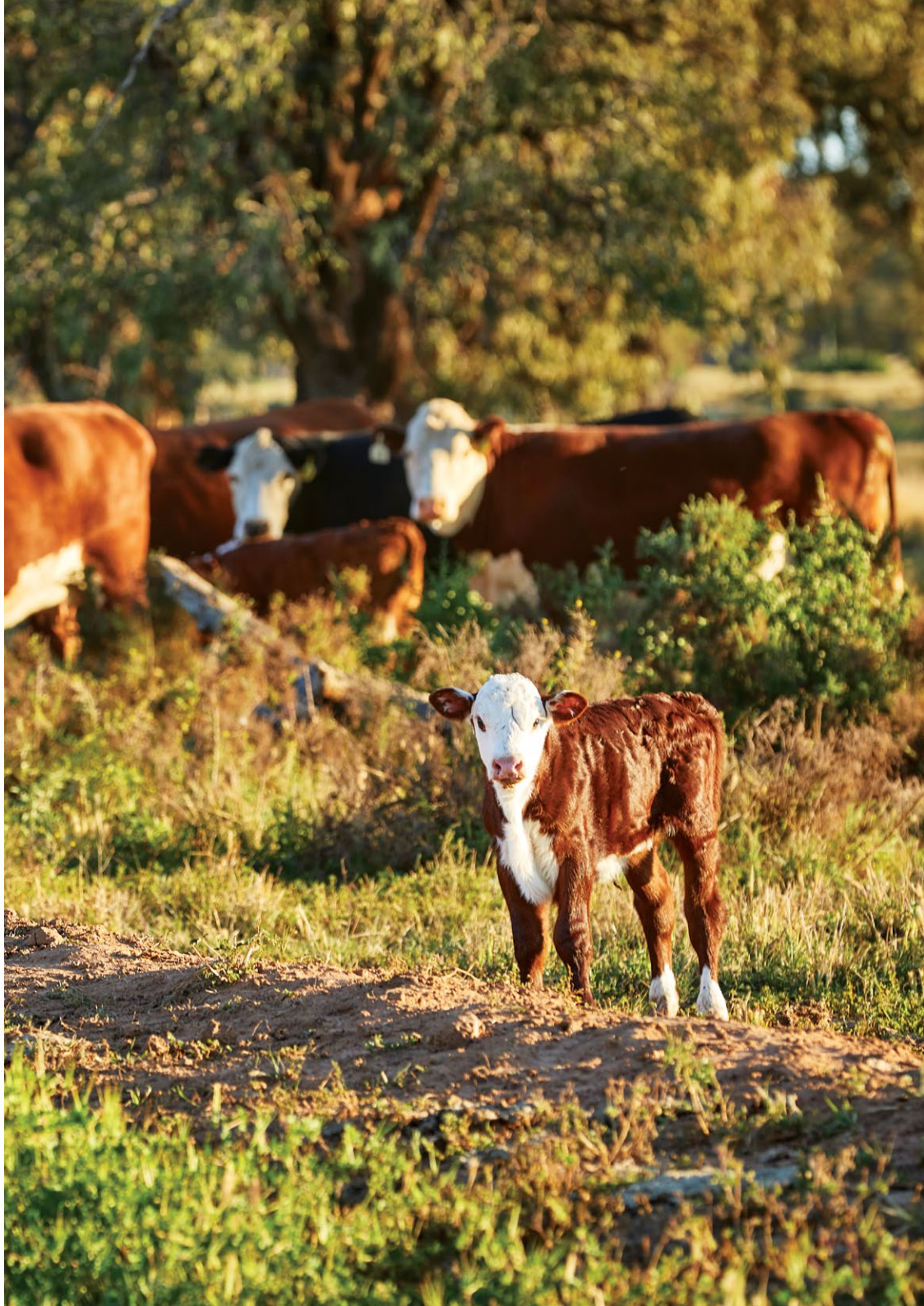
A discussion on the ethics of eating meat and the moral considerations if meat consumption is reduced.

Cellular agriculture: current gaps between facts and claims regarding cell-based meat

Billions of dollars in investment are flowing into cellular agriculture but there are significant technical, ethical, regulatory and commercial challenges before it impacts on the meat industry.

Challenges and opportunities for defining the role and value of meat in our global society and economy

The meat industry must recognise the changing political and social environmental and respond with policies that promote meat's critical importance to world nutrition, culture and the economy and foster the next generation of consumers, researchers, and industry leaders.



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Paper 2

Executive summary

The role of meat in the human diet: evolutionary aspects and nutritional value

Frédéric Leroy, Nick Smith, Abegbola T. Adesogan, Ty Beal, Lora Iannotti, Paul J. Moughan, and Neil Mann

Historically and from an evolutionary perspective, meat has been cherished by humans as a nutritious and highly symbolic food. However, arguments for a widespread reduction in meat consumption are today advocated by a variety of groups, most typically from high-income countries. Understanding the nutritional aspects of meat consumption is imperative to individuals and those influencing the diets of populations making informed and balanced decisions on food intake.

Throughout time, human anatomy, digestion and metabolism have evolved to be compatible with, and indeed rely on, substantial meat intake. Of particular note is the nutritional benefit of meat for children aged six to 23 months (a finding supported by the World Health Organization) who have intensified nutritional requirements for growth and brain development. Lack of meat and dietary diversity in children's diets may contribute to nutritional deficiencies, infection and metabolic issues.

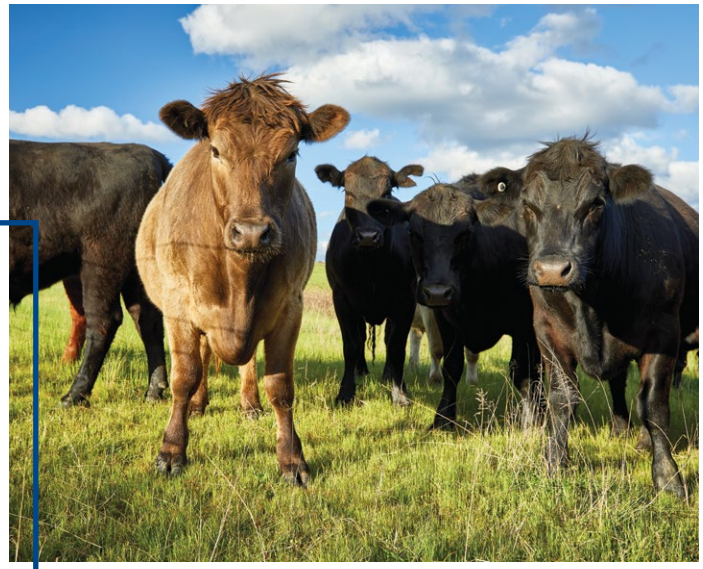
Meat also plays an important role in the diets of pregnant and lactating women, women of reproductive age, older adults and individuals in low- and middle-income countries. Not all proteins are of equal nutritional value and meat supplies high-quality protein, and a range of nutrients, that are not easily obtained through meat-free diets.

Although meat makes up a small minority of global food mass and energy, it delivers most of the global vitamin B12 intake and plays a key role in the supply of other B vitamins, retinol, long-chain omega fatty acids, several minerals in bioavailable forms (e.g. iron and zinc) and a variety of compounds with health-improving potential such as taurine, creatine and carnosine. In lower-income countries which rely on cereal staples, meat can make a powerful contribution to nutritional status, serving as a keystone food in food-based dietary interventions.

Additionally, efforts to lower global meat intake for environmental and other reasons may hinder progress towards reducing undernutrition and stifle economic development. This is of particular concern for populations with increased needs and in regions where current meat intake levels are low.

The dietary role of meat goes far beyond the provision of food mass, energy, or even protein, to numerous essential nutrients and beneficial bioactive compounds, all of which are held together in a complex food matrix.

Meat is a nutrient-dense food, well suited to meeting human nutritional requirements and, with a demonstrated role in human evolution, it continues to have a role in human health and development today. Removal or large reductions of meat from the diet, as well as prevention of increases in meat intake where consumption is low, carries a risk which must be appreciated when considering its value in food systems.



Animal Frontiers Paper 3

Executive summary

Meat and non-communicable diseases

Bradley Johnston, Stefaan De Smet, Frédéric Leroy, Andrew Mente, and Alice Stanton

Red meat and processed meats have long been part of human diets as a source of high-quality protein and bioavailable macronutrients, yet they have become increasingly discouraged by a vocal group of scientists and organisations.

The frequently repeated association between red meat consumption and an increased risk of obesity, heart attack, stroke, diabetes, and particular cancers has led to recommended maximum intake levels.

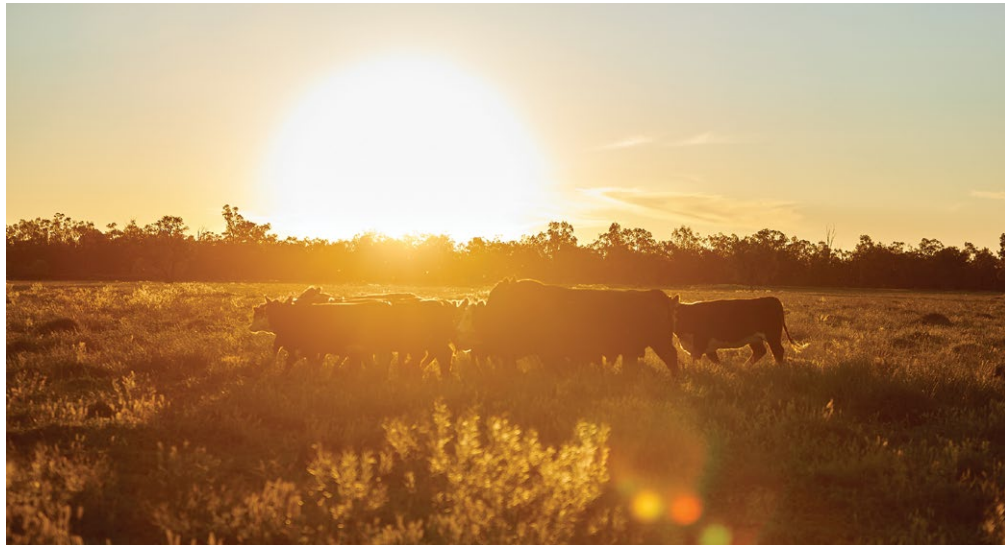
However, while there may be an association with these non-communicable diseases the evidence shows we cannot be sure it is one of cause and effect. There is an absence of rigorous long-term randomised trials of red and processed meat intake and clinical health outcomes. Many of the studies are based on self-reported questionnaires about what is eaten with outside factors not sufficiently ruled out.

The evidence shows when meat consumption is part of a healthy dietary pattern, harmful associations tend to disappear, suggesting the risk is more likely related to the entire diet and lifestyle factors than the meat itself.

Creating upper limits for healthy intake is further complicated by individual differences in age, genetics, sex, health status, and socio-economic background. For example, some people may need more iron where others may be prone to iron accumulation. Care must be taken not ignore the health benefits of meat consumption and the risks of recommending reduced intake such as iron-deficiency anaemia, sarcopenia and child and maternal malnutrition. The evidence does not suggest that red meat consumption is harmful below 75 grams per day and beyond this level the certainty of evidence remains somewhere between low and very low.

Put simply, the reduction of meat intake below current levels of consumption is not sufficiently supported to warrant a change to public policy for health reasons.

Dietary recommendations should focus on healthy meal patterns tailored to individual needs, while noting that red meat is an excellent source of bioavailable nutrients not readily available from other foods.



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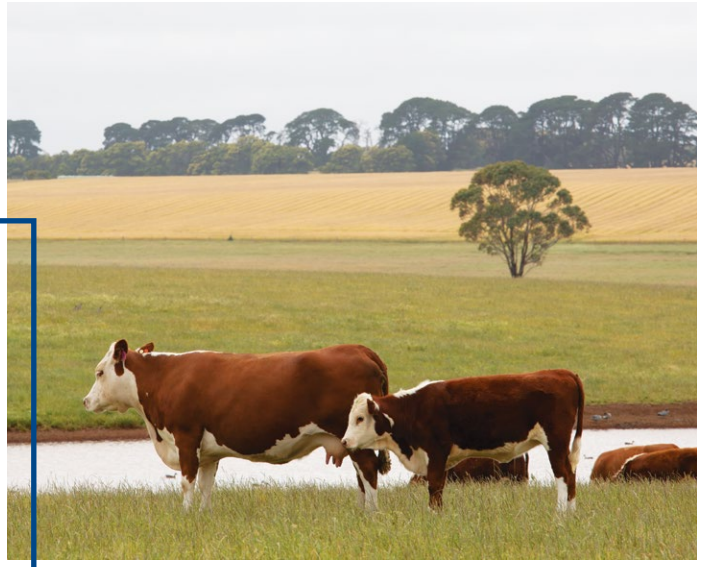

Ecosystem management using livestock: embracing diversity and respecting ecological principles

Logan Thompson, Jason Rowntree, Wilhelm Windisch, Sinéad M. Waters, Laurence Shalloo, and Pablo Manzano

Agricultural land is a scarce resource globally and will continue to encounter challenges to sustainably increase food production in response to global changes such as population growth, environmental impacts and climate change. At the same time, the role of livestock in the world's terrestrial ecosystem has been negatively impacted by the dominant view of "Nature" as landscapes that are not influenced by human activity.

However, even if livestock production has contributed to these problems, as have other forms of human activity, it is well-place to contribute to the solution, provided it operates within an agroecological framework and environmental boundaries.

Herbivores are a natural part of the world's ecosystem and have played a key role in the last several million years efficiently grazing vast areas that cannot be cropped. As the numbers of wild herbivores have greatly decreased, largely due to human action, the maintenance of such roles depends on the practice of adequate livestock management.

Key ecological benefits of livestock production include the conversion of massive quantities of non-edible biomass into human food, recycling plant nutrients back into the land, sequestration of carbon, improvement of soil health and a variety of other ecosystem services.

Livestock also provide broad and underutilised diversity both in species and breed, as well as production methods and management strategies that can optimise environmental impact, biodiversity and food supply.

Today, much of the discussion on the impact of livestock on the environment commonly focuses on methane, leading to a narrow approach to improving the ecological consequences of food production. However, the positive impact of livestock on other ecosystem services, and as tools to manage and improve the land we rely on to produce food, can often be overlooked or minimised.

One of the most critical of these services is livestock's impact on soil health and carbon sequestration, particularly in soils that have a legacy of mismanagement. A recent review of literature found soil carbon sequestration as having the largest potential to reduce beef emissions globally, both per unit of product and per unit of land.

Adaptive grazing management is an outcome-based approach that can improve soil health and increase carbon sequestration. Centred around high-intensity grazing for short periods, it leaves adequate plant cover for plant recovery, increases plant diversity and minimises the need for synthetic inputs.

Protection of ecological resources and commercial livestock production are not contradictory practices. On the contrary, the one necessitates the other. Except for the very few remaining untouched wilderness areas of the world, ecological management towards environmental protection requires active human management.

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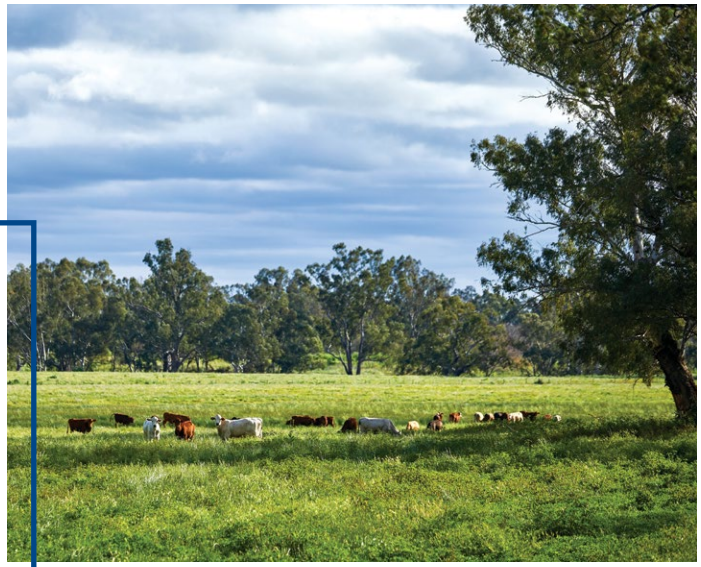

Challenges for the balanced attribution of livestock's environmental impact

Pablo Manzano, Jason Rowntree, Logan Thompson, Agustin del Prado, Peer Ederer, Wilhelm Windisch, and Michael R.F. Lee

Meat production is often listed among the largest contributors to climate change, largely based on methane emissions and land use. However, environmental assessments have frequently oversimplified the impact, overlooked net rather than gross emissions and not factored in the benefits of well-managed land.

It is typically claimed that methane (CH_4) is 28 times more potent than carbon dioxide (CO_2) in terms of its global warming potential over a 100-year period, a figure attributed to an Intergovernmental Panel on Climate Change Assessment Report from 2013. In the decade since it has been revised slightly down, with different time periods offered ranging from 20 years to 500 years, suggesting an accuracy of understanding which in reality is not available.

There are complexities relating to the relative speed at which CH_4 decomposes in the atmosphere under the influence of hydroxyl radicals, nicknamed the detergent of the atmosphere because of the way it cleans the air of otherwise-damaging build-ups. This highly complex chemical system is currently insufficiently understood.

Arguably a more apt metric is GWP*, which treats methane more accurately as a flow gas rather than a gas that stockpiles, such as CO_2. When using GWP*, researchers have found that reducing global livestock emissions by 7% from 2020 to 2040 (0.35% annually) would stop further agricultural CH_4-related increases in global temperatures — effectively net zero for methane.

It is important to note that this metric is not "livestock friendly". If CH_4 emissions were to rise by 1.5% annually, the GWP* method resulted in 40% greater climate impact than if CH_4 emissions had been converted to CO_2 using the GWP_{100} metric.

Those who argue for a decrease in the global livestock herd must also consider the impact of alternative land uses. For example, after the Chernobyl disaster, wild herbivores reoccupied grazing lands, emitting CH_4. Removing large herbivores may also result in greater termite numbers and more frequent and intense bushfires, both of which can release large amounts of CH_4 and CO_2.

In addition, metrics need to account for the benefits of meat production and well-managed land including:

- the high proportion (54% in Australia) of agriculture land unsuitable for cropping
- the high bioavailability and digestibility of meat compared to many plant-based foods
- the extensive conversion of food industry and crop by-products and inedible biomass upcycled by livestock to high quality human food
- livestock's role in raising capital, social status and educational funding, particularly in developing countries
- systems that increase biodiversity, soil carbon and water-holding capacity.

A single metric will not do justice to the complexity of various livestock production system impacts and radical actions based on unbalanced metrics can greatly impact livestock operations that make a valuable contribution to rural livelihoods across the world.

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Executive summary

Affordability of meat for global consumers and the need to sustain investment capacity for livestock farmers

Peer Ederer, Isabelle Baltenweck, James N. Blignaut, Celso Moretti, and Shirley Tarawali

With meat a nearly indispensable part of global food supply and, according to the World Farmers Organisation, livestock the most common type of private capital ownership in the world, the economics of meat production are pivotal to world nutrition and wealth.

Four questions can be used to dissect the economics of meat:

- Is there enough meat to meet protein requirements?
- What does it cost consumers to buy meat and is it affordable?
- How can investment in livestock production be increased without reducing affordability?
- What is the future of smallholder livestock farming particularly in low and middle-income countries?

The answer to the first question is contested and emotionally charged with proponents of increasing or decreasing meat production both claiming science to be on their side. It comes down to the assumptions being relied upon, such as the current level of supply and waste, and the level of recognition of meat's higher bioavailability and nutrient density, along with realistic land use. Outcomes have ranged from there being no protein deficiency at all to requiring an increase in supply of 78% to meet global nutritional needs.

Affordability is a key concern. In 2017, a minimum nutritionally adequate food basket was financially out of reach for three billion people, or 37% of the world population, mostly driven by the high cost of protein and other nutrient-rich foods.

Significant investments in livestock production systems are required, especially in lower-income countries where investment conditions are poor due to high levels of debt, weak and fragmented institutions, poorly developed markets, and labour shortages. But the difficulties are not insurmountable. In Ethiopia, the privately owned company Ethiochicken tripled per person egg supply in the five-year period from 2015 to 2020 and enabled the formation of more than 8,000 small enterprises, strengthening the livelihoods of at least four million smale-scale farmers. On the Shangani ranch in Zimbabwe, 16,000 head of cattle co-exist with elephants, zebras, giraffes, antelope and leopards, grazing the grasses while the wildlife keeps bush growth under control. Measurements have shown carbon sequestration of the rotationally grazed cattle fully compensates for their methane emissions.

These investments, and others, show greater productivity does not necessarily come at the expense of the environment and can support smallholders while supplying vulnerable consumers in low-income countries with cost-effective, locally produced and affordable sources of protein and nutrients.

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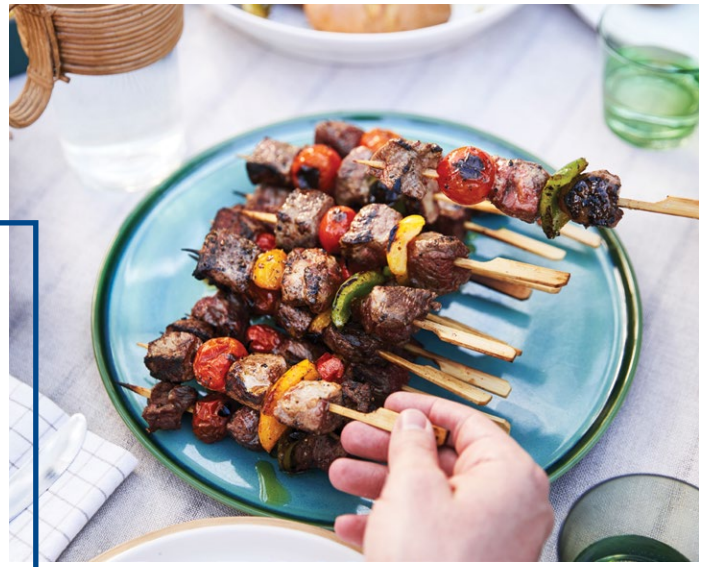

Is meat eating morally defensible? Contemporary ethical considerations

Candace Croney and Janice Swanson

As prosperity grows in the developing world, demand for animal protein is increasing, but in more developed nations, where food security and access are relatively assured, the ethical justification for meat consumption is questioned.

Some members of the public in these food-secure countries have shifted to “ethical consumerism”, avoiding food that does not align with their values, which commonly involve concerns about:

- The rearing and killing of animals for food;
- Animal quality of life in large-scale, intensive systems of production; and
- The related impacts on the environment and human health.

Several companies have taken note, resulting in significant investment in plant-based alternatives to meat such as Beyond Meat™ and Impossible Foods™, however poor performance and in some cases removal from menus hints at issues of consumer acceptance. Nevertheless, the idea that vegetarianism is virtuous and morally responsible is being socially normed and it appears few people in published literature have attempted to make compelling ethical arguments for eating meat.

However, the nutritional value of meat is often mentioned, as the current generation of plant-based alternatives lack equal nutrient value, such as B12, zinc and protein. The growing movement towards regenerative and sustainable agriculture is also addressing environmental concerns around soil health, water use and greenhouse gas emissions.

Proponents of regenerative agriculture also point out there is a global limit to land suitable for crops, and many areas currently used for grazing would not support intensive cropping. There is also the least harm principle. A diet that includes some grazing animals may cause fewer animals to die than a vegan diet due to the number of field animals killed in the production of crops. Few philosophical arguments have engaged either arguments or provided viable solutions.

The obligation to meet the needs of a growing global population for food suggests it may be ethically problematic to reduce rather than increase the number of options available to people who critically need high-quality protein for survival. The debate about whether the act of meat consumption is ethically defensible, though, remains.

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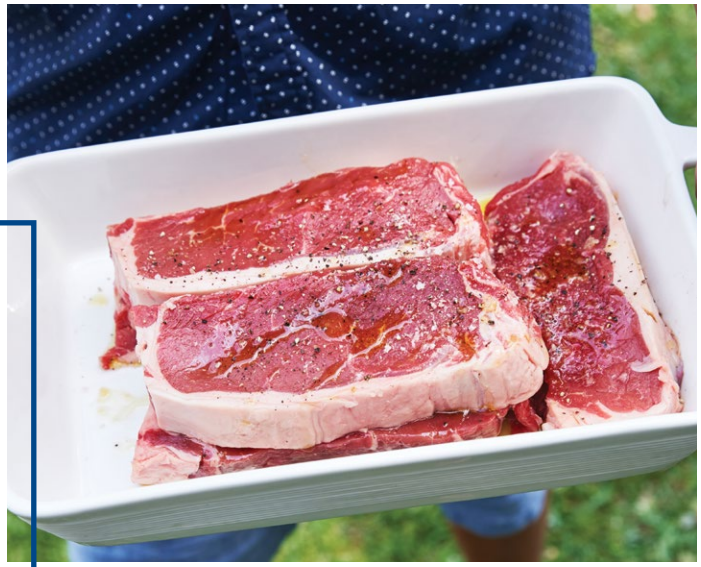

Cellular agriculture: current gaps between facts and claims regarding cell-based meat

Paul Wood, Lieven Thorrez, Jean-Francois Hocquette, Declan Troy, and Mohammed Gagaoua

Despite the billions of dollars being invested in “cellular agriculture”, including cell-based meat and precision fermentation, there are significant technical, ethical, regulatory, and commercial challenges to making these products widely available in the market.

Precision fermentation is the process of engineering the gene sequence for a specific protein into a bacterium or yeast strain and then growing that strain in large-scale fermenters to produce the required protein. It has been used for decades in cheese making and is being focused on in the pursuit of dairy substitutes, and also advocated for meat substitutes. Impossible Foods uses it to give plant-based burgers the look and smell of red meat when cooked with others such as Steakholder Foods developing 3D printing of alternative “steaks”.

The major technical challenge is the cost of precision fermentation, as it is energy intensive and requires complex engineering. The regulatory process is relatively straightforward in the United States, but precision fermentation products will be difficult to register in Europe under current legislation due to the use of genetically modified organisms. Consumers may also be wary of genetically modified products. These combinations of factors make it unlikely that precision fermentation will disrupt the livestock industry but may provide high-value products for niche markets.

The process of creating cell-based meat (CBM) has significant hurdles to overcome.

Muscle used in meat is made of several cell types, the most abundant being myofibers, but includes connective tissue cells (fibroblasts), fat cells (adipocytes), endothelial cells, and blood cells. The current focus is on expanding myoblasts, the precursor cells to myofibers. However, these cells not only deteriorate with age, but they grow far more slowly than the bacteria and yeast cells used in precision fermentation. Yeast can expand well over a thousand times in a day whereas this takes over 10 days for animal cells. There is additional complexity when including other cell types in this process.

Prolonged stimulation is then required to attain the characteristics of skeletal muscle, a process not currently accounted for and will significantly increase production time, making current claims related to CBM’s sustainability seem unsubstantiated or, at best, speculative.

The perception of unnaturalness and the low or poor cultural acceptance by consumers, mainly because of lack of familiarity and uncertainties about the aesthetics are other barriers to social acceptance. Sensory properties such as texture, colour and flavour can perhaps be adjusted with food engineering techniques but may change during cooking or interaction with other ingredients. Nutritional quality currently cannot be verified and if nutrients are added to the CBM products the impact on bioavailability is unknown.

The greatest challenge for CBM products, however, is cost, primarily driven by the cost of culture media and the capital cost of sophisticated manufacturing facilities that can produce at scale. With most of the global population growth in developing countries, a major barrier in the development and uptake of novel foods from “cellular agriculture” will be price and distribution logistics.

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Paper 9

Executive summary

Challenges and opportunities for defining the role and value of meat in our global society and economy

Rod Polkinghorne, Mohammad Koohmaraie, Collette Kaster, Declan Troy, and Andrea Rosati

With meat's role in society being robustly challenged there is a significant need to develop future leaders and scientists across the meat industry, which has seen resources for meat and animal sciences substantially decline.

The traditional model of meat science delivered through large government-funded institutions has almost passed requiring historic "silos" of individual disciplines to evolve to highly collaborative and integrated arrangements where various sciences embrace their common base.

A return to more open science and shared resources is needed, paired with timely access and early commercial application of scientific advances to improve productivity, human diet and environmental outcomes.

Two major changes are recommended:

- Greater involvement of large and small commercial meat business enterprises (beneficiaries of much of the research outcomes) in investing/funding; and
- To maintain and increase industry's involvement, scientists need to deliver timely solutions.

Lack of, or a reduction in, sustainable funding has contributed to a reduction in the number of young scientists choosing meat science as a career, and competition for limited and shrinking funds has resulted in reduced collaborative problem-solving projects and more salary competition between business and research-related roles.

The industry needs to engage with people at a young age to encourage curiosity, interest, and positive views of meat as a food and livestock and meat industries that produce it.

A report presenting the findings of an extensive global survey of meat scientists and industry management revealed that societal concerns relating to meat production and consumption were rated highly as a major challenge, requiring at least equal attention as the core muscle and biology science base.

Anti-meat rhetoric has extended to environmental debates with ruminant livestock challenged on gross greenhouse gas emissions, mostly without reference to net emissions and the potential for offsets due to the short-term methane cycle and recycling of carbon through grazed pastures. Seemingly ignored is the potential to valorise marginal lands for livestock that are otherwise unsuitable for food production, and the unique ability of livestock (especially ruminants) to produce nutrient-dense food from non-human edible by-products and plant material.

The reality is the world will need to feed an estimated two billion more people by 2050, mostly in Africa and Southeast Asia. Animal products ought to be viewed as an essential resource to prevent malnutrition and starvation in regions where food security is already a critical concern. Furthermore, a substitution of natural animal foods for non-animal based, ultra-processed, high-calorie, high carbohydrate and low-nutritional value products associated with adverse health outcomes in the global north would deliver significant benefits.