

Feeding the Future: Plant-Based Meat for Global Food Security and Environmental Sustainability

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ABSTRACT

Humanity is facing one of its greatest challenges as it contends with sustaining its global agricultural systems and environment and feeding more than 9 billion people by 2050. The world's growing population and its increasing demand for meat will continue to compete for limited land, water, and energy resources, such that conventional meat, alone, will not be able to fulfill the commensurately growing protein demands: The future population cannot be adequately fed. Plant-based meat, though, is a more sustainable food product, and it could feed a considerably larger population. Unlike its conventional meat counterpart, the per-unit production of plant-based meat requires substantially less agricultural land and water, emits less greenhouse gas, and produces less aquatic nutrient pollution. Some technological, sensory, and nutritional issues need to be addressed, both to stimulate the shift of consumers toward plant-based meat diets and to accelerate the growth of the plant-based meat market.

The United Nations has identified that humanity faces grand global challenges in ensuring food security and sustaining the environment. It has estimated that approximately 800 million people are still chronically undernourished. The prospects for feeding those 800 million people and the future population (which is projected to grow from 7.6 billion to 9.7 billion by 2050) seem grim. The total demand for food will outpace the global population in the coming decades, and the world will need to produce 40–90% more of various food staples by 2050 (Fig. 1) (8). However, viable agricultural land, freshwater, and fossil energy resources have already been diminished and deteriorated due to climate change, desertification, and other ecological issues. In fact, land availability, one of the main constraints on mass food and feed crop production, will only decrease further as more and more of it is apportioned to enabling the world's meat-centered diets and self-depreciating industry.

Conventional Meat Production Is Less Sustainable and Cannot Meet Increasing Population Demands

Animal production inefficiently “transforms” plant protein into animal protein, as livestock animals consume much more protein than they produce. It is estimated that plant-based replacements for the major animal meat categories (i.e., beef, pork, dairy, poultry, and eggs) in the United States can produce 2- to 20-fold more nutritionally similar foods per unit of cropland (13). On average, livestock animals require up to 10 lb of plant protein to produce 1 lb of animal protein (1). Meat production also requires enormous environmental resources such as land, water, and energy to grow, harvest, and transport feed

for farm animals, to house and raise animals and dispose of their waste, and eventually to transport the animals to slaughter and process their bodies into edible meats. Additionally, the meat industry and its livestock cultivation are a major source of greenhouse gas emissions around the world.

At present, livestock cultivation accounts for approximately two-thirds of agricultural land usage, and nearly 70% of grain produced in the United States is fed to farm animals rather than for consumption by people (14). Based on current Western diet patterns, taking into account growing populations, rising incomes, consumption growth, and increasing meat-based dietary adaptations (especially in developing countries), the demand for meat products is expected to grow more than 65% by 2050 (8).

Humanity needs a solution for those critical issues. More creative and sustainable ways of utilizing the available resources need to be developed to avoid future global food scarcity. Some strategies to help address the challenge of feeding the growing population include closing the yield gap, increasing production limits, reducing food waste, increasing multipurpose systems, expanding aquaculture, and shifting diets (5,15). For the purpose of this article, however, a more direct solution is presented.

Plant-Based Meat Is More Sustainable and Can Complement Animal Meat to Feed the Future Population

Because of growing populations, increasing demand for meat, and limited resources, conventional meat alone cannot sufficiently meet the corresponding protein demands, and it cannot adequately feed the future population (3). Some consumers, however, may already be pushing toward a solution: the demand for plant-based meat alternatives has been growing dramatically as consumers have become increasingly aware of and concerned about health and wellness, environmental sustainability, food safety, and animal welfare (Fig. 2) (11). Plant-based meat avoids both livestock cultivation and tremendous protein losses. Thus, eating minimally processed plant foods is fundamentally more

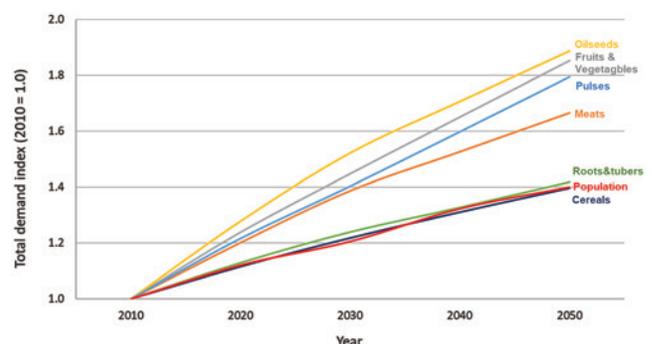


Fig. 1. Growing demand for agricultural products. (Reproduced, with permission [Open access under CC-BY-4.0 license], from International Food Policy Research Institute [8].)

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efficient than growing plants to feed animals and then eating those animals (12).

Several “cradle-to-distribution” life-cycle assessments have been conducted to compare the environmental impacts of plant-based meat products with respective conventional meat counterparts (2,6,9). To produce the same unit of meat products, plant-based meat requires substantially fewer land, water, and energy resources when compared with conventional meat production systems. Depending on the specific type of alternative products, plant-based meat uses 47–99% less land and 72–99% less water, emits 30–90% less greenhouse gas, and causes 51–91% less aquatic nutrient pollution than conventional meat (Table I) (17). In addition, producing plant-based meat does not require the use of antibiotics, which have been administered in animal agriculture to speed growth and prevent disease.

Unlike its conventional meat counterparts, plant-based meat is produced directly from plant proteins through a series of industrial unit operations, such as extrusion texturization, reformulation and mixing, formation, cooking, etc., to develop meaty texture and sensory properties. Extrusion texturization is a major, viable technology used to convert globular or irregular plant proteins into fibrous, meat-like structures. Different protein sources, especially soy, wheat, and pea proteins and their blends, have been and can be processed to develop texturized products. During extrusion texturization, a moisturized protein matrix undergoes a series of physical, chemical, and structural changes that greatly influences the texture quality of the extruded prod-

uct (7). Plant proteins can be unfolded, cross-linked, and aligned to form microscopic and macroscopic fibers. Alterations of both covalent bonds, such as peptide bonds and disulfide bonds, as well as noncovalent interactions, such as hydrogen bonding, hydrophobic interaction, and ionic linkage, and the generation of other new linkages, such as through physical and chemical cross-linking, are expected (10).

Challenges of Expanding Plant-Based Meat Consumption

Although plant-based meat products are attracting ever more interest from consumers worldwide, the small, natal market only comprises US\$939 million and accounted for barely 1% of overall meat sales in the United States in 2019 (16). The American market is a formidable, yet tantalizing obstacle, since about 69% of dietary proteins consumed by Americans come from animal sources compared to the global average animal protein consumption rate of only 26% (1). Although some consumers are organically becoming more attracted to plant-based meat products, accelerated market growth depends on addressing several challenges to encourage more consumers to shift to a plant-based meat diet:

- 1) Sensory quality, especially taste, texture, and other sensory traits of new meat products, needs to be significantly improved to meet the expectations of consumers who are accustomed to conventional meat products.
- 2) Although conventional meats, such as some red meat products, have been criticized for their high saturated fat and cholesterol contents, conventional meats are still important sources of complete amino acids, minerals (iron, zinc), and B vitamins.
- 3) Consumers have become increasingly concerned about the allergenicity of wheat and soy products, as well as GMO soy, which, along with pea proteins and their blends, have been the major protein ingredients utilized in currently available plant-based meats.

Thus, it is important to formulate new plant-based meat products with comparable and even more desirable sensory and nutritional qualities and nutrient contents to meet dietary requirements—a process that will require redoubling research efforts into both the contents of plant-based meat and creation methodologies. Innovative protein sources with more desirable functional properties must be explored to satisfy future needs. Current plant protein sourcing and restructuring processes for the development of plant-based meat have largely been driven by trial and error approaches and empirical experience. As a

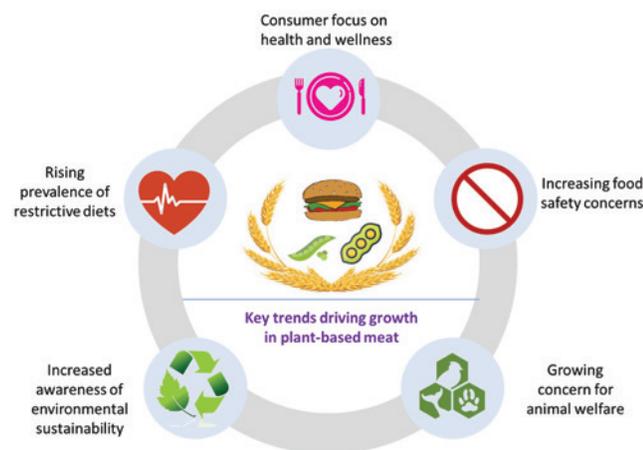


Fig. 2. Key trends driving growth in plant-based meat. (Reproduced, with permission, from L.E.K. Consulting LLC [© 2020 L.E.K. Consulting LLC] [11].)

Table I. Life cycle assessment results of plant-based meat products^{a,b}

Plant-Based Meat	Conventional Meat Counterpart	Environmental Impact Reduced by Consuming Plant-Based Meat (%)			
		Land Use (m ² year/kg)	Greenhouse Gas Emission (kg CO ₂ eq/kg)	Water Use (L/kg)	Aquatic Eutrophication Potential (g PO ₄ ³⁻ eq/kg)
Impossible Burger 2.0	Beef burger*	96	89	87	91
Beyond Burger	Beef burger**	–	89	99	–
Grillers Original Burger	Beef burger*	93	85	95	77
Spicy Black Bean Burger	Beef burger*	97	89	96	76
Roasted Garlic & Quinoa Burger	Beef burger*	93	88	98	73
Grillers Crumbles	Ground beef**	99	90	96	–
Original Sausage Patties	Pork sausage patties*	47	30	81	51
Original Chicken Patties	Breaded chicken patties*	84	36	72	75

^a Reproduced, with permission, from The Good Food Institute (17).

^b * indicates sold frozen; ** indicates sold fresh.

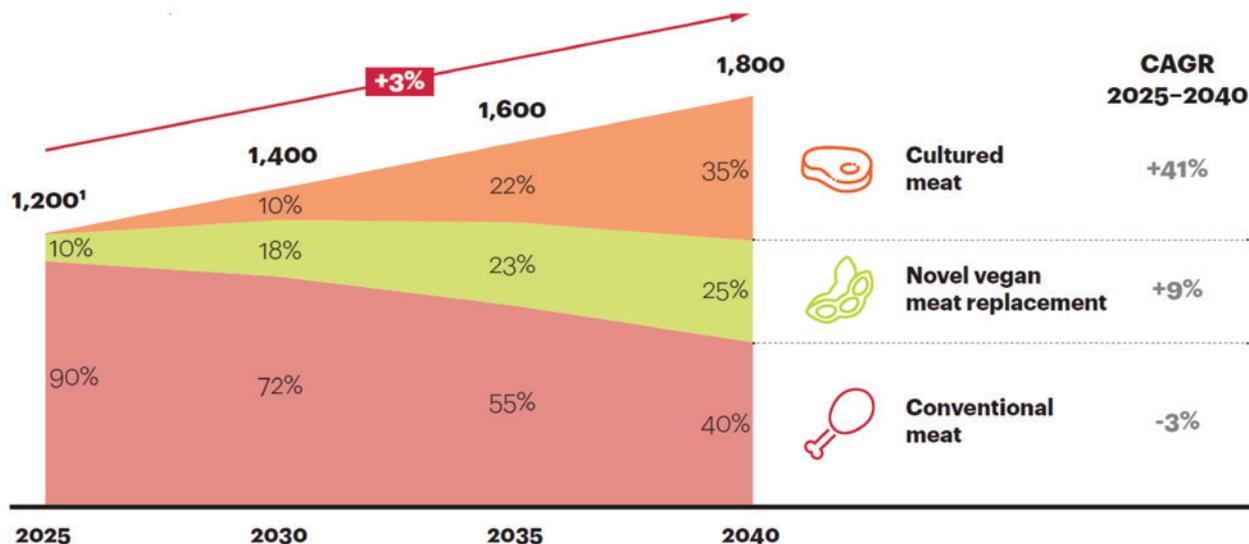


Fig. 3. Global meat market forecast (in billion U.S. dollars). (Reproduced, with permission, from ATKearney [4].)

result, the critical contributions of protein functional characteristics and related molecular changes during the aforementioned restructuring processes remain poorly understood. Further fundamental and applied research studies are warranted to provide more accurate guidance in rationally sourcing and tailoring plant proteins for more desirable functionality and performance in plant-based meat and accelerating the development of quality, innovative meat products.

Conclusions

Despite the challenges, plant-based meat is gaining in popularity among consumers, and the market will continue to grow. These products will complement conventional meat products to help mitigate the challenges of global food security and environmental sustainability. A recent report estimated that plant-based meat and cultured meat together will account for 60% of the total meat market by 2040 (Fig. 3) (4). Currently, though, the plant-based meat industry is being challenged by the conventional meat industry for legal and regulatory classification, which needs to be resolved for the industry to progress. Given the limited land, water, and energy resources available for agricultural production, plant-based meat and other alternative meats are a more sustainable solution to feeding the growing population. However, we urgently need to develop more innovative technologies and formulations to enhance the sensory traits, appearance, and nutritional profiles of plant-based meat and accelerate the shift of consumers toward plant-based diets.

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References

- Bomgardner, M. M. Calling on plants to fulfill protein's promise. *Chem. Eng. News* 93(6):8, 2015.
- Dettling, J., Tu, Q., Faist, M., DelDuce, A., and Mandlebaum, S. A comparative life cycle assessment of plant-based foods and meat foods. Published online at www.morningstarfarms.com/content/dam/morningstarfarms/pdf/MSFPlantBasedLCAR-report_2016-04-10_Final.pdf. 2016.
- Gaydhane, M. K., Mahanta, U., Sharma, C. S., Khandelwal, M., and Ramakrishna, S. Cultured meat: State of the art and future. *Biomannuf. Rev.* 3(1):1, 2018.
- Gerhardt, C., Suhlmann, G., Ziemßen, F., Donnan, D., Warschun, M., and Kuhnle, H.-J. How will cultured meat and meat alternatives disrupt the agricultural and food industry? Published online at www. Kearney.com/documents/20152/2795757/How+Will+Cultured+Meat+and+Meat+Alternatives+Disrupt+the+Agricultural+and+Food+Industry.pdf/06ec385b-63a1-71d2-c081-51c07ab88ad1?t=1559860712714. 2019.
- Godfray, H. C. J., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. E., Pretty, J., Robinson, S., Thomas, S. M., and Toulmin, C. Food security: The challenge of feeding 9 billion people. *Science* 327:812, 2010.
- Heller, M. C., and Keoleian, G. A. Beyond Meat's Beyond Burger life cycle assessment: A detailed comparison between a plant-based and an animal-based protein source. Published online at <http://css.umich.edu/publication/beyond-meats-beyond-burger-life-cycle-assessment-detailed-comparison-between-plant-based>. 2018.
- Ilo, S., and Berghofer, E. Kinetics of lysine and other amino acids loss during extrusion cooking of maize grits. *J. Food Sci.* 68:496, 2003.
- International Food Policy Research Institute. 2017 Global Food Policy Report. DOI: <https://doi.org/10.2499/978080896292529>. International Food Policy Research Institute, Washington, DC, 2017.
- Khan, S., Dettling, J., Loyola, C., Hester, J., and Moses, R. Comparative environmental LCA of the Impossible Burger with conventional ground beef burger. Published online at <https://impossiblefoods.com/mission/lca-update-2019>. 2019.
- Liu, K., and Hsieh, F.-H. Protein-protein interactions during high-moisture extrusion for fibrous meat analogues and comparison of protein solubility methods using different solvent systems. *J. Agric. Food Chem.* 56:2681, 2008.
- Picciola, M., Steingoltz, M., and Craigwell-Graham, J. Plant-based products—Not just for vegans anymore. Published online at www.lek.com/sites/default/files/insights/pdf-attachments/2020-Plant-Based-Products-EI_V3.pdf. L.E.K. Consulting LLC. 2020.
- Poore, J., and Nemecek, T. Reducing food's environmental impacts through producers and consumers. *Science* 360:987, 2018.
- Shepon, A., Eshel, G., Noor, E., and Milo, R. The opportunity cost of animal based diets exceeds all food losses. *Proc. Natl. Acad. Sci. U.S.A.* 115:3804, 2018.
- Shiva, V. *Stolen Harvest: The Hijacking of the Global Food Supply*. South End Press, Cambridge, MA, 2000.

15. Smith, P., Haberl, H., Popp, A., Erb, K.-H., Lauk, C., et al. How much land-based greenhouse gas mitigation can be achieved without compromising food security and environmental goals? *Global Change Biol.* 19:2285, 2013.
16. The Good Food Institute. Plant-based market overview. Published online at www.gfi.org/marketresearch. GFI, 2019.
17. The Good Food Institute. Plant-based meat for a growing world. Published online at www.gfi.org/files/pb-meat-sustainability.pdf. GFI, 2019.



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