Market Analysis for Cultured Proteins in Low- and Lower-Middle Income Countries

October 2019

PATH

Acknowledgments

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Abbreviations

ADM	Archers Daniel Midland
B2B	business-to-business
B2C	business-to-consumer
FAO	Food and Agriculture Organization of the United Nations
GM	genetically modified
GMO	genetically modified organism
LMICs	low- and lower-middle income countries
N/A	not available
RUF	ready-to-use food
US	United States
USAID	US Agency for International Development

Key terms

Alternative proteins	A broad term that refers to any proteins intended to replace animal-source proteins derived from traditional livestock. These might include proteins derived from plants, microorganisms, or animal cell culture.
Business-to-business (B2B)/ Business-to-consumer (B2C)	Business-to-business (B2B) describes a transaction that is conducted between two businesses, such as a manufacturer and a corporate retailer.[1] This is in contrast to a business-to-consumer (B2C) transaction, in which a company sells its products directly to consumers via retail channels.[2]
Bioengineered food	Defined by the US Department of Agriculture as "detectable genetic material that has been modified through in vitro recombinant deoxyribonucleic acid (rDNA) techniques and for which the modification could not otherwise be obtained through conventional breeding or found in nature; provided that such a food does not contain modified genetic material if the genetic material is not detectable."[3]
Cellular agriculture	Cellular agriculture is the manufacture of animal products from cells rather than from traditional animal farming methods of breeding, rearing, and slaughter.[4] The two main types of cellular agriculture are fermentation-based and tissue engineering–based processes.[5]
Cultured proteins	Also known as "synthetic," "lab-grown," "fermentation-derived," and "flora-based" proteins, cultured proteins are produced through fermentation wherein unicellular organisms (e.g., microflora such as fungi and yeast) express a desired organic molecule end product during the fermentation process.[6]
Cell-based meat	Also known as "clean," "lab-grown," "cultivated," "cultured," and "in vitro" meat, cell-based meat is the product of a cellular agriculture process that utilizes a cell or tissue line from a living animal to grow and culture a desired product in a laboratory.[5]
Genetically modified (GM) food	Defined by the World Health Organization as "foods derived from organisms whose genetic material (DNA) has been modified in a way that does not occur naturally (e.g., through the introduction of a gene from a different organism)."[7]
Genetically modified organism (GMO)	Defined by the World Health Organization as "organisms (i.e., plants, animals or microorganisms) in which the genetic material (DNA) has been altered in a way that does not occur naturally by mating and/or natural recombination. The technology is often called 'modern biotechnology', or 'gene technology', sometimes also 'recombinant DNA technology', or 'genetic engineering.'"[8]
Market size	Market size refers to the total potential market for a product. In this analysis, this may be calculated in terms of number of people reached, volume of food, or value in dollars. Note that this is not indicative of the potential uptake or demand for this product, but instead estimates the total size.
Microflora	A group of microorganisms, including algae, fungi, and bacteria, that live in a particular habitat (e.g., intestines).[9]

Executive summary

The global burden of malnutrition is unacceptably high. Animal-source foods are important components of diverse diets and provide high-quality proteins and other essential nutrients that promote optimal growth and development. The global demand for animal-source foods is projected to increase substantially, particularly in many low- and lower-middle income countries (LMICs). However, cost is a significant barrier to access, and meeting this growing demand through livestock production will be highly resource intensive. As such, sustainable, high-quality alternatives to protein from livestock have the potential for significant transformative impact for both people and the planet.

This analysis focuses on fermentation-derived cultured proteins as a specific alternative to animal-source proteins, given their near-term time to market, product qualities, and potential to be used in LMIC settings. Most cultured protein manufacturers are currently focused on creating milk (casein and whey) and egg white cultured protein products. Using a process known as fermentation-based cellular agriculture, animal proteins found in milk and eggs can be produced without animals. Through this method, a gene encoded with an animal protein is introduced into a starter culture of microflora (e.g., fungi or yeast). This culture is grown in controlled fermentation tanks, where it expresses the desired protein. Finally, the protein is separated from the microflora, generally producing a purified protein powder. These resulting "cultured" proteins are designed to be identical to the corresponding animal-source proteins produced through traditional livestock farming and can be used as ingredients in existing or new food products. Although there are many potential sustainability and nutrition-related benefits of these innovations, they also face several challenges to commercialization and market uptake.

To assess the market for cultured proteins in LMICs, we collected secondary data and conducted interviews with 25 key stakeholders between January and September 2019. Stakeholders included knowledge experts in the food industry, manufacturers of cultured proteins and other alternative proteins, and individuals working in food aid and nonprofit organizations. This paper identifies key manufacturers and provides insights into the attributes of their products, time to market, prioritized geographies, key partnerships, ability to scale, and opportunities and challenges for commercialization. Secondary data are used to assess the current market for alternative proteins and estimate the cultured protein market size for different market segments. Additionally, perceptions from non-manufacturer stakeholders are presented to understand the value of these proteins for use in LMIC settings. Several key findings were identified.

1. **The existing market size for milk and eggs varies substantially across countries by income status, and the rapid rise in plant-based protein alternatives in high-income countries suggests increased demand for alternative non-animal protein products.** The global market for milk and eggs is sizable, estimated at US$874 billion and $258 billion, respectively. Of this, consumption in LMICs makes up approximately 33% of the milk-based product market and 15% of the egg market. High-income countries consume roughly six times more milk products per capita and nine times more eggs per capita than low-income countries. Within the food aid market, only a small proportion of the current products contain milk protein and no food aid products contain egg protein. However, new data are beginning to elucidate the value of more diverse diets and the contribution of animal-source foods for early childhood growth and development. Consumption of milk and eggs in high-income countries is likely driven by a variety of factors, including advertising; lobbying; detailed food-based dietary guidelines; and government programs, including school milk programs. Such efforts aimed at increasing consumption, which are common in high-resource markets, are lacking in most LMICs. Furthermore, sales of plant-based milk and egg alternatives have grown rapidly in recent years in high-income countries, highlighting the demand for alternatives to proteins made from animals among select consumers.
2. **Cultured proteins are expected on the market in high-income settings in early 2020 and contain several attributes that may make them suitable for use in LMICs.** Two companies that are expecting to launch their products in 2020 have partnered with large, multinational food companies with the goal of expanding capabilities to scale proteins and launch in broader geographic markets. Business-to-business sales strategies will likely be common given that many manufacturers plan to sell cultured proteins as an ingredient rather than as a complete end-to-end food product. Product attributes that may be compelling for LMIC settings include the potential to store without refrigeration, possibly a longer shelf life, and improved distribution (lighter and more compact). Products will likely initially be priced similar to existing animal-source foods, but price reductions may be possible with economies of scale.
3. **Most non-manufacturer stakeholders were "very aware" or "somewhat aware" of cultured proteins before being interviewed, and in aggregate had very positive perceptions for use in LMICs but questioned feasibility of product pricing.** According to these stakeholders, the

top-valued attributes of cultured proteins for use in LMIC settings were equally high nutritional value, lower environmental footprint, and equivalent or lower cost than their respective animal-source proteins. However, some stakeholders questioned whether cultured proteins could be made at a lower cost than animal-source foods. Low cost was deemed as a key success factor for market uptake in LMIC settings. In addition, some stakeholders thought that with additional research and development, cultured proteins could possibly be designed to meet the nutritional needs of specific at-risk populations, by adding in vitamins, minerals, specific amino acids, or other components.

4. **Continuing to expand on the evidence base for the use of cultured proteins in LMICs will be important to generate demand in these countries.** Additional evidence should be collected to assess factors such as cost and nutritional benefits, especially for use in vulnerable, malnourished populations. Stakeholders agreed that having a low-cost product would be a significant success factor for market uptake in LMICs. More research is needed to understand what price reductions may be possible with large-scale production. Pricing analysis should consider potential cost reductions of cultured proteins over animal-source proteins in terms of delivery and refrigeration. Information was also desired on how cultured proteins compare to animal-source foods in terms of health and nutrition. Many of the stakeholders participating in this research noted that there may be other beneficial components in milk and eggs that contribute to health besides proteins.

Cultured proteins hold promise for significant transformative impact in the areas of health, agriculture, and the environment. The large market size, recent demand for alternative plant-based proteins, promising product attributes, and positive perceptions for use in LMIC settings make them a compelling area for future investment. Additional evidence and demand generation activities will be needed to support use in vulnerable, malnourished populations.

Background

Introduction

The global burden of malnutrition is unacceptably high.[10] Worldwide, an estimated 22% of children under the age of five were stunted and 8% were wasted in 2018.[11] Low-quality diets lacking in essential vitamins, minerals, proteins, and other nutrients are a key contributor to this burden.[12] Animal-source foods—such as meat, poultry, fish, eggs, and dairy—are important components of a diverse diet and provide high-quality proteins and other essential nutrients that promote optimal growth and development.[13,14,15,16,17] As populations and incomes grow, the global demand for animal-source foods is projected to increase substantially, particularly in many low- and lower-middle income countries (LMICs).[18,19]

However, cost is currently a significant barrier to animal-source food consumption. In addition, meeting this growing demand for animal-source foods will require rapid increases in livestock production, which has significant environmental impacts, requiring considerable land, water, chemical, and energy inputs.[10,17,18] Global food production is responsible for roughly one-quarter of all greenhouse gas emissions, most of which (up to 80%) are related to livestock.[20,21] Livestock production is also a contributor to water pollution, deforestation, land degradation, overfishing, and antimicrobial resistance.[20,22,23]

Given these challenges, this report aims to assess the market for potentially more sustainable alternative proteins and their potential for use in LMIC settings. The report focuses on proteins derived from fermentation-based cellular agriculture, called cultured proteins, given their potential near-term time to market and their potential impact in LMIC populations. Most cultured protein manufacturers are developing proteins that are present in animal-source milk and eggs.

Cellular agriculture

The term "cellular agriculture" broadly refers to the manufacture of animal products from cell cultures under controlled conditions, as opposed to traditional animal farming methods.[6] According to Stephens et al. (2018), cellular agriculture can be broadly categorized into two main groupings: fermentation based and tissue engineering based.[5,24] Tissue engineering–based cellular agriculture produces cell-based meat (also known as "clean," "lab-grown," "cultivated," "cultured," and "in vitro" meat) and uses a cell or tissue line from a living animal. Stem cells are extracted from the tissue to grow and culture the desired product.[5]

Fermentation-based cellular agriculture—the focus of this paper—uses microflora (e.g., fungi or yeast) to express a desired organic molecule end product (such as protein) during fermentation.[6] Through this process, which bears resemblance to brewing beer, many of the same animal proteins found in milk and eggs can be produced without animals.[6] The process uses a gene encoded with the animal protein, which is introduced into the DNA of a starter culture of microflora. This culture is then fed on a substrate (e.g., sugars) in controlled fermentation tanks, where it expresses the desired protein(s).[6] In most cases, the proteins are separated from the microflora and purified into a powder. The resulting "cultured" proteins—also known as "synthetic," "lab-grown," "fermentation-derived," and "flora-based" proteins—are theoretically identical to the corresponding animal-source protein with respect to structural, organoleptic, and nutritional properties.[a,6]

Cultured proteins could therefore be substituted for animal-source proteins as an ingredient in existing or new food products, such as milk or egg substitute products. They might also be used to improve the nutritional content of products that do not currently contain milk or egg protein. However, cultured milk and egg proteins produced through this technique are not equivalent to whole animal-source foods (e.g., powdered whole milk or powdered whole eggs) because they do not contain other nutrients such as carbohydrates, fats, or other bioactive compounds. Several emerging biotechnology companies are creating cultured milk and egg proteins for use in food products, with the earliest commercial products expected on the market in 2020.

a. For the remainder of this paper, we will refer to proteins derived according to this approach as cultured proteins.

Furthermore, the microflora (e.g., yeast) used as a starter culture in the production of cultured milk and egg proteins is often genetically modified (GM). Genetically modified organisms (GMOs) are defined by the World Health Organization as "organisms (i.e., plants, animals or microorganisms) in which the genetic material (DNA) has been altered in a way that does not occur naturally by mating and/or natural recombination."[7,8] Foods that are produced from or with GMOs are often referred to as GM foods.[7] The technology used to alter the genetic material of an organism is often referred to as "genetic engineering."[8] However, in the case of cultured milk and egg protein production, it is important to note that, in most cases, the GM microflora is removed from the final product, meaning that the resulting purified protein powder does not contain GMOs. Although the use of genetically engineered microbial strains in food production is not a new phenomenon, nuances in the details of the role of GMOs in the production of cultured proteins, as well as various country/institutional classification guidelines for GMOs and GM products, may add a layer of complexity to their regulation within various contexts. These considerations are discussed in detail in the accompanying Policy and Regulatory Environment paper.

Potential benefits and challenges

Benefits

Cultured milk and egg protein production techniques and resulting products have the potential to benefit the environment, agriculture, and health, including for malnourished populations in LMICs. Relative to the same proteins from animal sources, it is possible that cultured proteins will contain the same high nutritional value; have a lower environmental footprint and produce fewer associated greenhouse gas emissions; require fewer agricultural inputs (e.g., land, water, chemicals, energy); require no animal breeding or slaughter; contain fewer or no hormones, antibiotics, or foodborne pathogens; have an extended shelf life (may not require cold storage); have the same taste, texture, and chemical structure; and eventually be lower cost and/or be subject to fewer price fluctuations. Due to these potential benefits and our growing understanding of the role of animal-source foods in promoting nutrition, particularly among young children,[13,14,15,16,17] cultured milk and egg proteins may have a role in sustainably supporting improved diets and nutritional outcomes in LMICs.

Challenges

At the same time, cultured proteins may also face or present commercialization challenges. Potential challenges associated with cultured proteins include displacement of other foods in the food system, difficulty in ensuring equitable access to products, the potentially high cost of these products when they first launch, negative livelihood impacts for farmers, and other possible unintended consequences.

Key objectives of this analysis

We conducted a market landscape and market analysis of cultured proteins based on desk research and stakeholder interviews. The key objectives of this analysis included:

1. Identifying key manufacturers in the cultured protein field.
2. Gaining insights on select product attributes and their suitability for use in LMICs.
3. Learning about time to market, geographies for introduction, scalability, and priority market segments.
4. Estimating the market size for select scenarios of use in LMICs.
5. Understanding perspectives on opportunities and challenges for commercialization in LMICs.
6. Articulating the value proposition of cultured proteins compared to animal-source proteins.

While the focus of this report is on cultured proteins, other alternative protein categories were investigated (plant-based protein products and cell-based meats) to gain additional insights on the alternative protein market as a whole. Plant-based protein products that are intended to replace animal-source foods (e.g., meat, milk, and eggs) are already on the market, seeing rapid growth in high-income countries, and are a useful analog to understand potential consumer demand for other alternative proteins. Cell-based meats have longer development timelines than cultured proteins but provide an opportunity to obtain additional perspectives from manufacturers on the potential opportunities and challenges in the alternative protein market.

Research methodology

Secondary research

To achieve the objectives of this project, we conducted a combination of secondary and primary research. Secondary data collection focused on identifying and gaining knowledge on cultured protein and other alternative protein manufacturers and their products, the market conditions and current market size for animal-source milk and egg proteins, and the uptake of other forms of alternative proteins. Approximately 40 manufacturers of cellular agriculture products (including cultured proteins and cell-based meats) were identified in the first quarter of 2019, via the Alternative Protein Show and other sources.[25] We collected publicly available information about each manufacturer's location, number of employees, types of proteins and products produced, timeline for commercial availability, production technology, funding sources, and other relevant details. Further, we researched select plant-based protein companies, and collected information on the existing market for animal-source milk and eggs, food aid in LMICs, and the evolving food industry. Secondary data sources included white papers, industry reports, manufacturer websites, news publications, United Nations agency websites (the Food and Agriculture Organization of the United Nations, or FAO), policy and research institutes (Good Food Institute, International Food Policy Research Institute, and New Harvest), and others. The secondary research information was used to inform stakeholder interviews and the market analysis. See the reference list for a full list of sources.

Stakeholder selection and interview methodology

To obtain a broad set of perspectives, a variety of stakeholder types were recruited for the interviews (Table 1). Stakeholders were identified through previous work in the field, industry conferences, desk research, and referrals. Some of these groups are known for their work in alternative proteins, while others participate in the broader food industry or are experts in food aid or the regulatory environments for innovative foods. In addition, we sought to obtain perspectives from around the world, or from respondents who work or have worked in LMICs.

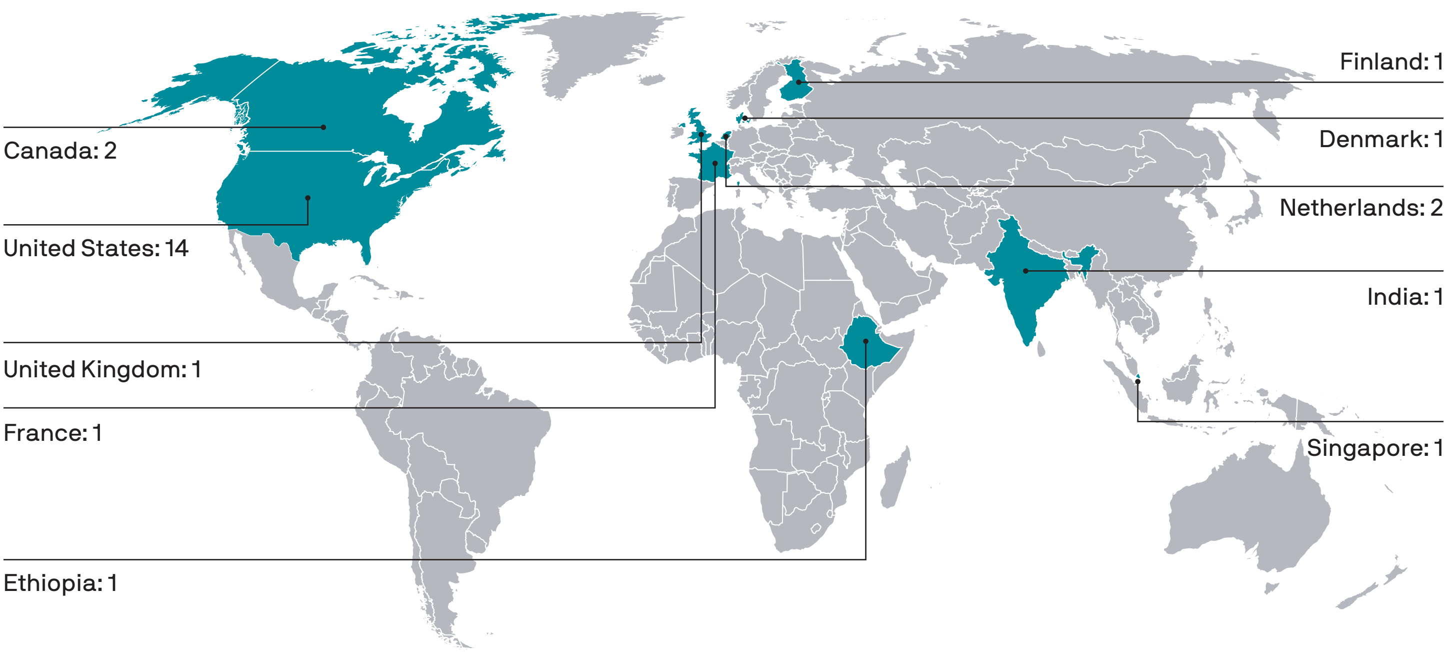
We interviewed representatives of companies that are developing cultured proteins, that are further along in the development process for cell-based meat, and that are already selling plant-based proteins. Most major identified cultured protein manufacturers were contacted with a request to interview, especially those focused on milk and egg proteins, while only select cell-based meat and plant-based companies were contacted. The five cultured protein manufacturers interviewed are profiled in this report.

In total, 50 people from 43 organizations were invited to participate in an interview. Of those, we interviewed 25 people from 24 organizations, located in ten countries. While 56% of respondents are based in the United States, the majority of non-manufacturer respondents have direct experience working in LMICs. See Table 1 for a summary of the stakeholders interviewed and Figure 1 for a map of stakeholders' locations.

TABLE 1. **Number of stakeholders interviewed by type.**

Type of organization	Number of stakeholders interviewed	Organizations included
Manufacturer (cultured protein)	5	BioscienZ, Clara Foods, New Culture, Perfect Day, Solar Foods
Manufacturer (other alternative protein)	5	*Cell-based meat:* Higher Steaks, Memphis Meats, Shiok Meats *Plant-based protein:* Impossible *Multiple:* JUST
Food aid organization (donor, supplier, procurer, or distributor)	6	Arla Foods Ingredients, Catholic Relief Services, Nutriset, US Agency for International Development, World Food Programme, World Vision
Non-profit organization (research, advocacy, or professional group)	4	Cellular Agriculture Society, Good Food Institute (x2), New Harvest
Other	5	*Academia:* Stanford University *Donor/incubator:* IndieBio Government agency: Ethiopia Agriculture Transformation Agency *Other:* Independent experts (x2)

FIGURE 1. **Map of stakeholder locations.**



Note: While 56% of respondents are based in the United States, the majority of non-manufacturer respondents have direct experience working in LMICs.

In order to conduct the interviews, the team generated a modular, semi-structured discussion guide that included both qualitative and quantitative questions. All interviews were designed to last approximately one hour. The discussion guide and research approach received a non-research determination from PATH's Office of Research Ethics, and each stakeholder consented to the interview. We asked manufacturers a series of questions about the alternative protein products they are creating, the regulatory processes they are navigating or anticipating, production and scale-up capabilities, prioritized market segments for introduction and scale, and industry partnerships.

We asked non-manufacturer stakeholders about a series of topics based on their expertise. Each participant was emailed a concept card describing cultured proteins to review before the interview (Appendix A). During the interview, we asked the participants questions related to their prior knowledge of cultured proteins, their perceptions on expected key benefits and potential challenges to market uptake, and their views on the utility of cultured proteins. When relevant, we asked stakeholders about their knowledge of the regulatory environment in various regions, specifically for innovative foods, GMOs, or cultured proteins. The policy and regulatory environment information is summarized in a separate report. Procurement organizations or organizations working in global food aid were asked additional questions about current procurement of animal-source proteins, levels of awareness about cultured proteins in their industry, data that should be generated for uptake, and thoughts on potential uses of these products. We compiled data from all interviews for analysis.

Current market for milk and eggs

Key messages

- Consumption of milk and eggs varies dramatically by country income, with high-income countries consuming roughly six times more milk products and nine times more eggs per capita than low-income countries.
- Country-level food-based dietary guidelines for dairy vary globally, and not all countries include dairy recommendations. Milk is included in guidelines more often than eggs.
- Detailed dietary guidelines, government initiatives, school programs, marketing campaigns, income, and lobbying efforts are factors that likely contribute to higher rates of dairy consumption in high-income countries compared to LMICs.
- Within the food aid market, milk is currently used as an ingredient in a small number of products (while eggs are not used), though there is potential to expand the use of milk in food aid products more broadly to increase protein content.
- In high-income countries, sales of plant-based alternatives to milk, eggs, and other animal-source proteins are rapidly expanding each year, indicating a demand for alternatives to animal-source proteins.

Global context

Several factors contribute to existing milk and egg consumption levels globally. These may include income levels, food-based dietary guidelines, marketing efforts, and school lunch programs and other initiatives. Variations in these factors across countries may help to explain why consumption rates differ so dramatically by country.

Food-based dietary guidelines can be used as a mechanism to translate evidence regarding food, dietary patterns, and health into culturally appropriate recommendations. These country-based guidelines are intended to inform consumer behavior and, in some circumstances, inform national or government policies. Food-based dietary guidelines are available for 90 countries globally; however, only 7 countries in Africa and 17 in Asia have guidelines on this topic.[26] One recent study that reviewed the various food-based dietary guidelines found that some elements of dietary guidance are nearly universal across all countries, while others, including dairy, are not (Table 2).[26]

The study found that 75% of available country dietary guidelines reviewed include dairy, either in messaging in the guidelines or in the visual food guide (a visual representation of the dietary guidelines).[26] Of the guidelines that include dairy, all messaging specifically mentions milk; 51% mentions milk products, yogurt, or cheese; and 11% mentions non-dairy alternatives to milk (such as soy milk). Eggs are less frequently mentioned in these country guidelines, and are mentioned in

TABLE 2. **Comparison of country food-based dietary guidelines.**

Recommendations that are nearly universal across most countries	Recommendations that are variable or inconsistently included across countries
• Consume a variety of foods. • Consume some foods in higher proportions than others. • Consume fruits and vegetables. • Consume legumes. • Consume animal-source foods.* • Limit sugar, fat, and salt.	• Dairy consumption. • Red meat consumption. • Fats and oils consumption. • Nuts consumption.

*In 31% of country guidelines, dairy is included in the animal-source food group. Dairy is a distinct category in the majority (59%) of country guidelines.

Adapted from Herforth A, Arimond A, Álvarez-Sánchez C, Coates J, Christianson K, Muehlhoff E. A global review of food-based dietary guidelines. *Advances in Nutrition.* 2019;10(4):590–605. https://doi.org/10.1093/advances/nmy130.

multiple places. In all, 31% of countries have key messaging related to eggs within the context of other protein foods, while only 3% (all in Latin America) include eggs within the context of dairy.[26]

Detailed dietary guidelines are one factor that may contribute to the high consumption of milk in high-income countries like the United States. In 2013, the average person in the United States consumed 255 kg of milk-based products per year (seventeenth in the world), while the country as a whole consumed 80 billion kg of milk-based products per year (second in the world, only behind India).[27] The US Department of Agriculture's 2015-2020 Dietary Guidelines for Americans includes dairy as one of six pillars for a healthy eating pattern.[28] Their dairy classification includes milk, yogurt, cheese, and fortified soy beverages, also known as soy milk. These guidelines make recommendations on consumption of dairy by age, ranging from two cups a day for children aged two to three years to three cups a day for children older than nine. The guidelines also make consumption recommendations for "protein foods," including seafood, meats, poultry, eggs, and other foods.[28] Specific recommendations on egg consumption quantities, however, are not provided.

In addition to the dietary guidelines, government initiatives are likely a contributor to levels of milk consumption, especially in high-income countries. In the United States, milk has been highly promoted in school lunch programs and other initiatives. The US government's National School Lunch Program, which provides "nutritionally balanced" low-cost or free lunches, served more than 30.4 million children in 2016.[29] The program was signed into law by President Harry Truman in 1946. In order to qualify for assistance, participating schools must adhere to standards set by the program. These standards specify the inclusion of milk (one cup), as well as fruits, vegetables, grains, and meat/meat alternatives.[30] Eggs are not specifically called out in the standards. The US government also has a Special Milk Program, which can provide milk to children in schools and childcare institutions that do not participate in other federal meal service programs.[31] These government-led efforts are supported by strong lobbying by the dairy industry to promote milk as the best source of protein and calcium for children.[32]

Finally, marketing efforts are a likely contributor to high consumption of milk and eggs. In the United States, the iconic "Got Milk?" campaign, launched in 1993 by the California Milk Processor Board, promoted increased milk consumption for nearly 20 years. The campaign was widely disseminated, and generated more than 90% awareness.[33] Similarly, the American Egg Board launched "The Incredible, Edible Egg" marketing slogan in 1976 to promote consumption of eggs.[34]

In contrast to the United States, fewer efforts are focused on increasing milk or egg consumption in LMICs. As mentioned previously, few African and Asian countries have reported food-based dietary guidelines.[35] Dairy consumption is strongly emphasized in North America and Europe, where 100% and 82% of countries in each region, respectively, have a key message about dairy in their guidelines. In contrast, only 57% of countries in Africa and 53% of countries in Asia have a key message regarding dairy in their guidelines. To raise awareness of the health benefits of school milk programs internationally, World School Milk Day was started in 2000 and is now promoted annually by the FAO and celebrated every September in more than 25 countries.[36] However, school milk direct-to-consumer marketing efforts to increase awareness of the benefits of milk, like "Got Milk?," are likely more limited in LMICs.

Other key constraints in LMICs that likely impact consumption of milk and egg products include lack of access to refrigeration and low/limited income. The nationally representative Demographic and Health Survey found that on average only 36% of households in LMICs had refrigerators.[37] In addition, milk and eggs are a relatively expensive source of calories in LMICs. Studies have found that the prices of these foods are strongly associated with consumption patterns.[26]

Consumer milk and egg market

According to the most recent data available, global consumption of milk-based products (including animal-based milk, milk powder, whey, casein, yogurt, cheese, and ice cream)[b] was estimated in 2013 to be 631 billion kg per year (an unweighted average of 114 kg per capita per year across 173 countries included in the dataset).[27] This was ten times larger on a volume basis than the annual egg consumption estimate arrived at in 2013, which was more than 63 billion kg per year (an unweighted average of 7 kg per capita per year across 173 countries included in the dataset).[27] When looking at the annual market value, both markets are sizeable. While the cost of milk can fluctuate substantially due to economic and political trends,[38] the average global retail cost of milk was approximately US$1.38 per kg[c] as of 2013-2014 (unweighted average across 151 countries).[39,40] Applying the cost of milk as a proxy to all milk-based products, the estimated annual global market value for milk-based products is almost $874 billion.[d] In comparison, eggs have a higher cost per kg than milk (approximately $4.08 per kg,[e] based on an unweighted average across 151 countries).[41,42] Therefore, the annual value of the egg market is estimated to be more than $258 billion, representing about 30% of the value of the milk market. Similar to milk, the cost of eggs can fluctuate seasonally or annually, often due to naturally increased supplies in the spring and summer.[43]

b. Milk consumption does not include human breast milk or infant formula.

c. This was reported as cost per liter of milk and converted to cost per kg of milk to match consumption data; 1 kg of milk is equal to 1.03 L of milk.

d. The price of milk is used as a proxy for the price of milk products (e.g., milk, cheese, and yogurt) to estimate the market value.

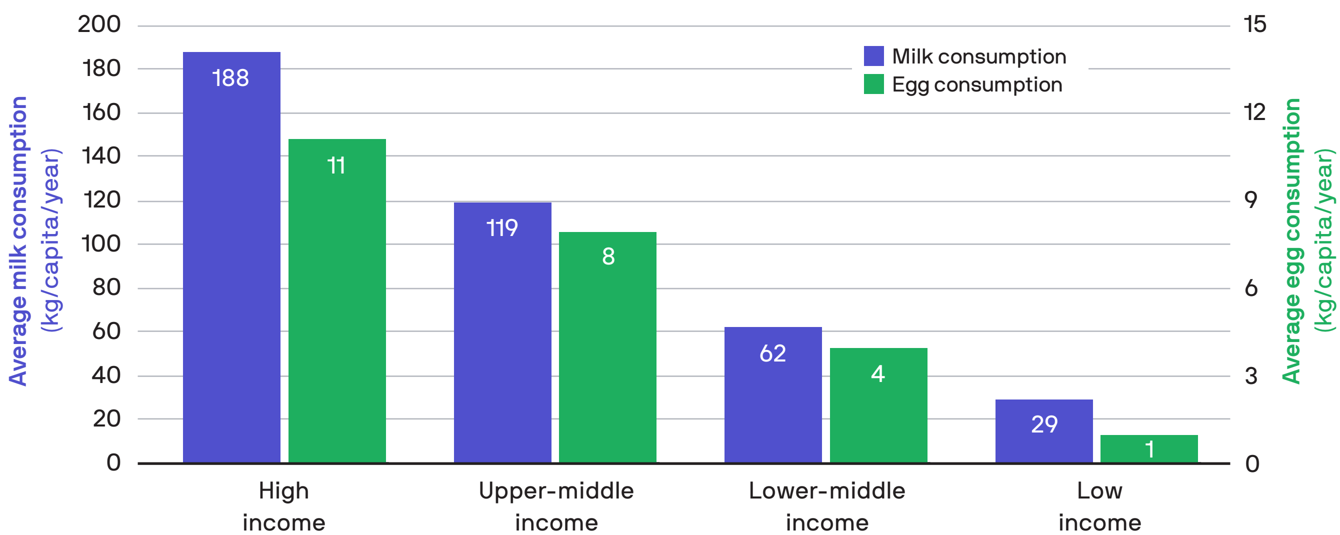
e. This was reported as cost per dozen eggs and converted to cost per kg of eggs to match consumption data; 1 medium egg is approximately 0.05 kg.

When looking at these data across all countries, there are clear disparities by income (Figure 2). High-income countries consume, on average, 188 kg/capita/year of milk-based products and 11 kg/capita/year of eggs.[27] This is roughly six times more than the average milk consumption in low-income countries (29 kg/capita/year) and roughly nine times more than the average egg consumption in low-income countries (1 kg/capita/year). Across only LMICs, the total annual market size for milk-based products is approximately 211 billion kg (or $292 billion),[39] while the annual market size for eggs is 10 billion kg (or $41 billion).[41] This represents the market size and value for complete milk and egg products, not just the protein content. When looking at the data over time, per capita consumption of milk-based products and eggs has seen only minimal growth in the past 20 years, with the most growth seen in low-income countries and the most year-over-year fluctuations seen in high-income countries.[27] However, as populations grow, total consumption of milk-based products and eggs continues to rise.

Food aid market

Food aid (or in-kind food commodities) is defined as the provision of food commodities by one country to another to help a country meet its food needs.[45] Several stakeholders mentioned the potential for cultured protein use in the food aid market for LMICs, particularly given that some fortified or specialized food products contain milk or milk powder. As such, an analysis was performed to estimate the annual market size for food aid globally. Food aid can be provided for emergency relief situations or to populations that are vulnerable to hunger or malnutrition.[46] Data on both total

FIGURE 2. **Consumption of milk-based products and eggs per capita by country income group (2013).**



Note: We grouped countries by income classification, according to the World Bank,[44] and calculated an unweighted average kg per capita consumption of milk and eggs.

Source: Food and Agriculture Organization of the United Nations website. FAOSTAT: Food balance sheets page. http://www.fao.org/faostat/en/#data/FBS. Accessed August 6, 2019.

food aid spending and total volume of food aid delivered each year are limited, thus available data and assumptions were used to estimate the market size.

The US Agency for International Development (USAID) is the largest provider of food assistance in the world, through its Office of Food for Peace.[45] In 2017, Food for Peace's total global food aid contributions, including only food aid and excluding community development funds and economic support funds, was $3.538 billion, which included 3.125 billion kg of food aid.[47] Based on these data, the average cost per kg of food delivered by Food for Peace in 2017 was approximately $1.13. While Food for Peace does not represent the entire food aid market, which is also supplied by other organizations, it represents a lower bound estimate for the size of the food aid market (Table 3).

TABLE 3. **Calculations for estimated market size for milk protein in food aid.**

Value	Detail	Source
$3,538,000,000	Total Food for Peace spending on food aid in 2017	Food for Peace 2017 annual report[i]
3,124,669,000	Total volume of food aid delivered by Food for Peace in 2017 (kg)	Food for Peace 2017 annual report[i]
10%	Maximum estimated amount of milk protein used in food aid (% of total food volume)	Assumption based on current USAID RUF guidelines[ii]
5%	Middle estimated amount of milk protein used in food aid (% of total food volume)	Assumption based on current USAID RUF guidelines[ii]
1%	Minimum estimated amount of milk protein used in food aid (% of total food volume)	Assumption based on current USAID RUF guidelines[ii]
312,466,900	Maximum estimated amount of milk protein used in food aid (kg)	Calculation
156,233,450	Middle estimated amount of milk protein used in food aid (kg)	Calculation
21,246,690	Minimum estimated amount of milk protein used in food aid (kg)	Calculation
$6	Cost per kg of milk protein	Dairy for Global Nutrition[iii]
$1,874,801,400	Maximum estimated value of milk protein used in food aid	Calculation
$947,400,700	Middle estimated value of milk protein used in food aid	Calculation
$187,480,140	Minimum estimated value of milk protein used in food aid	Calculation

Abbreviations: RUF, ready-to-use food; USAID, US Agency for International Development.

Note: The 2017 Food for Peace funding values include only food aid, and exclude community development funds and economic support funds.

Sources:

i. US Agency for International Development (USAID). *Food for Peace Fiscal Year 2017* Year in Review. Washington, DC USA: USAID; 2017. https://www.usaid.gov/sites/default/files/documents/1866/FY17_Annual_Report_FINAL_508_compliant.pdf.

ii. US Agency for International Development (USAID). RUF: *Ready-to-Use Nutritional Food for Use in International Food Assistance Programs.* Washington, DC USA: USAID; 2015. https://www.usaid.gov/sites/default/files/documents/1866/USAID_RUF_Specification.pdf.

iii. Dairy for Global Nutrition website. Dairy price trends page. https://www.dairyglobalnutrition.org/price-and-supply-trends/dairy-price-trends. Accessed September 30, 2019.

Of the global food aid market, it is unknown exactly how much of this is protein, or more specifically milk protein. Egg protein or egg powder was not identified as an ingredient in any food aid products. Stakeholders who participated in interviews for this project said that at present, milk is incorporated into only a few food aid products. Ready-to-use supplementary food, ready-to-use therapeutic food, Nutriset's Plumpy'Nut®,[48] and Super Cereal Plus are specialized food products known to contain milk protein and that are often provided through food aid channels. Approximately 10% to 15% of these products is milk protein by weight.[49] Therefore, of the 3.125 billion kg of food aid donated annually by Food for Peace, it is estimated that a small fraction currently contains milk. This analysis estimates a range of 1% to 10%, which represents approximately 31 million to 312 million kg of milk protein (Table 3). Note that this is the volume of milk protein only, and not a complete milk product.

The estimated cost of the protein content of skim milk powder in 2017 was approximately $6 per kg of protein.[50] Applying this cost to the volume of milk proteins estimated above, the estimated market value for milk protein powder in the food aid market for Food for Peace is between $187 million and $1.875 billion. It is important to note that the cost per kg of milk protein (assumed to be $6) is much higher than the average cost per kg across all types of food aid products ($1.13, as stated above).

Market size summary for milk and egg proteins in low- and lower-middle income countries

The current market sizes for milk and egg proteins in the consumer and food aid markets in LMICs are summarized in Table 4. The current consumer market size for milk is the largest market, while the food aid milk market makes up a fraction of the consumer milk and consumer egg markets. Cultured proteins could be used as replacements for milk and egg proteins in existing spaces (e.g., consumer diets and food aid products that currently contain milk), or could be used to increase the size of the protein market as a whole (i.e., be added into diets or foods that do not already contain protein). One interview participant said that it would be possible to increase protein levels in food aid products generally by adding dried milk powder or milk protein isolates (including possibly cultured milk proteins) to existing food aid products that do not currently contain protein.

Rising rates of alternative protein consumption in high-income countries

In high-income markets, the high consumption rates of animal-source milk and eggs, along with meat as a source of protein, are starting to be disrupted by alternative proteins, notably plant-based alternatives. In the United States, for example, sales of plant-based alternatives as a whole grew by more than 20% in 2018 to a total market of $3.3 billion, whereas sales of all foods grew by only 2% in comparison.[51] Plant-based milk sales grew 9% in 2018 and now represent 15% of the total milk market, while sales of cow's milk declined 6%. Similarly, sales of plant-based meats grew by 24% in 2018, while animal meats grew by only 2%. Sales of plant-based eggs and plant-based mayonnaise grew 16%.[51] See Table 5 for more data.

Similar trends have been seen in the United Kingdom, where 23% of households reported using plant-based milk at least once in the three months leading up to February 2019, up from 19% in 2018. Overall, sales of plant-based milk have grown 30% in the United Kingdom since 2015.[52] The global plant-based milk industry was estimated to be approximately $16 billion in 2018, up from $7.4 billion in 2010 (a 116% increase over eight years).[53]

This growth in plant-based protein sales may be attributed to a variety of factors. According to one expert, "The dairy alternatives market has seen rising levels of interest in recent years, spurred mainly by consumers increasingly looking for lactose-free, dairy-free, and plant-based/vegan options as healthy lifestyle choices, rather than regarding

TABLE 4. **Annual estimated market size for milk and eggs in low- and lower-middle income countries in 2017.**

	Consumer milk market (complete milk product, 2013)	Consumer egg market (complete egg product, 2013)	Food aid milk market (milk protein only, 2017)
Volume (kg)	**210.7 billion**	10.0 billion	31 million to 312 million
Dollars (US)	**$291.6 billion**	$40.8 billion	$187 million to $1.9 billion

Note: The consumer milk and egg markets represent complete milk and egg products, while the food aid milk market represents the estimated market for milk proteins only. Generally, skim milk contains about 35% protein by weight.

them as simply for those with allergies or intolerances."[53] The number of lactose-intolerantf individuals may be up to two-thirds of the global population.[52] Data from the United Kingdom have shown that 37% of individuals aged 16 to 24 years—the leading consumers of plant-based milk—have reduced intake of cow's milk for health reasons, while 36% agree that dairy farming negatively impacts the environment.[54] Additionally, in the United Kingdom 40% of milk consumers reported they would be willing to pay more than the current price of milk, indicating an ability to pay more for the product.[54] It is important to note that most plant-based milks do not have the same protein content or amino acid profile as animal-source milks.[52] While less of a consideration for high-income countries, in LMIC settings where animal-source protein is lacking, it is more important to secure sufficient high-quality "complete" proteins, which are largely found in animal-source foods (and not their plant-based alternatives).

f. Lactose intolerance refers to the absence of the lactase enzyme to break down milk proteins.

TABLE 5. **Market value and annual growth of plant-based alternatives in the United States, by category (2018).**

Category	Dollars (millions US)	Year-over-year growth
Milk	$1,600	9%
Meat	$670	24%
Other plant-based dairy substitutes (total)	$697	50%
Ice cream	$222	38%
Yogurt	$162	55%
Cheese	$124	43%
Creamer	$109	131%
Butter	$68	23%
Dressing	$12	32%
Meals	$210	28%
Tofu/tempeh	$108	11%
Egg/mayonnaise	$42	16%
Grand total	**$3,300**	**20%**

Adapted from Plant Based Foods Association website. Consumer access: 2018 U.S. retail sales data for plant-based foods page. https://plantbasedfoods.org/consumer-access/nielsen-data-release-2018/. Accessed September 30, 2019.

Cultured protein manufacturer landscape

Key messages

- Five manufacturers of cultured proteins were included in this analysis, of which two are developing milk proteins, two are developing egg proteins, and one is developing a novel cultured protein.
- Most manufacturers formed their companies within the past five years, and the first products are expected to launch business-to-business in high-income markets in 2020.
- Some product attributes (e.g., room temperature storage and potential for improved shelf life) may make cultured proteins more suitable for use in LMICs than traditional animal-source milk and eggs.
- Most manufacturers are initially aiming to price products at parity to existing milk and egg products but acknowledged that price reductions are possible once the products are being sold at scale. To scale operations globally, two cultured protein companies have partnered with large, multinational food companies.

Key manufacturers

The market for cultured proteins is rapidly evolving, with new companies launching every year and most existing companies joining the market after 2015. As of February 2019, when this analysis began, approximately eight to ten major cultured protein manufacturers had been identified. Five of these manufacturers were included in this landscape: BioscienZ, Clara Foods, New Culture, Perfect Day, and Solar Foods. Each of these companies is working to develop a cultured dairy, egg, or other powdered protein product, though no cultured protein products are commercially available as of the time of writing. Information included in this section is from company websites, news articles, press releases, and stakeholder interviews. The information and tables below outline in further detail information about each selected cultured protein manufacturer and the key product attributes for their cultured protein products.

BioscienZ

Netherlands-based BioscienZ was founded in 2011 as a consulting company and established its first laboratory in 2014 to transition into a solutions provider to conduct in-house contract research. It currently employees a staff of approximately ten people. In order to solve the global problem of how to feed a growing population, the company has both food projects and agricultural projects. On the food side, BioscienZ is looking to develop a fermentation-based egg white protein and a fermentation-derived plant-based meat product. These proteins are designed to be more environmentally responsible, sustainable, and efficient than animal-source proteins. The egg white protein is created by over-expressing a chicken ovalbumin gene in a fungus, which is fed sugar beets or grains to induce

TABLE 6. **Summary of BioscienZ's cultured protein product attributes.**

Protein type	Product type	Price	Shelf life	Required storage conditions	Nutritional content	Production technology	Estimated date of commercial availability
Cultured egg protein (ovalbumin)	Primary: additive (liquid); secondary: Stand-alone	N/A	N/A	N/A	N/A	Fermentation-based cellular agriculture with a fungus	2024

N/A: Information not available.

Sources: BioscienZ website. https://www.bioscienz.nl/. Accessed August 16, 2019. PATH interview with manufacturer.

fermentation. This product will be used in the company's plant-based meat product as a binding agent, though may also be sold and used as a stand-alone liquid egg white product. BioscienZ received funding to develop its egg white protein in 2018 from the Dutch government's Small Business Innovation Research Programme and in 2019 from the Municipality of Breda. It hopes to launch its first commercial product in 2024.[55] See Table 6 for further details.

Clara Foods

Clara Foods was founded in 2015 out of IndieBio (a life sciences accelerator) and now has nearly 40 employees. The San Francisco, California, USA–based company has developed a technology to create a vegan replacement for egg white proteins, with the goal of producing nutritious proteins more sustainably than through livestock production. The proteins are created by a fermentation process that involves cultivating yeast strains and feeding them a sugar substrate to produce tailor-made egg proteins. By focusing production on individual egg white proteins, Clara Foods can ensure higher purity and lower costs than would be feasible by creating a complex protein mix. This company is starting its product line with proteins found in chicken eggs. These manufactured proteins are better for the environment because less waste is produced in their creation. The additive products can be used as a performance supplement, preservative, baking product, food and beverage ingredient, or general egg replacement. Clara Foods received $15 million in Series A funding in 2016 and Series B funding of $30 million in 2019. The company recently partnered with Ingredion, a global company focused on making ingredients such as sweeteners, starches, and biomaterials, to distribute and market their protein products, and plans to launch its first commercial product(s) in 2020.[56] See Table 7 for further details.

TABLE 7. **Summary of Clara Foods' cultured protein product attributes.**

Protein type	Product type	Price*	Shelf life	Required storage conditions	Nutritional content	Production technology	Estimated date of commercial availability
Cultured egg white protein	Additive (powder)	Selling price: Goal is to be cost competitive with farm-raised eggs	N/A	N/A	Protein content and amino acid composition will match that of select egg white proteins	Fermentation-based cellular agriculture with yeast	2020

N/A: Information not available.

*Price information was gathered based on available data. Prices are described differently and not necessarily comparable across companies.

Sources: Clara Foods website. https://www.clarafoods.com/. Accessed August 16, 2019. PATH interview with manufacturer.

TABLE 8. **Summary of New Culture's cultured protein product attributes.**

Protein type	Product type	Price*	Shelf life	Required storage conditions	Nutritional content	Production technology	Estimated date of commercial availability
Cultured casein protein	Stand-alone (complete mozzarella cheese that includes fermentation-derived casein)	Production cost: Aiming for less than $30/kg in 2024 (for a product with 100% recombinant casein protein)	~2 weeks (same as standard mozzarella)	Refrigeration or freezing	Protein content, major minerals, and vitamins will be on par with fresh mozzarella	Fermentation-based cellular agriculture with a unique microbe	2023-2024

*Price information was gathered based on available data. Prices are described differently and not necessarily comparable across companies.

Sources: New Culture website. https://www.newculturefood.com/. Accessed August 16, 2019. PATH interview with manufacturer.

New Culture

New Culture was founded in 2018 with the goal of creating animal-free dairy cheese products, starting with mozzarella. The company is a recent member of San Francisco-based IndieBio's four-month life science accelerator program and was granted $250,000 in seed funding to develop its proof of concept. Currently, New Culture has approximately four employees. Its animal-free, cholesterol-free, and lactose-free dairy cheese products are created using microbial fermentation to generate casein proteins, which give cheese its dairy characteristics. New Culture aims to improve upon traditional cheese manufacturing practices with respect to water usage, sustainability, animal welfare, land shortage, food shortage, and dairy allergies.

While casein is the key ingredient in cheese, it will be supplemented with plant-based ingredients to create the mozzarella cheese product. The company recently secured a $3.5 million seed round and plans to launch this product commercially in 2023-2024.[57] See Table 8 for further details.

Perfect Day

Perfect Day was founded by two co-founders who were passionate about creating vegan dairy products. After meeting through New Harvest, they created Perfect Day in 2014, based in Emeryville, California, USA. The company was originally called Muufri, but the name was changed to Perfect Day in August 2016. Perfect Day, which has nearly

TABLE 9. **Summary of Perfect Day's cultured protein product attributes.**

Protein type	Product type	Price*	Shelf life	Required storage conditions	Nutritional content	Production technology	Estimated date of commercial availability
Cultured milk protein (whey and casein)	Additive (powder)	Selling price: Goal is to be cost competitive with equivalent animal-source proteins (whey: ~$30/kg; casein: ~$23/kg)	N/A (potential to be longer than traditional milk)	Room temperature	Will be identical to whey and casein pure protein isolates	Fermentation-based cellular agriculture with a microflora	2020

*Price information was gathered based on available data. Prices are described differently and not necessarily comparable across companies.

Sources: Perfect Day website. https://www.perfectdayfoods.com/. Accessed August 16, 2019. PATH interview with manufacturer.

70 employees, uses a fermentation process to create milk proteins. It introduces essential milk genes into microflora, which then convert plant sugar into whey and casein proteins. This protein can then be used to create vegan and lactose-free versions of cheese, yogurt, ice cream, and other products. The protein is also free of hormones, antibiotics, and cholesterol, and has the potential to have a longer shelf life than traditional milk. Perfect Day has received $61 million in funding through Series B. In the future, the company will likely sell its protein powder as an additive to other commercial food companies through a business-to-business (B2B) model. In 2018, it announced a key partnership with Archer Daniels Midland, one of the world's largest agricultural processors and food ingredient providers, to help develop, scale, and commercialize production. Products are expected on the market in 2020.[58] See Table 9 for further details.

Solar Foods

Solar Foods is a Finnish company with approximately six employees that was founded in late 2017 by scientific experts from the Technical Research Centre of Finland Ltd. and the Lappeenranta University of Technology. Its novel protein, Solein, was created using a concept from the US National Aeronautics and Space Administration space program. The company aims to produce "food out of thin air." The fermentation process used to create Solein involves introducing carbon dioxide, hydrogen, and renewable energy into a unique, natural microorganism in water. The microorganism reproduces in a fermenter as it consumes carbon dioxide, hydrogen, and nitrogen. As the liquid is removed and dried, a powder is formed. The end product looks and tastes like wheat flour and includes 50% protein (covering all essential amino acids), along with fat, vitamins, and nutrients. This bioprocess could be used to create food ingredients, plant-based meat alternatives, or cultured meat. The company claims Solein is 100 times more climate friendly than any animal- or plant-based alternative. Solar Foods has received more than $2.2 million in two rounds of funding, and is hoping to launch its product in 2021.[59] See Table 10 for further details.

TABLE 10. **Summary of Solar Foods' cultured protein product attributes.**

Protein type	Product type	Price*	Shelf life	Required storage conditions	Nutritional content	Production technology	Estimated date of commercial availability
Cultured novel protein (Solein)	Additive (powder)	Production cost: ~$6/kg (for a 100% protein product)	N/A	N/A	50% protein (contains all essential amino acids), 5–10% fat, 20–25% carbohydrates	Fermentation-based cellular agriculture with a natural, nonmodified microorganism	2021

N/A: Information not available.

*Price information was gathered based on available data. Prices are described differently and not necessarily comparable across companies.

Sources: Solar Foods website. https://solarfoods.fi/. Accessed August 16, 2019. PATH interview with manufacturer.

Product attributes

In order to compare cultured milk and egg proteins to animal-source milk and egg proteins, we captured information on several key product attributes, including those that may be relevant to the commercialization of cultured milk and egg proteins in LMIC markets. The earliest cultured protein products are expected on the market in early 2020 (in high-income countries); they are currently undergoing the final steps leading up to a product launch. Ahead of this, some companies may pre-launch products to create buzz around their brand. For example, in July of 2019, Perfect Day distributed a limited release (1,000 three-pack pints) vegan ice cream product made with cultured milk proteins that sold out in hours. However, most of the cultured protein companies interviewed, including Perfect Day, ultimately plan to produce ingredients they will sell to other companies via a B2B model. These buyers could then use them as ingredients in a variety of products.

When compared to animal-based milk and eggs, cultured milk and egg proteins could have several advantages in LMICs. While more data are needed, some manufacturers mentioned the potential for the proteins to have a longer shelf life than proteins produced through traditional farming, given they are made in a more sterile environment with fewer contaminants. In addition, access to refrigeration and electricity is limited in LMICs, and at least one manufacturer of a cultured milk protein product claimed the product can be stored at room temperature (20°C). While the exact prices of these products are still unknown, most manufacturers aim to have their products priced at parity to animal-source proteins. Once the products are produced at scale, price reductions are possible. Given the price-sensitive nature of vulnerable populations in LMICs, reductions in price of cultured proteins over animal-source proteins will be critical for the successful market penetration of cultured proteins. However, when comparing the total cost of animal-source proteins versus cultured proteins, it is also important to consider other relevant costs such as those of delivery and refrigeration.

Prioritized geographic and end user markets

Three interviewed companies plan to initially prioritize product launches in the United States, and two companies will likely first target product launches in Europe and Asia. These initial geographic markets were chosen by manufacturers for a variety of reasons. According to some, the United States is often an early adopter of new food and has established regulatory requirements (see the accompanying Policy and Regulatory Environment paper for more details). It has seen tremendous growth in the markets for other alternative protein products (e.g., plant-based meat and milk),[60] has a relatively large market size (due to its large population), and is a high-income country with wealthy consumers. Multiple companies indicated that the European regulatory process will likely be lengthy and tedious, thus it may not be an ideal first market to enter. However, as noted previously, European consumers may be willing to pay more for high-quality proteins.

Most of the companies included in this market landscape plan to begin selling B2B, primarily looking to sell their protein as an ingredient to major food companies. However, they have also done research to determine the consumer end users they would like to target. Initially, most companies plan to target consumers who are willing and able to pay a price premium for a high-quality protein product, produced without harming animals and with a better environmental footprint. Three cultured protein companies specifically mentioned targeting vegan markets (products will be labeled as vegan), as vegans may be attracted to innovative, animal-free versions of existing proteins. However, these companies also mentioned that vegans will likely not be the sole target consumer segment. Environmentally conscious consumers and consumers focused on proteins for improving health and athleticism were also mentioned as possible key consumer segments. New Culture, the only company making a complete product, plans to sell a business-to-consumer (B2C) retail product as their market entry strategy.[61] While two companies stated they have considered the use of their products in LMICs or emergency relief settings, these would likely be lower-priority markets, targeted after they have achieved a larger scale and costs have decreased. Nevertheless, whey protein isolate is already part of USAID's procurement list for food aid, and with new research on the role of animal-source proteins in human growth and development in LMIC settings,[13,14] the food aid market for these products may grow in the future.

As a comparison, in addition to companies producing cultured milk and egg proteins, a variety of other alternative protein companies and products were reviewed to understand how producers are prioritizing geographic markets and market segments. These five additional companies were making products such as cell-based meat/poultry (Memphis Meats, JUST, Higher Steaks), cell-based crustaceans (Shiok Meats), plant-based eggs (JUST), and plant-based meat alternatives (Impossible Foods). These companies are based in the United States (California: Memphis Meats, JUST, and Impossible Foods), the United Kingdom (Higher Steaks), and Singapore (Shiok Meats).

Similar to the cultured protein companies, most other alternative protein companies interviewed plan to launch products first (or have already launched) in the United States and higher-income regions of Asia. Europe was not mentioned. Asia is an appealing market to manufacturers for a variety of reasons. According to manufacturers, Asia is a large and fast-growing market (in terms of population), has a declining supply of animal-source foods,[62] has affluent populations that are willing to pay more, and includes regions that have high rates of importing meat and have shown interest in new food technologies (e.g., Singapore and Hong Kong). In addition, most high-income Asian countries have a well-defined food regulatory process and regulators who are open to supporting new food technologies. Unlike cultured protein companies, these other alternative protein companies employ a mix of B2B and business-to-consumer approaches, with most planning to begin sales to high-end restaurants, along with either grocery stores, food companies for frozen meals, or other premium consumer markets. Many of these decisions were attributed to the fact that it is much easier to integrate innovative foods as ingredients or flavorings from a regulatory perspective, as opposed to selling directly to consumers (see the accompanying Policy and Regulatory Environment paper for more details).

These learnings from select cell-based meat and plant-based protein food manufacturers indicate there may be overlap between the markets for these two types of alternative proteins and the markets for cultured proteins. While cultured protein products are not currently available, there is a perceived market opportunity in high-resource settings. Given that these products may be competing with plant-based protein alternatives, the alternative protein space may become more crowded, creating competition and potentially market efficiencies. The LMIC market is likely much less contested and could potentially provide health benefits to malnourished populations as well as companies and their shareholders.

Partnerships

Two of the manufacturers included in the landscape have partnered with large, multinational food companies. Both companies have stressed that these partnerships are critical for scaling up operations. Larger-scale operations could create production efficiencies and drive down costs. In May of 2019, Clara Foods partnered with Ingredion, a global ingredient solutions provider. Ingredion makes sweeteners, starches, nutrition products, and other ingredients that are used for a variety of purposes and had net sales in 2018 of $5.8 billion.[63] The company currently has a presence in select LMICs, including offices in Kenya[64] and Vietnam.[65] Clara Foods CEO Arturo Elizondo said, "We see extraordinary value in partnering with Ingredion to distribute our products globally and look forward to jointly transforming the status quo means of making animal protein at scale."[66]

In November of 2018, Perfect Day announced their partnership with Archers Daniel Midland (ADM) to commercialize animal-free dairy products. ADM is one of the world's largest agricultural processors and food ingredient providers. The company serves products to nearly 200 countries globally, and has offices in select LMICs such as India, Indonesia, and Vietnam.[67] In 2018, ADM's net sales were $6.8 billion.[68] Ryan Pandya, CEO of Perfect Day, said, "We are on a journey to bring sustainable, nutritious and delicious dairy to everyone. We are thrilled to partner with ADM, a global leader in fermentation, to accelerate our path to market. With this partnership, we will enable brands to make your favorite foods in a kinder, greener way."[69]

Stakeholder perceptions of cultured proteins

Key messages

- Almost all stakeholders interviewed were either "very aware" or "somewhat aware" of cultured proteins prior to the interview, with positive perceptions of the proteins for use in LMICs.
- The most important expected key benefits of cultured proteins to stakeholders were that they have an equally high nutritional value, lower environmental footprint, and equivalent or lower cost than their respective animal-source proteins.
- Stakeholders questioned whether cost reductions were feasible, how potential GMO status may impact product labeling and market uptake, and whether consumers would readily adopt these new foods.
- Many stakeholders mentioned that milk and eggs have additional beneficial compounds besides proteins and that more evidence is needed on whether cultured proteins will provide similar nutritional benefits as the whole product.
- More data should be generated to show the benefits of cultured proteins in terms of cost and environmental impact.

As part of the interview process, non-manufacturer stakeholders were interviewed about their previous knowledge of cultured proteins and their reactions to the concept card (Appendix A).[g] The concept card focused on the use of cultured proteins in LMICs, and the majority of respondents have experience working in LMIC markets. Key findings from the results of these questions are detailed below.

g. While the concept card was focused specifically on cultured milk and egg proteins, Solar Foods represents a company making a cultured protein product from the same process (fermentation-based cellular agriculture) but that does not directly replicate a milk or egg protein.

Awareness and perceptions of cultured milk and egg proteins in low- and lower-middle income countries

Among 14 stakeholders, 9 claimed to be "very aware" of cultured milk and egg proteins before the interview, 4 claimed to be "somewhat aware," and 1 claimed to be "not at all aware." Overall, on a scale of 1 to 5, with 1 being "extremely negative" and 5 being "extremely positive," the average perception of cultured proteins for use in LMICs was a 4.0 (n = 14). Interestingly, the perception of cultured proteins slightly increased with awareness level. The average perception of those who were "very aware" of cultured proteins was 4.3, compared to 3.8 for those "somewhat aware," and 3.0 for the individual who was "not at all aware." The stakeholders in nonprofit organizations (research/advocacy/professional groups) and other

TABLE 11. Summary of stakeholder awareness and perceptions.

	Very aware	Somewhat aware	Not at all aware	Total
Number of responses	9	4	1	14
Average perception score	4.3 (range: 2–5)	3.8 (range: 3–5)	3.0 (range: 3)	4.0 (range: 2–5)

Note: These questions were not asked to companies manufacturing cultured proteins.

stakeholders (in academia, donors, government, and independent experts) were almost all "very aware" of cultured proteins, while four of five food aid suppliers/procurement/distribution agencies were only "somewhat aware." See Table 11 for a summary of results.

Top-valued attributes

Eight expected key benefits of cultured proteins were listed on the concept card (Appendix A).[h] These benefits, relative to traditional animal-source milk and egg proteins, were derived from secondary research and reviewed by select manufacturers. Compared to animal-source proteins, cultured proteins are expected to:

- Contain the same high nutritional value.
- Have a lower environmental footprint and fewer greenhouse gas emissions.
- Require less agricultural inputs (e.g., land, water, energy).
- Do not require any animal breeding or slaughter (is a vegan product).
- Contain no hormones, antibiotics, or foodborne pathogens.
- May have an extended shelf-life (may not require cold storage).
- Have the same taste, texture, and chemical structure.
- May be lower-cost and/or have fewer cost fluctuations.

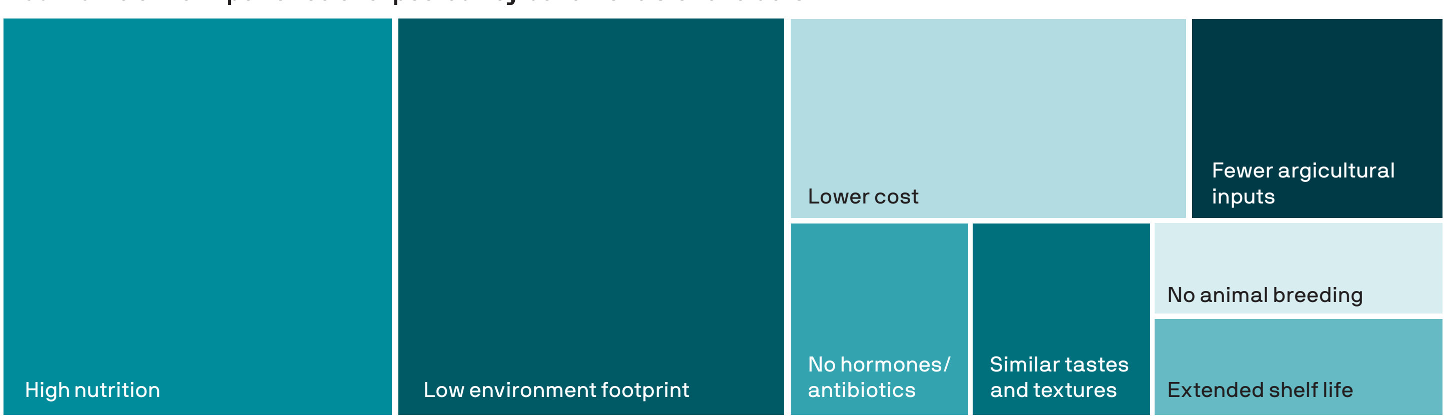
h. While these benefits are expected, and were vetted with select manufacturers, data will need to be generated to support each of these claims.

Of these attributes, stakeholders were asked to rank their top three perceived benefits in order of importance. The highest-ranking attribute was nutritional value, closely followed by lower environmental footprint. For nutrition, select stakeholders pointed out that cultured proteins could potentially have improved nutrition over their animal-source equivalents; for example, if undesirable contents, such as cholesterol, could be eliminated. However, multiple stakeholders also specified that while these cultured proteins could replace their equivalent animal-source proteins, many complete animal products (e.g., milk and eggs) have other important nutritional components besides the protein themselves.

The third highest ranked benefit was cost; however, this was also the most controversial. Many stakeholders indicated that cost is a key potential benefit of cultured proteins, if they can indeed be made at a lower cost than equivalent animal-source proteins. However, others did not believe this was possible, citing high production costs. All other factors were somewhat evenly distributed, and overall less important to stakeholders (though each did receive at least one first- or second-place ranking). See Figure 3 for a map of relative importance to stakeholders of each expected key benefit.

In addition to the listed benefits, stakeholders were asked if they saw other potential benefits that could come from

FIGURE 3. Relative importance of expected key benefits to stakeholders.



Note: The size of each box represents the relative importance of each expected key benefit to stakeholders.

cultured proteins. Select additional benefits listed by stakeholders included:

- Cultured proteins could be specifically designed to fill a key protein gap (with a specific amino acid profile) for a particular context.
- The nutritional status of a product could be maximized by increasing protein content relative to other content (e.g., fat).
- If in-country production were feasible, local food security might improve.
- Products made with cultured proteins could be specifically regulated in terms of fat, sodium, carbohydrates, salt, and other relevant components of their nutrient profiles.
- Cultured proteins may not have the same allergens as animal-source proteins (e.g., lactose in milk), which may allow more people to benefit from them.
- Proteins may be easier to ship if a concentrated protein powder is produced (compared to eggs or liquid milk).

Potential challenges to commercialization and market uptake in low- and lower-middle income countries

Although cultured proteins were generally perceived positively by participating stakeholders, there were several mentions of potential challenges to commercialization and market uptake. The leading concern for stakeholders was cost, with low cost deemed as a key success factor for market uptake in LMIC settings. Many stakeholders mentioned these products will need to be priced on par with, or less than, traditional animal-source proteins to be adopted in LMIC markets. Stakeholders and manufacturers mentioned that a substantial up-front investment will be needed to build fermentation/product plants in order to scale production, improve production efficiencies, and drive down costs. Additionally, there are substantial costs associated with other parts of the process, such as purification (most cultured proteins will be sold in a purified form). Technological advances, such as less costly growth media or improved strains of microflora, could also potentially contribute to reduced prices. Two companies have partnered with large, multinational companies to help scaling efforts.

Stakeholders also frequently mentioned potential challenges with regulation, labeling, and evidence. In some places, such as Europe (select countries), Ethiopia, and India, the fact that a GM product is used in the production of cultured proteins may pose a problem (see the accompanying Policy and Regulatory Environment paper for more details). Labeling was also frequently cited as a concern, and whether these products could be labeled as "GMO free," "organic," or other labels. This may be further complicated by lobbying from the dairy industry, which will not want these products to be labeled in the same way as animal-source products such as milk). In addition, some stakeholders noted the need for clinical studies to demonstrate effectiveness, especially for use in food aid products.

Uncertainty around consumer acceptance was mentioned by stakeholders as a potential challenge. Stakeholders reported that consumers are often hesitant to accept new foods or food technologies, having concerns about their safety, inclusion of GMOs, or eating products that are not "natural." While these products do not contain GM ingredients, they are made with a GM organism. Consumer acceptance of GM products is mixed globally. Additionally, it is unclear if consumers will like the taste and texture of the products. Furthermore, consumption of milk and eggs is low in many LMICs, thus consumers may be less likely to adopt cultured egg proteins if they are not already familiar with consuming animal-source eggs. Lastly, there was some concern regarding how cultured proteins may potentially negatively impact the livelihoods of farmers in LMICs (e.g., loss of jobs or cows as a financial asset).

Evidence desired to support adoption

Some stakeholders said that additional evidence may be needed to support use in LMICs. One piece of evidence mentioned was data to prove these cultured proteins are equivalent to animal-source proteins. In addition, evidence supporting their digestibility, and how they differ from complete milk products, would be beneficial. Some stakeholders desired information on how the cost of cultured proteins compares to the cost of animal-source proteins, in addition to how the environmental footprint of generating cultured proteins is less than that of producing animal-source proteins. Consumer data may be needed to prove consumer acceptance and show that cultured proteins have an acceptable sensory profile. Finally, multiple stakeholders mentioned they trust guidance from select "well-regarded organizations" that work in the food industry, so generating buy-in from groups like the Good Food Institute, World Food Programme, United Nations Children's Fund, US Food and Drug Administration, World Health Organization, FAO, and US Department of Agriculture may help to accelerate acceptance and adoption of these proteins.

Conclusion

The cultured protein market in the United States and Europe is at a pivotal phase, with products expected to launch in early 2020. The rise of the plant-based milk market in high-resource markets, and the concurrent decline of animal-source milk, has demonstrated that consumers in high-resource markets are demanding alternative protein products and are often willing to pay a price premium for them. Cultured proteins have potential to tap into this consumer interest and further grow the alternative protein market. To match the growing demand, cultured protein manufacturers may initially target vegans, athletes, and environmentally conscious consumers in high-income countries. However, their products have several attributes that make them interesting for potential use in LMICs, in which select manufacturers have expressed interest as long-term market opportunities. For example, some cultured protein products may not need refrigeration and may have a longer shelf life than animal-source products. As electricity and refrigeration are often very limited in LMICs, a heat-stable protein powder may be a good fit in these settings.

While cultured protein manufacturers are aiming to have a similarly priced product to animal-source products, potential reductions in price may be possible with manufacturing efficiencies. Two cultured protein manufacturers have partnered with large, multinational corporations that can help create more efficient manufacturing processes and distribute their products on a larger scale. Because the fermentation-based manufacturing process is similar to producing beer, it may be possible to manufacture these products in LMICs to reduce distribution costs and decrease reliance on food imports. Lastly, stakeholders participating in this exercise (the majority of which have worked in LMIC settings) had positive perceptions of cultured proteins and thought there would be potential value for these products in LMIC markets. Many would like to see prices reduced and clinical evidence demonstrating the comparability to farm-raised animal proteins and the potential health benefits to vulnerable populations. In addition, stakeholders mentioned that close attention needs to be paid to possible disruptions in the livelihoods of LMIC farmers and mitigation strategies need to be developed to address this and other consumer concerns.

Limitations

There are several limitations with this analysis:

- Cultured protein products are not yet on the market. Therefore, their market potential is based on stakeholder perceptions and analysis of other alternative protein products that have already launched (plant-based replacements for animal-source proteins).
- The cultured protein space is evolving rapidly, and the manufacturing landscape will shift in the future. Most cultured protein companies were founded less than five years ago.
- Final prices of cultured protein products are unknown. Manufacturers have indicated a desire to sell products at the same price as, or potentially a lower price than, animal-source proteins. They have also indicated that prices will likely decline once production of the products reaches scale.
- While stakeholder perceptions of cultured proteins were very positive, the sample size for this project was small; only 25 stakeholders participated in the interviews. Consumer perceptions in LMIC markets were not collected.
- This paper does not directly assess the supply chain or distribution for cultured proteins, or the direct potential for these proteins to be produced in LMICs. We were unable to interview large, multinational food companies that work in the protein space for this analysis.

Recommendations

Recommendations for future work to augment this analysis and generate further findings include:

- Develop a target product profile for a cultured protein product that could help ensure that product development efforts are aligned with the needs of consumers in LMICs.
- Conduct consumer acceptance studies to gain further insights into potential demand in LMICs, especially given the near-term time to launch of cultured proteins.
- Conduct costing analyses to understand the potential for cost reductions once cultured proteins are manufactured at scale and to understand other potential cost savings that cultured proteins may offer, such as delivery or refrigeration.
- Gather additional evidence on the impact of cultured proteins on health in vulnerable populations.

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Appendix

Concept card: Cultured milk and egg proteins for use in low- and lower-middle income countries

Background

Undernutrition of children and mothers is the leading underlying cause of child morbidity and mortality worldwide,[1] and is a significant health problem in low- and lower-middle income countries (LMICs). Low-quality diets that are lacking in essential proteins, sufficient energy, and essential vitamins and minerals are a key contributor to undernutrition.[2] Studies have shown that increasing consumption of animal-source proteins can combat child malnutrition,[3,4] while other studies have shown the negative agricultural and environmental impacts of raising livestock (including high land/water use requirements and greenhouse gas emissions).[5] The commercialization of cultured proteins (also referred to as synthetic proteins, flora-based proteins, or fermentation-derived proteins) has the potential to increase access to high-quality and affordable proteins, which could sustainably support global nutrition while reducing the environmental and agricultural pressures of producing animal-source proteins.

Cultured proteins, which are identical to their equivalent animal-source proteins, are made through cell cultures in a laboratory setting (Figure A). While this process can create many types of animal-source proteins, this concept card focuses specifically on "cultured" milk and egg proteins. Several emerging biotechnology companies are creating cultured milk and egg proteins for use in food products (Figure B), though none are yet commercially available.

TABLE A. **Characteristics of cultured milk and egg proteins**

Production process	To produce cultured milk or egg proteins, the gene encoding the animal protein is introduced into the DNA of a starter culture of microflora (e.g., yeast or fungi). This culture is fed sugar and grown in controlled fermentation tanks, where it expresses the desired protein. This end protein is then separated from the host cells and purified into a powder (see Figure A). This fermentation process is similar to that of brewing beer or creating probiotics, and the proteins could potentially be manufactured in LMICs.
End product	A purified protein powder that is identical in structural, organoleptic, and nutritional properties to the same protein derived from an animal source. This purified protein can be used as a stand-alone protein powder product or as an ingredient in other products, including animal-source food (e.g., milk or egg) substitutes. The final product is GMO free.
Development stage	Research and development
Time to market	Expected to launch in 2020 (at the earliest) for small scale/limited markets, with large scale/global production possible beginning in 2025.[6]
Target cost	Final product cost will depend on the form of the end-product, and will differ between additive (e.g., purified milk protein powder) or complete (e.g., alternative milk that is ready for consumption) products. Cost will also depend on scale, and will likely decrease as sales and production capacity increase. Once scale is achieved, costs may be on par with or less expensive than animal-source proteins.
Expected key benefits over animal-source proteins	• Contains the same, high nutritional value. • Have a lower environmental footprint and fewer greenhouse gas emissions. • Require less agricultural inputs (e.g., land, water, energy). • Do not require any animal breeding or slaughter (is a vegan product). • Contain no hormones, antibiotics, or food-borne pathogens. • May have an extended shelf-life (may not require cold storage). • Have the same taste, texture, and chemical structure. • May be lower-cost and/or have fewer cost fluctuations.

FIGURE A. **Diagram of the production process for cultured milk and egg proteins.**[7]

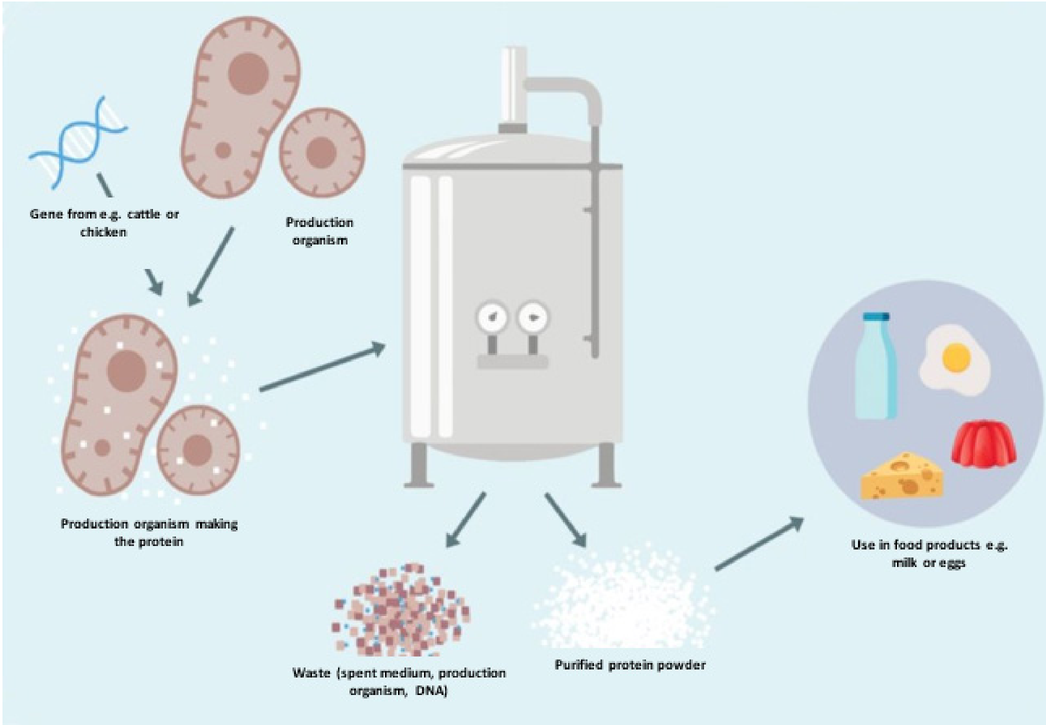

FIGURE B. **Select cultured milk and egg protein manufacturers.**

- BioscienZ
- Clara Foods
- Motif
- New Culture
- Perfect Day

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