CHOICES

A publication of the Agricultural & Applied Economics Association

AAEA Agricultural & Applied Economics Association

1st Quarter 2019 • 34(1)

How Might Cellular Agriculture Impact the Livestock, Dairy, and Poultry Industries?

Monica Saavoss

JEL Classifications: Q1, Q5, O3
Keywords: Cellular agriculture, Cultured meat, In vitro meat, Meat industry

Cellular agriculture refers to the use of animal cell culture technology to grow animal tissue directly from animal cells, rather than from a live animal, or to the use of yeast, bacteria, or fungi to synthesize proteins in animal products such as eggs, gelatin, or milk. As companies come closer to bringing cellular agriculture to market, researchers, policy makers, and stakeholders will be faced with addressing structural changes to the livestock industry that the technology may instigate.

Interest in cellular agriculture has been motivated by concerns about the effects of conventional animal agriculture on animal welfare, public health, and the environment. The growing industry is composed mostly of companies founded in the past 10 years but has attracted investments from major food companies, such as Cargill and Tyson Foods (Durisin, 2018). Several producers estimate that the first cellular agriculture products will be available within the next five years (Bryant and Barnett, 2018). The industry is bolstered by academic research and nonprofit organizations, such as the Good Food Institute and New Harvest.

The two major techniques of cellular agriculture are (i) tissue-based engineering to make cell-based beef, poultry, and seafood; and (ii) protein-based engineering to make leather, dairy, and egg analogs. Tissue-based engineering methods replicate the entire cell of the animal, making the product molecularly identical to animal-based meat. Protein-based engineering methods replicate the proteins naturally occurring in animal products but also add plant-based ingredients such as vegetable fats into the final product (Kadim et al., 2015; Waschulin and Specht, 2018).

Tissue-Based Engineering

Tissue-based engineering adapts technologies originally used in the medical field for growing human organ or muscle tissue. The process involves first taking a sample of stem cells from an animal (non-stem cells are sometimes used as well). Next, the cells are placed in a bioreactor with a three-dimensional scaffolding material that provides structure for the cells to grow on. The scaffolding can be either biodegradable or integrated into the final product. A nutrient-rich medium provides the cells with salts, sugars, amino acids, and signaling proteins. The signaling proteins control cell behavior, such as whether the cells multiply; whether they multiply as fat, muscle, or connective tissue; and how they attach to the scaffolding. Within the bioreactor, the cells multiply for several weeks until they are ready for consumption (Kadim et al., 2015; Specht et al., 2017).

In 2013, a team of researchers led by Mark Post at Maastricht University introduced the first tissue-engineered hamburger at a public exhibition in London. As the company had not yet incorporated fat into the product, the patty was entirely muscle tissue rather than the blend of muscle and fats found in conventional hamburgers. Since then, scientists have worked to incorporate fats into the final product, although since none are commercially available, the precise level of progress is unclear. In 2016, Memphis Meats created a cellular agriculture meatball, and in 2017 Finless Foods created a cellular agriculture fish patty and Memphis Meats created cellular agriculture chicken and duck patties, and in 2018, Aleph Farms created a thin slice of cellular agriculture steak.

The industry is currently working toward addressing several key technological hurdles. First, the bioreactors currently used for cellular agriculture were designed for medical applications. Additional research is needed to develop new bioreactors that can scale to commercial levels of production (Stephens et al., 2018). Second, the original media used to grow the cell-based meats used fetal bovine serum (Stephens et al., 2018). This practice was based on technologies that used biomedical applications of tissue engineering, but high costs and concerns for animal welfare have caused firms to move away from animal-based media and develop serum-free methods (Reynolds, 2018; Specht et al., 2017). Designating a serum-free, chemically defined medium that optimizes for factors such as viscosity and pH while greatly reducing media cost is an ongoing challenge for the industry (Specht et al., 2017). Third, while current technologies can produce ground meats and patties, the production of well-structured layers of proteins, fats, and connective tissues found in certain cuts of meat, such as steaks is an on-going challenge (Stephens et al., 2018). Aleph Farms unveiled the first cellular agriculture steak in December 2018, although the prototype was thinner than a conventional steak. Finally, the methods for sourcing cells and creating cell lines are still in development (Stephens et al., 2018). Cell lines are created from genetically modifying or chemically programming source cells to proliferate indefinitely or by harvesting mutated cells that express immortality. Another option involves directly using cell cultures taken from an animal (Stephens et al., 2018).

Protein-Based Engineering

Protein-based engineering methods modify yeasts, which create proteins during fermentation (Waschulin and Specht, 2018). The yeasts are mixed with nutrients and sugars and placed in a fermenter. The yeasts consume the sugar and nutrients and produce proteins. This technology is already commercially used to produce insulin for people with diabetes and food enzymes such as rennet and is now being expanded to a wider set of animal proteins. For example, the company Perfect Day has created milk proteins using this process, and Clara Foods has produced egg white proteins (Carrington, 2018). In the case of cell-based dairy, plant-based fats and sugars are added to replace the animal-based fat and sugar found in cow’s milk. Geltor has already brought to market a cellular agriculture collagen product for use in cosmetics. It has also developed a cellular agriculture gelatin. Like Geltor, Modern Meadow uses cellular agriculture to synthesize collagen, but Modern Meadow uses the collagen to create leather rather than skin products. As with tissue engineering, a key technological hurdle is scaling production and, for food products, refining the taste, texture, and nutrition profiles of the proteins and completed products.

Environmental Implications

As with any production system, cellular agriculture has numerous environmental implications. However, current measurement of the environmental impacts of cellular agriculture is in its infancy. An environmental lifecycle analysis by Tuomisto and Teixeira de Mattos (2011) compared the energy use, greenhouse gas emissions, land use, and water use of beef, sheep, pork, and poultry to their cellular equivalents. The study did not include factors like water pollution from manure and pesticide runoff and did not compare eggs and dairy to their cellular equivalents. The study found that cellular agriculture uses 7%–45% less energy than conventionally produced European beef, sheep, and pork but slightly more energy use than poultry. It also found that cellular agriculture meat products create 78%–96% less greenhouse gas emissions than conventionally produced European meat, use 82%–96% less water than conventionally produced European meat, and use 99% less land.

Mattick et al. (2015) conducted a similar lifecycle analysis to compare beef, pork, and poultry to their cellular agriculture equivalents in terms of industrial energy use, global warming potential, land use, and eutrophication potential. Like Tuomisto and Teixera de Mattos (2011), they found that cellular agriculture uses less land than beef, poultry, and pork but by a smaller margin than the previous study. They also diverged from Tuomisto and Teixeira de Mattos (2011) in their other conclusions, which did not address eutrophication of waterways. Mattick et al. (2015) found that the eutrophication potential of conventionally raised beef and pork was substantially higher than for cellular meat and that cellular meats had comparable eutrophication potential to poultry. However, the authors noted that the eutrophication potential is not perfectly comparable because they assumed managed waste flows from livestock but untreated waste flows from cellular agriculture. Their estimate of eutrophication potential also does not include other sources of water pollution, such as pesticide applications on feed grains.

Mattick et al. (2015) further estimated that the industrial energy use for cellular agriculture is higher than for traditional animal agriculture. However, they also estimated the human-edible energy return on investment and found that cellular agriculture products result in a higher percentage of edible energy relative to energy invested than any of the livestock products compared. Also, while they found the global warming potential of cellular meat to be substantially lower than that of beef, they diverged from the Tuomisto and Teixeira de Mattos (2011) study, finding that it was higher for pork and poultry. Mattick et al. (2015) note that this divergence between their estimates and the prior study's estimates is due to differing assumptions about the nutrient liquid (media) content production and that technological innovations may bring the environmental impacts in line with Tuomisto and Teixera de Mattos's (2011) estimates. Importantly, both studies were based on theoretical assumptions about how cellular agriculture might work rather than observed measurements. Further research is needed to estimate the environmental impacts of cellular agriculture based on empirical data at production scale.

Public Health

Like all food systems, cellular agriculture has implications for public health. First, traditional livestock operations tend to rely on antibiotics, prompting concerns about antibiotic residues in food products and the threat of drug-resistant bacteria (Sneeringer, 2015). Cellular agriculture does not require the use of any antibiotics, so it does not contribute to antibiotic resistance. Second, the food safety profile of cellular agriculture may differ substantially from traditional livestock. Traditional livestock production runs the risk of contamination with fecal bacteria such as salmonella. Since cellular agriculture grows cells or proteins rather than an entire animal, the risk of contamination from fecal material is eliminated. However, cellular agriculture will face new food safety challenges. Bacterial growth in bioreactors could pose a food safety risk if it is not managed well. Similarly, the growth medium could introduce harmful bacteria if it is contaminated. In November 2018, USDA Secretary Perdue and FDA Commissioner Gottlieb issued a joint statement on the regulation of cellular agriculture meat products (U.S. Department of Health and Human Services, 2018). The plan stated that the FDA would oversee cell collection, cell banks, and cell growth and differentiation while the USDA would oversee cell harvesting and the production and labeling of food products.

Current industry research focuses on mimicking the properties of animal agriculture products as closely as possible in terms of nutrition, appearance, texture, and functional properties (Post, 2012). However, cellular agriculture may allow the nutritional properties of animal products to be intentionally altered to meet specific consumer demands. For example, saturated fats in red meats may be replaced with unsaturated fats, or egg proteins could be mixed with plant-based ingredients to create a low-cholesterol egg analog.

Consumer Attitudes

As with most food innovations, consumer attitudes toward cellular agriculture will be an important determinant of the success of the industry. Since cellular agriculture animal product analogs are not on the market yet, the literature of consumer acceptance relies on survey data. Bryant and Barnett (2018) reviewed 14 studies that surveyed respondents, conducted focus groups, analyzed online comments, or used other premarket consumer acceptance metrics. Their review focused on acceptance of cell-based products such as cellular agriculture meats rather than protein-based products such as egg and milk analogs. Overall, the authors found that most consumers were willing to try cellular agriculture products, but few would prefer them to conventional meat or plant-based alternatives on a regular basis. Few of the studies contained quantitative surveys of representative samples of the population. The authors suggested that in several studies, familiarity with cellular agriculture was associated with higher acceptance rates. For example, Verbeke, Sans, and Van Loo (2015) found that focus group participants became more willing to try cellular agriculture products when they were given information about the potential environmental and public health benefits.

Common concerns that participants raised across studies reviewed in Bryant and Barnett (2018) were that cellular meat products were unnatural, less healthy, poor tasting, had an unpleasant texture or appearance, or were too expensive. Also, in qualitative studies such as those with focus groups or online comments, participants tended to list safety as a concern. However, quantitative studies that directly asked participants about their perceptions of the safety of cellular meat products found more favorable estimates of perceived safety. Common positive perceptions from studies included benefits to animal welfare, the environment, food security, and public health.

Thus far, three quantitative, survey-based studies on consumer acceptance of cellular agriculture products have appeared in peer-reviewed journals: Hocquette et al. (2015), Wilks and Phillips (2017), and Slade (2018). The three studies' estimates of the percentage of consumers willing to eat cellular agriculture products vary considerably. This discrepancy is partly explained by variation in respondents' demographics, the descriptions of cellular agriculture products, and the specific question asked. Since cellular agriculture is an emerging field, there is little agreement on what to call it. Alternative descriptions include "cultured meat," "in-vitro meat," "lab-grown meat," "clean meat," "cell-based meat," and others. For example, Hocquette et al. (2015) disproportionately sampled French and international scientists and meat industry workers, using the terms "lab or factory grown meat" and "in-vitro meat." They asked, "to solve the potential problems in the meat industry, do you think human beings should a) Change nothing in consumption, b) Eat less meat, c) Eat no Meat, or d) Eat in vitro meat" (p. 276). They then asked which of those four options the respondent would personally prefer to do. Given those options, they found that 5%–11% of respondents reported that they would personally prefer to solve the problem by eating "in-vitro meat" compared with 55%–75% of respondents who individually preferred to eat less or no meat and 19%–36% of respondents who preferred to change nothing about their meat consumption. However, respondents did not have the option to select multiple options, and the survey did not ask participants whether they would be willing to try a cellular agriculture product even if they did not view it as a solution to "potential problems in the meat industry" (p. 276).

Wilks and Phillips (2017) used Mechanical Turks, an online service for conducting surveys, to survey a sample representative of the general U.S. population. They used the terms "in vitro meat," "cultured meat," and "synthetic meat." They asked, "Would you be willing to try in vitro meat" and found that 65% of respondents were either definitely or probably willing to try it. They then asked, "Would you be willing to eat in-vitro meat regularly" and found that 33% of respondents were either probably or definitely willing to eat it regularly, 31% were unsure, and the remainder were either probably or definitely unwilling to eat it regularly.

Slade (2018) conducted a survey using random digit dialing. Participants were asked "Given the available selection, which burger would you purchase: a) Plant-based burger (organic), b) beef burger (organic), c) cultured meat burger, and d) would not purchase" (p. 431), after being given a description of each option. The author estimated that at equal prices, 65% of respondents would purchase the beef burger, 21% would purchase the plant-based burger, 11% would purchase the "cultured meat" burger, and 4% would make no purchase. One limitation of this study for assessing consumer acceptance is that respondents were allowed to choose only one option, and the beef and plant-based options were both organic, while the cellular agriculture option was not labeled as such, so it may measure something other than their preferences for cellular agriculture versus conventional beef or plant-based analogs.

Industry Implications

The market implications for cellular agriculture products are highly uncertain at this point. The industry could evolve into a small niche market with few implications for livestock, dairy, and poultry outlook, or it could offset a significant portion of the demand for conventional animal products. If the cellular agriculture industry does capture a large share of the market, then the animal products industry will face adjustments. Larger protein companies such as Cargill and Tyson Foods have anticipated a possible decrease in demand in traditional meat by diversifying their investment portfolio to include cellular agriculture products (Durisin, 2018). However, at the time of this writing, no cellular agriculture companies are publicly traded, so investing via the stock market is not an option for individual farmers who may wish to insure against decreased demand. If major cellular agriculture companies do become publicly traded at a time when they do not capture a significant share of the targeted animal products market, then individual farmers will be able to hedge risk through this investment, or specialize in other products. Farmers who continue producing traditional livestock might concentrate in geared toward consumers who prefer traditional animal meat. In such a scenario, the aggregate demand for traditional animal products would still be decreased and existing farmers (and potentially communities) that have historically relied on livestock farming will need to find new income sources to maintain current income levels. For example, some dairy farms have repurposed their equipment to brew beer in response to recent declines in dairy prices (Bernstein, 2018). Similarly, Evans (2003) found that poultry and swine production facilities could potentially be used for mushroom production.

The implications for the livestock, poultry, and dairy industries may vary across sectors. For example, the U.S. beef industry specializes primarily in grain-fed beef production, while it imports lean, grass-fed beef for processing (U.S. Department of Agriculture, 2016). Since current cellular agriculture technologies that mimic processed beef products such as hamburgers and meatballs are further along in development than those that mimic beef cuts such as steaks, the first U.S. beef industry implications may be reductions in imports. For dairy, the introduction of a cellular agriculture milk analog may reduce the demand for skim milk solids, but not for milk fats and butter, because current technologies synthesize the milk protein but use plant-based fats to make milk analogs. While the trajectory of the cellular industry remains uncertain, research monitoring its impact on the environment, animal welfare, public health, as well as the livestock, poultry, and dairy outlook may become increasingly relevant over the coming years.

For More Information

Bernstein, J. 2018, June 11. "Dairy Farms Find a Lifeline: Beer." *New York Times*.

Bryant, C., and J. Barnett. 2018. "Consumer Acceptance of Cultured Meat: A Systemic Review." *Meat Science* 143: 8–17.

Carrington, D. 2018, April 30. "The New Food: Meet the Startups Racing to Reinvent the Meal." *The Guardian*.

Durisin, M. 2018, January 29. "Tyson Joins Bill Gates, Cargill to Invest in Lab-Meat Producer." *Bloomberg*.

Evans, M. 2003. *Technical and Economic Analysis of the Potential for Conversion of Poultry and Swine Production Facilities to Greenhouses and Mushroom Houses*." College Park, MD: Sustainable Agriculture Research and Education, Final Report for LS02-145 2003.

Hocquette, A., C. Lambert, C. Sinquin, L. Peterolff, Z. Wagner, S.P.F. Bonny, A. Lebert, and J.-F. Hocquette. 2015. "Educated Consumers Don't Believe Artificial Meat Is the Solution to the Problems with the Meat Industry." *Journal of Integrative Agriculture* 14(2): 273–284.

Kadim, I., O. Mahgoub, S. Baqir, B. Faye, and R. Purchas. 2015. "Cultured Meat from Muscle Stem Cells: A Review of Challenges and Prospects." *Journal of Integrative Agriculture* 14(2): 222–233.

Mattick, C., A. Landis, B. Allenby, and N. Genovese. 2015. "Anticipatory Life Cycle Analysis of in Vitro Biomass Cultivation for Cultured Mean Production in the United States." *Environmental Science and Technology* 49: 11941–11949.

Reynolds, M. 2018, March 20. "The Clean Meat Industry Is Racing to Ditch Its Reliance on Foetal Blood." *Wired*.

Slade, P. 2018. "If You Build It, Will They Eat It? Consumer Preference for Plant-Based and Cultured Meat Burgers." *Appetite* 125: 428–437.

Sneeringer, S., and J. MacDonald. 2015. *Economics of Antibiotic Use in U.S. Livestock Production*. Washington, DC: U.S. Department of Agriculture, Economic Research Service, Economic Research Report 200, November.

Specht, E., D. Welch, E,R. Clayton, and C. Lagally. 2017. "Opportunities for Applying Biomedical Production and Manufacturing Methods to the Development of the Clean Meat Industry." *Biomedical Engineering* 132: 161–168.

Stephens, N., L. Di Silvio, I. Dunsford, M. Ellis, A. Glencross, and A. Sexton. 2018. "Bringing Cultured Meat to Market: Technological, Socio-Politico, and Regulatory Challenges to Cellular Agriculture." *Trends in Food Science and Technology* 78: 155–166.

Tuomisto, H., and M.J. Teixeira de Mattos. 2011. "Environmental Impacts of Cultured Meat Production." *Environmental Science and Technology* 45: 6117–6123.

U.S. Department of Agriculture. 2016, February. "Agricultural Projections to 2025." Available online: https://www.ers.usda.gov/webdocs/publications/37809/56725_oce-2016-1-d.pdf?v=0 [Accessed 2/4/2019].

U.S. Department of Health and Human Services. 2018, November 16. "Statement from USDA Secretary Perdue and FDA Commissioner Gottlieb on the Regulation of Cell-Cultured Food Products from Cell Lines of Livestock and Poultry." Washington, DC: U.S. Food & Drug Administration, FDA Statement.

Verbeke, W., A. Marcu, P. Rutsaert, R. Gaspar, B. Seibt, D. Fletcher, and J. Barnett. 2015. "'Would You Eat Cultured Meat?' Consumers' Reactions and Attitude Formation in Belgium, Portugal, and the United Kingdom." *Meat Science* 102: 49–58.

Verbeke, Wim, Pierre Sans, and Ellen Van Loo. 2015. "Challenges and prospects for consumer acceptance of cultured meat." *Journal of Integrative Agriculture* 14 (2): 285-294

Waschulin, V., and L. Specht. 2018. "Cellular Agriculture: An Extension of Common Production Methods for Food." The Good Food Institute.

Wilks, M., and C. Phillips. 2017. "Attitudes to in Vitro Meat: A Survey of Potential Consumers in the United States." *PLoS ONE* 12(2).

Author Information
Monica Saavoss (monica.saavoss@ers.usda.gov) is Research Economist, U.S. Department of Agriculture, Economic Research Service, Washington, DC.
Disclaimer: The findings and conclusions in this preliminary publication have not been formally disseminated by the U.S. Department of Agriculture and should not be construed to represent any agency determination or policy. This research was supported by the intramural research program of the U.S. Department of Agriculture, Economic Research Service.