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Meat substitutes: current status, potential benefits, and remaining challenges

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Replacing traditional meat with meat substitutes may reduce environmental degradation and improve people's health. We discuss two categories of meat substitutes: plant-based meat alternatives (PBMA) and cultured meat (CM). Despite their benefits, some people may not accept these foods. Neither PBMA nor CM take the form of a solid piece of meat (e.g. a steak), and such cuts are popular. PBMA and CM are novel, and some people may avoid or be uninterested in trying these unfamiliar foods. People may be threatened by PBMA and CM because they have strong attachments to traditional meat or it threatens their social values as a meat eater. Also, PBMA and CM may be too expensive. An important limitation of the available research is that some meat substitutes are still relatively unknown or unavailable. Understanding consumers' perceptions of meat substitutes will require them to have more direct experience with these products.

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Introduction

Raising animals for slaughter to produce meat, something we refer to as 'traditional' meat, has come under increasing fire, primarily for three reasons. (1) Ecological/environmental — the production of traditional meat damages the environment, (2) personal health — the consumption of traditional meat has been shown to have health risks, and (3) ethical concerns — in addition to the fact that they are killed, animals that are raised for slaughter are often treated inhumanely.

One solution to these three problems is for people to reduce or eliminate meat from their diets. Unfortunately, such a solution is difficult to achieve because people enjoy eating meat and they believe it provides important nutritional benefits [1–3]. The food industry has tried to cut this Gordian knot by producing meat substitutes that are meant to replace traditional meat, and this paper focuses on two such substitutes: (1) plant-based meat alternatives (PBMA), and (2) meat grown in laboratory settings (CM, cultured meat).

We focus on PBMA and CM because presently, they are the two most widely discussed meat alternatives. In this paper, we discuss how transitioning from traditional meat to these products may affect the environment and human health, and we discuss potential obstacles to consumer acceptance of these products. For reviews of this topic, see Rubio et al. [4] and Santo et al. [5].

Note that PBMA and CM are in very different places in their respective market cycles. PBMA are available in most major markets, there are numerous producers of PBMA worldwide, and consumers have some experience with PBMA. In contrast, CM has very limited availability. Although many companies are developing CM, only a very few have scalable methods of production, and consumers have virtually no direct experience with CM.

Consistent with the goals of articles in this journal, our review is not exhaustive, rather, it is more illustrative of what is presently known. We cite review articles that contain numerous references that interested readers can pursue. We cite individual papers when they have something distinctive to say or illustrate a point clearly.

What are plant-based meat alternatives and cultured meat?

PBMA are meant to be substitutes for meat, not simply alternative sources of protein. Protein alternatives such as tofu, tempeh, and seitan have been available for hundreds of years and were not intended to be meat substitutes per se (e.g. [6]). In contrast, PBMA are much more recent, and He et al. [6] distinguish two generations of PBMA (1.0 and 2.0). Although PBMA 1.0 and

textured vegetable protein are well accepted by vegetarians, "meat consumers are often not satisfied with the appearance, flavor, and taste of these products when considered as meat alternatives" [6]. This led to the development of PBMA 2.0, whose appearance, nutritional profile, and taste are similar to traditional meat. Although PBMA 1.0 are important parts of the food landscape, much of the recent attention to PBMA has concerned PBMA 2.0 because of its intended (and apparent) broader appeal.

CM, also known as '*in vitro* meat' or 'clean meat,' is produced using cells taken from an animal. As noted previously, CM is at the beginning of the product cycle, and the technologies to produce CM are still being developed. See Hong et al. [7] and Lee et al. [8] for reviews of the technology used to produce CM. Regardless, CM does not involve the use of plant-based material, and at least at the cellular level, it is meat.

Effects on the environment of transitioning to meat substitutes

There is broad agreement that replacing traditional meat with either PBMA or CM will have positive effects on the environment [5,7,9,10]. The production of traditional meat requires large amounts of land and water and produces large amounts of greenhouse gas (GHG) emissions. The production of PBMA and CM requires considerably less land and water, and according to most analyses, it does not emit as much GHG. There is also the indirect benefit that production facilities for meat substitutes can be located closer to consumer markets, reducing the environmental impact of transporting products to consumers.

Noting this, some suggest that the environmental benefits of transitioning to PBMA and CM may not be as uniformly positive as has been suggested [4]. For example, as discussed by Treich [11], many have not considered factors such as what happens to land that is no longer used to pasture livestock, when estimating the environmental benefits of transitioning to CM. Santo et al. [5] make a similar point. More pointedly, van der Weele et al. [12] question the basic premise that transitioning from traditional meats will lead to benefits: "Therefore, the priority given to meat alternatives with limited sustainability potential is not just a problem of technological optimization of production systems, but also a second order problem of problem framing, network building, assumptions about innovation and economic-technological imagination" (p. 512).

On balance, although we acknowledge that PBMA, CM, and other methods of producing meat substitutes are not panaceas, we believe they have the potential to meet consumer's demands for meat or meat-like products in ways that will cause meaningfully less harm to the environment than the production of traditional meat. The extent to which this potential is realized remains to be seen, particularly for CM about which there are numerous unanswered questions [13].

Effects on people's health of transitioning to meat substitutes

People's health is directly affected by what they eat, and there is broad agreement that present patterns of the consumption of traditional meat are associated with increased risk of cardiovascular disease, cancer, and obesity, leading to increased morbidity [4–6]. Some of these risks are due to the nature of some types of meat (e.g. high saturated fat), and some are due to the additives that are used when making processed meat. Traditional meat also poses health risks in terms of foodborne diseases that are more common for products based on traditional meat than other sources. Transitioning to PBMA and CM could either eliminate or drastically reduce the health risks associated with consuming traditional meat.

Nevertheless, in terms of health, there are some possible downsides to transitioning from traditional meat. For example, many PBMA are highly processed, some are high in saturated fats, and they may not offer the same nutritional benefits as the foods from which they are derived such as legumes and soy beans [5,9]. He et al. [6] and Santo et al. [5] also discuss possible problems with process-induced hazardous chemicals. Also, PBMA may not contain the same amounts of protein as the traditional products they are meant to replace. In terms of protein replacement, an analysis of Irish food products by Safefood concluded that "Over a quarter of processed, vegetarian meat-substitute products are not a source of protein" [14]. We should emphasize that this conclusion referred to a wider variety of products than PBMA.

As discussed by Van Vliet et al. [15], although PBMA may be meat alternatives in terms of sensory experiences, they are not true nutritional replacements for meat. For example, animal-based foods facilitate the uptake of plant nutrients such as zinc and non-heme iron. Consistent with this, Day et al. [16] concluded that "that designing plant-based foods to mimic animal foods requires much more than simple substitution of one ingredient with another" (p. 428). Day et al. went on to suggest that "In the short to medium term, nutritional and functional synergies between plant and animal proteins may offer a path to creating nutritious and attractive foods."

Regardless, on balance, it appears that PBMA and CM have the potential to serve as healthy sources of protein. Many of the reservations expressed about the

healthfulness of PBMA and CM concern potential or possible problems. To be certain, the food industry needs to be mindful of problems regarding the healthfulness and nutritional benefits of PBMA and CM, and it remains to be seen if it will.

Global trends in consumption of meat and plant-based meat alternatives

Although there are differences across market segments, the alternative meat sector is growing globally (e.g. [17]). In 2018, sales of PBMA surpassed $10 billion globally and are predicted to surpass $30 billion by 2026 [18]. The Smart Protein report [19] used Nielsen scanning data of plant-based food purchases in 11 European countries between 2018 and 2020 to summarize trends in the consumption of various plant-based foods. Although increases varied across country, category of product (e.g. frozen vs. not-frozen), and outlet (discounter or not), the conclusion is clear. Sales (in Euros and volume) of PBMA increased in Austria, Belgium, Denmark, France, Germany, The Netherlands, Romania, Spain, and the United Kingdom. Italy was the only country in which sales of PBMA declined.

Although impressive, these trends need to be understood in terms of the consumption of traditional meat. As of 2018, traditional meat held 96% of market value relative to alternative meat (e.g. [17]). Nevertheless, no single trend captures what is occurring globally in terms of consumption because trends vary by region and by the type of meat being considered.

For example, globally, meat consumption is on the rise and is expected to continue to increase in the near future [20]. In the United States, over the last 40 years, it appears that beef consumption is down, pork consumption is flat, and poultry consumption is up [21]. In the United Kingdom, although overall meat consumption was down from 2008 to 2019, consumption of poultry and fish was up [22]. Over the next 10 years, beef and pork consumption are expected to decline in the European Union, whereas poultry and sheep meat consumption is expected to grow slightly [23]. These are just illustrative findings. In summary, it is important to understand that while the market for meat substitutes has seen substantial growth, it has some distance to travel before it achieves parity with the market for traditional meat.

How are meat substitutes perceived by consumers?

To some extent, consumers' acceptance of meat substitutes depends upon their organoleptic properties, such as their appearance, texture, smell, and taste. As reviewed by Eckl et al. [24], a variety of studies have investigated the role of these sensory characteristics in the acceptance of PBMA. Although a variety of products have been tested, with participants across a variety of countries, the results consistently show that people generally prefer traditional meat products over their plant-based analogs. For example, after a blind taste test, participants in France were more willing to purchase pork-based sausage over a plant-based sausage analog [25]. Similarly, in a study conducted in the United States, participants preferred and were more willing to pay for a 100% beef burger than plant-based alternatives [26]. In a German survey, participants indicated that meat products were tastier than the corresponding PBMA. In particular, steak was perceived as being tastier than tofu, chicken nuggets, vegetarian nuggets, wiener sausages, and vegetarian sausages [27].

In contrast to PBMA, CM is not yet available in most places, and therefore it is difficult to determine how consumers will respond to its taste, texture, and mouthfeel. Some recent research suggests that younger, university-educated consumers may be more open to trying CM [28], but as reviewed in Pakseresht et al. [29], the extent to which consumers perceive CM as healthy, natural, safe, or as real meat, will also play an important role in its acceptance when it becomes more widely available. See also Onwezen et al. [30] for a review of consumer acceptance of meat substitutes.

According to Zhang et al. [31], it can be difficult to develop an acceptable flavor and texture of plant-based meats. Inhibiting flavors derived from raw materials (e.g. beany smell) and dynamic changes in flavor during processing are just two of these challenges. Moreover, presently available PBMA (and CM) are primarily limited to products that resemble ground meat. For red meat, the typical form is patties and sausages, and for poultry, this may take the form of nuggets. At present, as noted by Blaustein-Rejito and Smith [20]: "There are simply no plant- or cell-based substitutes that taste, look, and feel similar to whole meat cuts like pork chops or sirloin. And these whole cuts make up a large share of meat consumption. In the US, for instance, whole cuts account for about 40% of beef consumption and most of the chicken that people eat."

Given the strong attachment some people have to meat, it seems unlikely that steak-eaters will find presently available PBMA or CM as legitimate substitutes for a sirloin steak — hamburgers, perhaps; steaks, probably not. Recently, Specht [32] suggested that microbial fermentation, which she described as the "third pillar of the alternative protein industry," might be able to create fibrous, aligned intact tissues akin to whole-muscle cuts, a goal she described as the 'Holy Grail.' Such products are just coming to the market and have very limited availability, so very little is known about consumer perceptions of these products.

Plant-based meat alternatives and cultured meat considered as new foods

PBMA and CM are novel and unfamiliar foods to many, perhaps most, people. This brings to the fore research on what has been called 'food neophobia,' that is, a fear of new foods, and researchers have found that food neophobia is negatively related to intentions to purchase PBMA and CM [33]. Consistent with this, Siegrist and Hartmann [34] found that food neophobia was negatively related to the acceptance of CM in ten countries, although such relationships may not be uniformly strong [35,36].

It is not clear however, the extent to which a lack of interest in PBMA and CM reflects a fear of new foods (food neophobia) or the extent to which it reflects a lack of interest in new foods. Recently, Nezlek et al. [37] demonstrated that the Food Neophobia Scale (FNS [38]), which has been used in most of the research about the topic, measures both approach and avoidance motives regarding new foods. The FNS does not provide a basis for knowing whether approach or avoidance motives are responsible for people's reluctance to try new foods such as PBMA and CM, whereas the measure Nezlek et al. proposed does. Confirming the importance of the distinction Nezlek et al. proposed, nearly 50% of the Australian consumers surveyed by Estell et al. [39] were "driven by curiosity … selecting 'new food trend' as a key factor influencing consumption." This is clearly not a manifestation of food neophobia as traditionally defined.

PBMA and CM are not only new foods, they are also produced using methods with which most people are probably not familiar, and this raises the issue of what is called "food technology neophobia" [40]. In their review, Siegrist and Hartmann [41] concluded that: "there is some evidence that food technology neophobia is a universal factor that influences acceptance of innovations related to food" (p. 345). Other research suggests that relationships between acceptance of food technologies and willingness to eat new foods are mediated by food-disgust sensitivity [42].

Relationships between attitudes about meat substitutes and attitudes about traditional meat

Understanding reactions to and perceptions of meat substitutes requires understanding people's attitudes toward meat, and the Meat Attachment Questionnaire [43] measures such attitudes. In a study conducted in the United States, India, and China, Bryant et al. [36] found that meat attachment was negatively related to acceptance of PBMA in the United States, whereas in China, the relationship was positive. Likewise, meat attachment was positively related to acceptance of CM in China and India.

In terms of present diet, in their review of 26 studies, Bryant and Barnett [44] concluded that meat-eaters found CM more appealing than vegetarians did. In contrast, a study of Swiss consumers, Siegrist and Hartmann [45], and a study of German consumers, Michel, Hartman et al. [27] found that consumers who ate more meat evaluated PBMA less positively than consumers who ate less meat. Similarly, in a three-nation study (DE, FR, and UK), Michel, Knaapila et al [46] found that meat commitment was negatively related to evaluations of meat substitutes. Based on a series of focus groups, Kerslake et al. [47], suggested that while an omnivore may be attracted by PBMA or CM that closely mimics traditional meat (e.g. its texture and apparent bloodiness), these same characteristics may repulse some vegans and vegetarians.

Another perspective on this topic is suggested by the results of Nezlek et al. [48] who measured evaluations of PBMA and CM and the extent to which people perceive vegetarianism as a threat to their social values [49]. In a study of Brazilian consumers, they found that "Omnivores' evaluations of both plant-based and CM were negatively related to their perceptions of vegetarianism as a threat to their social values." It is important to note that these evaluations included perceptions of the safety and health of these products, not just a simple preference for eating them. These results suggest that evaluations of meat substitutes are influenced by factors that are not inherently part of the product (see also Michel et al. [27]).

The available data do not provide a basis for a neat and tidy summary of the relationships between attitudes toward traditional meat and meat substitutes, and understanding such relationships is important for understanding the adoption of meat substitutes. The phrase 'meat substitutes' implies that people will stop eating meat. Although possible, it seems more likely that people will eat traditional and nontraditional meat, perhaps in the same dishes or in 'hybrid products' in which a proportion of meat is replaced by plant-based protein sources [50]. Research suggests that the introduction of such products may bridge the gap between meat and meat-free products by providing a more acceptable alternative to consumers [51].

The importance of cost

At present, PBMA and CM are meaningfully more expensive than traditional meat. For example, in the United States, as noted by Axworthy [52]: "Though retail sales for plant-based meat grew by 45% in 2020, on average, Neilson data demonstrates that plant-based meat on a per-pound basis is currently twice as expensive as conventional beef, three times as expensive as pork, and four times as expensive as chicken." Higher

prices decrease the likelihood of experimentation and regular consumption.

The critical issue is when/if PBMA and CM will achieve parity in pricing with traditional meat, and a well-informed discussion of this can be found in Witte et al. [53]. Based on expert interviews, industry reports, and Blue Horizon and BCG analyses, Witte et al. concluded "Each of the three types of alternative protein is currently at a different stage of parity with conventional proteins. We expect that plant-based alternative proteins will achieve parity by 2023, those based on microorganisms by 2025, and those based on animal cells by 2032."

On balance, we think that the 2023 is probably a bit early for price parity for PBMA. For example, Chafin and Larson [54] concluded that "At the current rate, it may take plant-based proteins five to seven years to reach price parity, but there's no reason why that timeline can't be shortened if manufacturers and retailers can agree to put consumer needs and preferences ahead of margin." Although it seems that the alternative protein market is poised for growth, prices will need to come down. Price parity can be facilitated by different types of governmental support, although this may not be occurring as quickly as needed [55].

Conclusions, limitations, and future directions

The production of traditional meat is wreaking havoc with the environment, and the consumption of meat has been associated with increased health risks for individuals. Consequently, the health of the planet and humanity depends upon reductions in the production and consumption of traditional meat. Assuming that the demand for meat is not likely to diminish and is likely to increase, replacing traditional meat with meat substitutes may reduce environmental degradation and improve people's health while meeting consumers' demands. Reducing the production of traditional meat will also improve animal welfare.

One of the most important limitations of the available research is that meat substitutes are still relatively unknown and/or unavailable, particularly for CM. CM exists only in the abstract for the vast majority of people, and so studies are limited to asking for evaluations and purchase intentions of products that do not exist and cannot be tasted. Studies based on descriptions of hypothetical products are valuable; however, understanding consumers' reactions to CM requires assessing people's reactions to real products. How does CM taste and feel? How can one cook with it? Is it affordable?

In contrast, numerous PBMA exist, and some PBMA are established products that are available in many, albeit not all, markets. Therefore, consumers' reactions can reflect direct experience with PBMA. In terms of total market share, PBMA are dwarfed by traditional meats, and it remains to be seen what effects the introduction of different types of PBMA will be, but the outlook for PBMA appears to be positive (e.g. [10]).

Much of the research and thinking about the necessity of transitioning from traditional meat to manufactured meat substitutes is predicated on the assumption that the demand for protein will not decline. Nevertheless, it has been suggested that if the demand for protein was to decrease (in many countries, average consumption levels are above what is needed for good health), there may not be a need to transition to meat substitutes on a mass scale [6,12,56]. Given present norms, it is difficult to imagine how this might happen on a scale large enough to remediate the climate and improve the health of humanity, but if replacing traditional meat with manufactured meat does not do the job, an overall reduction in protein consumption may be necessary.

Conflict of interest

Both authors declare no conflict of interest.

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References and recommended reading

Papers of particular interest, published within the period of review, have been highlighted as:

- • of special interest
- •• of outstanding interest

1. Dagevos H: **Finding flexitarians: current studies on meat eaters and meat reducers**. *Trends Food Sci Technol* 2021, **114**:530-539.

2. Kemper JA: **Motivations, barriers, and strategies for meat reduction at different family lifecycle stages**. *Appetite* 2020, **150**:104644.

3. Fehér A, Gazdecki M, Véha M, Szakály M, Szakály Z: **A comprehensive review of the benefits of and the barriers to the switch to a plant-based diet**. *Sustainability* 2020, **12**:4136.

4. Rubio NR, Xiang N, Kaplan DL: **Plant-based and cell-based approaches to meat production**. *Nat Commun* 2020, **11**:6276.

5. •• Santo RE, Kim BF, Goldman SE, Dutkiewicz J, Biehl EMB, Bloem MW, Neff RA, Nachman KE: **Considering plant-based meat substitutes and cell-based meats: a public health and food systems perspective**. *Front Sustain Food Syst* 2020, **4**:134.
This paper presents a critical review of research on plant-based meat substitutes. It covers public health, environmental, animal welfare, economic, and policy implications related to the production and consumption of plant-based meat substitutes and cell-based meats. Although the authors see many potential benefits of the widespread adoption of meat substitutes, they conclude that support for the benefits of meat substitutes is not as strong as many claim or represent it to be and more research is needed.

6. •• He J, Evans NM, Liu H, Shao S: **A review of research on plant-based meat alternatives: driving forces, history, manufacturing, and consumer attitudes**. *Compr Rev Food Sci Food Saf* 2020, **19**:2639-2656.

This article provides a context for understanding the origins and present status of PBMA. The historical overview of PBMA the authors provide is particularly informative. The paper reviews research on environmental, health, and ethical concerns of transitioning to PBMA. They also describe production techniques in an accessible fashion and do a reasonable job of covering consumer attitudes. There is a nice section on the outlook for the future.

7. •• Hong TK, Shin D-M, Choi J, Do JT, Han SG: **Current issues and technical advances in cultured meat production: a review**. *Food Sci Anim Resour* 2021, **41**:355-372.

This article provides a thorough, yet accessible, review of the current status of CM. Consumer acceptance is briefly reviewed, and economic, environmental, and ethical issues are also considered. The authors also describe the production of different types of CM (chicken, duck, beef, and pork), and the different technologies that are used to create CM.

8. Lee DY, Lee SY, Jung JW, Kim JH, Oh DH, Kim HW, Kang JH, Choi JS, Kim GD, Joo ST, Hur SJ: **Review of technology and materials for the development of cultured meat**. *Crit Rev Food Sci Nutr* 2022, https://doi.org/10.1080/10408398.2022.2063249

9. • Choudhury D, Singh S, Seah JSH, Yeo DCL, Tan LP: **Commercialization of plant-based meat alternatives**. *Trends Plant Sci* 2020, **25**:1055-1058.

This article provides an overview of the recent commercialization and growth of PBMA markets as well as projections for the future. It highlights strategies companies have employed to encourage growth as well as ongoing challenges the sector faces. The authors encourage collaboration between scientists and economists to ensure the future success of this sector.

10. • Zhao S, Wang L, Hu W, Zheng Y: **Meet the meatless: demand for new generation plant-based meat alternatives**. *Appl Econ Perspect Policy* 2022,1-18, https://doi.org/10.1002/aepp.13232.

The authors focus on the market for PBMA in the US. They analyzed retail-level scanner data from January 2017 to January 2022. They found that PBMA accounted for between 0.008 and 0.864% of total expenditures for fresh meat, with a marked acceleration beginning in 2019. PBMA was the most price elastic product they examined, that is demand was related more strongly to relative prices for PBMA than for other meat products. The authors concludes that "PBMA is a complement to beef and pork, and is a substitute to chicken, turkey, and fish."

11. Treich N: **Cultured meat: promises and challenges**. *Environ Resour Econ* 2021, **79**:33-61.

12. •• van der Weele C, Feindt P, Jan van der Goot A, van Mierlo B, van Boekel M: **Meat alternatives: an integrative comparison**. *Trends Food Sci Technol* 2019, **88**:505-512.

As noted in the main text, van der Weele et al. offer a meaningfully different perspective on the potential of meat alternatives than many researchers. They are not at all convinced that transitioning to PBMA and CM (and three other meat alternative) will provide the benefits that have been promised. They do not believe that “the nutritional implications, potential sustainability gains and required technological and social-institutional change” have been considered adequately. We encourage readers who are strong advocates of transitioning from traditional meat to meat substitutes to read this article. They may not agree with it, but it is good food for thought.

13. Stephens N, Di Silvio L, Dunsford I, Ellis M, Glencross A, Sexton A: **Bringing cultured meat to market: technical, socio-political, and regulatory challenges in cellular agriculture**. *Trends Food Sci Technol* 2018, **78**:155-166.

14. Morrison O: **1 in 4 meat substitutes ‘do not contain enough protein to be considered a source of protein**. *Food Navig* 2021, https://www.foodnavigator.com/Article/2021/03/31/1-in-4-meat-substitutes-do-not-contain-enough-protein-to-be-considered-a-source-of-protein.

15. van Vliet S, Kronberg SL, Provenza FD: **Plant-based meats, human health, and climate change**. *Front Sustain Food Syst* 2020, **4**:128.

16. • Day L, Cakebread JA, Loveday SM: **Food proteins from animals and plants: differences in the nutritional and functional properties**. *Trends Food Sci Technol* 2022, **119**:428-442.

Thorough, yet accessible, summary of the differences between plant and animal based proteins. "The differences include molecular structure, amino acid profile, digestibility, and technical functionality in food, that is the ability to gel, emulsify, bind water etc." The authors discuss how the bioavailabilty of proteins are influenced by these factors, and the implications of such influences for the manufacture of plant-based meat and protein substitutes.

17. Joseph P, Searing A, Watson C, McKeague J: **Alternative proteins: market research on cosumer trends and emerging landscape**. *Meat Muscle Biol* 2020, **4**:1-11.

18. Watson J.: **Plant-based meat market to reach USD 30.92 billion By 2026**. Reports Data 2019, https://www.globenewswire.com/news-release/2019/10/14/1929284/0/en/Plant-based-Meat-Market-To-Reach-USD-30-92-Billion-By-2026-Reports-And-Data.html/.

19. Smart Protein Project**: Plant-based foods in Europe: How big is the market? Smart Protein Plant-based Food Sector Report by Smart Protein Project, European Union’s Horizon 2020 research and innovation programme (No 862957)** 2021, https://smartproteinproject.eu/plant-based-food-sector-report.

20. Blaustein-Rejito D, Smith A: **We’re on track to set a new record for global meat consumption**. *MIT Technol Rev* 2021, https://www.technologyreview.com/2021/04/26/1023636/sustainable-meat-livestock-production-climate-change/.

21. Widman D: **U.S. Meat Consumption Trends and COVID-19 - Agricultural Economic Insights**. *Agric Econ Insights* 2021, https://aei.ag/2021/04/05/u-s-meat-consumption-trends-beef-pork-poultry-pandemic/.

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26. Caputo V, Sogari G, Van Loo EJ: **Do plant-based and blend meat alternatives taste like meat? A combined sensory and choice experiment study**. *Appl Econ Perspect Policy* 2022,1-20, https://doi.org/10.1002/aepp.13247

27. Michel F, Hartmann C, Siegrist M: **Consumers’ associations, perceptions and acceptance of meat and plant-based meat alternatives**. *Food Qual Prefer* 2021, **87**:104063.

28. Garcez de Oliveira Padilha L, Malek L, Umberger WJ: **Food choice drivers of potential lab-grown meat consumers in Australia**. *Br Food J* 2021, **123**:3014-3031.

29. Pakseresht A, Ahmadi Kaliji S, Canavari M: **Review of factors affecting consumer acceptance of cultured meat**. *Appetite* 2022, **170**:105829.

30. • Onwezen MC, Bouwman EP, Reinders MJ, Dagevos H: **A systematic review on consumer acceptance of alternative proteins: pulses, algae, insects, plant-based meat alternatives, and cultured meat**. *Appetite* 2021, **159**:105058.

This review focuses on drivers of consumer acceptance of five alternative proteins: pulses, algae, insects, PBMA, and CM, as well as interventions to increase consumer acceptance of these foods. This review of 91 articles illustrates that the primary drivers of acceptance varies across products and groups of consumers, highlighting the need for targeted interventions to increase acceptance of these foods.

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32. Specht L: **Tiny organisms, huge potential**. *Food Technol Mag* 2020, https://www.ift.org/news-and-publications/food-technology-magazine/issues/2020/december/features/tiny-organisms-huge-potential.

33. Gómez-Luciano CA, de Aguiar LK, Vriesekoop F, Urbano B: **Consumers’ willingness to purchase three alternatives to meat**

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