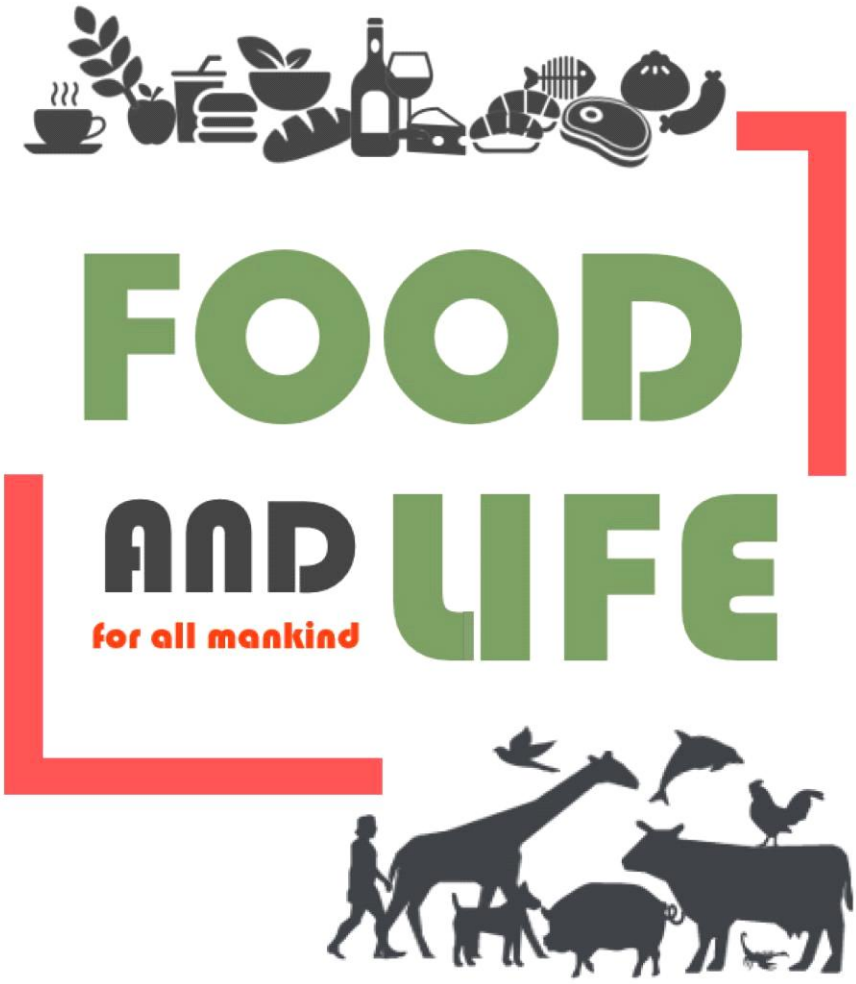

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Food and Life (2022) 2022(2):51-57
https://doi.org/10.5851/fl.2022.e8

Review Article Open Access

Meat analogues: an assessment of plant-based protein options and the parameters of their success: a mini review

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Abstract

Consumer interest in meat analogues, plant-based alternatives that mimic traditional meat properties, are on the rise. These food products are formulated with alternative proteins to provide adequate nutritional value while closely resembling the general characteristics (e.g., texture, flavor, juiciness) of meat. Meat substitutes are of specific interest to consumers who are concerned about the ecological footprint and healthfulness of what they consume. Attributes such as taste, texture, and emotional attachment to meat are primary factors determining the success of many meat substitutes in the retail space. Other parameters of interest regarding meat alternatives are sustainability, consumer acceptance, industry challenges, and how these various traits interact to influence the success of products. Studies show that these parameters are closely related, and there is a considerable amount of interplay determining the success of meat analogues. The two principal parameters to success are sensory evaluation and sustainability. Both traits are important to the consumer, and the industry will need to consider both when designing novel products for the retail space. It is anticipated that meat analogues will continue to rise in popularity among consumers, providing them with numerous alternative protein options soon.

Keywords: alternative proteins, sensory evaluation, plant-based, food neophobia, consumer perspective

Introduction

Alongside a rapidly growing population is a rising need for an increased food supply (Lee et al., 2020). As the need for food steadily rises, it has been estimated that the global demand for meat will approximately double by 2050 (Joseph et al., 2020). It has been suggested that this increased demand for meat may no longer be met by further industrialization of conventional meat production and livestock cultivation. As such, meat analogues (representing plant-based alternatives that mimic traditional meat properties) may possibly offer a potential solution to this uneven relationship between supply and demand (Lee et al., 2020). However, it is not fully understood what factors are critical to the success of meat analogues in the retail space. Thus, discussing these success characteristics, which can be categorized by consumer or industry, are the primary purpose of this paper. For meat analogues, consumer perspective encompasses sensory characteristics, nutritional content, safety, price, and sustainability. From an industry perspective, the relationship between conventional meat production and mass manufacturing of meat analogues is the biggest consideration. This paper will address the various parameters influencing acceptability and feasibility of meat analogue products, providing further insight into the future of the growing plant-based protein sector.

Consumer perspective

As with all products attempting to occupy market share and retail space, consumer perspective and opinion cannot be underplayed. Generally, consumer enthusiasm for meat analogues centers on drawbacks of traditional meat such as complications associated with animal welfare, land and resource use, and health concerns. Alternatively, consumer skepticism stems from taste, safety, price, and perceived 'naturalness' of meat analogues (Bryant et al., 2019). Analysis of the concern and enthusiasm surrounding meat analogues can be used as explanatory factors regarding success on grocery store shelves, which will be

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discussed more in-depth in the following sections.

Technological properties: sensory evaluation and nutritional content

Consumer perspective is one of the most important parameters determining success of any food product. As the ultimate purchaser of the product, consumer attitudes towards meat analogues heavily influence sales and product success. Survey data from the UK and Netherlands has shown that although consumers consider ethical, political, and sustainable factors, purchasing decisions regarding food products are ultimately determined by the consumers' sensory evaluation of the product (Fiorentini et al., 2020). Additionally, in the USA, a survey from 2019 found that at least 86% of adults make food purchasing decisions with taste as the primary factor (Fiorentini et al., 2020). In line with a consumer's sensory evaluation is food neophobia; the reluctance, refusal, and/or fear of eating new and unfamiliar foods (Dovey et al., 2008). To combat this, meat analogue packaging often relies on a 'tastes like meat' marketing phrase to persuade consumers (Fiorentini et al., 2020). A non-meat taste or off-flavor would have harmful consequences for a meat analogue product and likely discourage repeat purchases.

For a sensory evaluation, important characteristics include taste, smell, texture, and appearance. Of these characteristics, texture is vital in fostering successful relationships between meat analogues and consumers. Traditional meat products are popular due to their mouthfeel, juiciness, and unique texture factor (Fiorentini et al., 2020). However, imitating these distinctive features using plant-based products is difficult as it encompasses further details such as water-holding capacity, encapsulation of fats, and properties relating to gelation and emulsification factor. Moreover, taste could be another challenging characteristics for consumers to accept alternative protein-based products (Joseph et al., 2020). Consumers prefer to have some conventional processed meat flavor attributes, such as seasoned, spicy and meaty (Elzerman et al., 2011). In general, meat analogues go through heavy processing steps during the manufacturing process, which can cause lipid oxidation of inherently unstable unsaturated fatty acids. As a consequence, it can generate compounds that induce undesirable tastes and odors (Fiorentini et al., 2020).

In addition to sensory evaluation of meat analogue food products, nutritional content and differences from traditional meat is another important parameter for success. Analyzing popular and common protein alternatives alongside other ingredients is beneficial when evaluating the overarching nutritional profile of meat analogues. Common protein alternatives include textured vegetable protein, soy protein concentrate, and pea protein isolate, as listed in Table 1. However, research on how these proteins react to processing and preparation techniques is currently limited. In the past, soy protein and soy protein concentrate have been the most common source of protein used in meat analogues. Out of all plant-based proteins, the soy protein concentrate offers amino acid contents comparable to those of traditional meat. Furthermore, the lipid content of traditional meat products and meat analogues is similar, specifically with respect to proportionality between saturated and unsaturated fatty acids (Bohrer, 2019). Another concern with meat analogues is the abundance of potentially anti-nutrients present. Even though some of non-meat ingredients have several beneficial factors, such as anti-obesity, lymphocyte stimulation, and antioxidant effects, these could exert some negative impacts. For example, some of nutrients contain phytic acid, which can induce micronutrient deficiency and reduce the bioavailability of essential micronutrients (Lee et al., 2020).

The largest discrepancy in macronutrient content between traditional meat and meat analogues is carbohydrates. Carbohydrates are present in most meat analogues but are in very limited quantities in traditional meat products. As the average American adult does not meet the recommended dietary allowance for dietary fiber, a dietary shift to include plant-based meat analogues can help bridge the difference between recommended and actual intake (Bohrer, 2019). While little is known about micronutrient content and how meat

Table 1. Plant proteins used for plant-based meat analogues

Plant	Protein
Wheat, rye, and barley	Gluten (gliadins, gluenins)
Soybean	β-Conglycinin
Legumes	Glycinin, vicilin
Oil seeds	Legumin, albumins, globulins, glutelins
Fusarium venenatum (filamentous fungus)	Mycoprotein

Adapted from Lee et al. (2020) with CC-BY.

analogues compare to conventional meat, iron is a definite nutrient of concern (Schönfeldt and Hall, 2011). Specifically, plant-based proteins contain non-heme iron, a form of iron that is less easily absorbed than heme iron. However, heme iron is a component of hemoglobin and myoglobin, proteins containing iron for oxygen transport in blood and muscle, respectively. Thus, heme iron is found only in meat products or meat-incorporated products. Given iron deficiency was the most common and widespread nutritional deficiency in the world (particularly women and those in developing countries), this raises micronutrient concerns for consumers who purchase meat analogues (Schönfeldt and Hall, 2011).

Color challenges for meat analogues

One of the major factors when consumers are purchasing traditional meat products is meat color (Trinderup and Kim, 2015). Since meat analogues lack myoglobin, the primary protein affecting meat color, they do not display a bright-cherry red color that consumers prefer to observe. Meat analogue producers have tried many different methods to mimic the typical fresh meat red color, such as adding beet juice extract or tomato paste (Lee et al., 2020). To further mimic color and flavor attributes that myoglobin provides to traditional meat products, some meat analogues contain leghemoglobin, which has a similar structure to myoglobin (Lee et al., 2020).

Viewpoint complications: safety, price, sustainability and others

Although sensory evaluation, especially taste, is of the utmost importance to consumers when making purchasing decisions, there are other considerations and concerns that influence the success of alternative meat products. For example, a survey of over a thousand German participants found that consumers value meat analogues in that it has an ease of preparation like that of traditional meat (Michel et al., 2021). In fact, there is a consistent growth of new alternative protein products in Europe (Fig. 1; Joseph et al., 2020). Demographic profiles of consumers can also play a role, where a study found that participants in India and China were more accepting of meat analogues than consumers in the US (Bryant et al., 2019). A large reaction from American consumers surveyed was 'disgust,' a sentiment not observed in the two other demographic groups (Bryant et al., 2019). This reaction by American consumers presents another obstacle for plant-based meats in

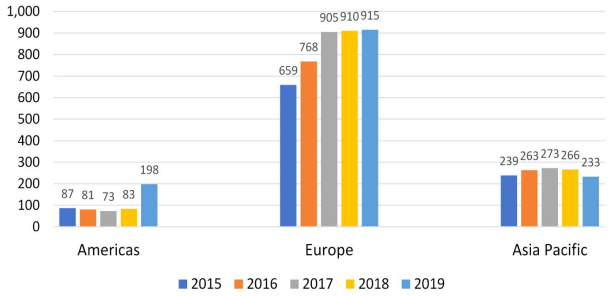

Fig. 1. Numbers of new product launches of meat substitutes, by region. Adapted from Joseph et al. (2020) with CC-BY.

the USA market as opposed to foreign markets like India and China.

Sustainability and concerns of traditional meat production methods encourage some consumers to purchase meat alternatives. Past studies have found that some consumers can recognize that meat production methods, especially regarding animal welfare, are 'morally unjustifiable (Michel et al., 2021). There is a distinction between this reaction to meat production and its power over purchasing decisions, as those more influenced by ethical considerations will avoid meat products for this reason (Michel et al., 2021). With respect to sustainability, a study investigated the inputs and outputs of commercial processing for 56 common meat analogues given the company's inventories for commercial recipes (Fig. 2). From this study, it was found that meat analogues, regardless of their primary plant protein source, had similar greenhouse gas (GHG) emissions, all lower

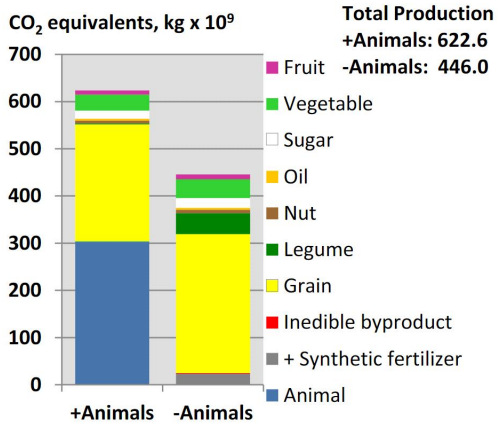

Fig. 2. Represents greenhouse gas emissions in the USA based on current animal production and if animal production was eliminated. Adapted from White and Hall (2017) with CC-BY.

than traditional meat (Fresán et al., 2019). However, incorporation of eggs in commercial recipes significantly increased associated GHG emissions. This is consistent with how incorporation of animal products, meat or otherwise, increases the GHGs from processing of food products. Furthermore, the study accounted for how various GHGs impact changes in climate and their lifecycle in the atmosphere. Consumer's conscious of this difference in GHG emissions are influenced and swayed to purchase meat analogues as an alternative to meat products (Fresán et al., 2019).

On the other side, price and consumer safety concerns are characteristics that can negatively impact the future success of meat analogues. Safety concerns regarding meat analogues are widespread and cover many aspects of meat analogues. In the context of allergies and health conditions, protein sources and ingredients used in meat analogues may be worrisome (Sun et al., 2021). Unlike traditional meat products, meat alternatives may contain gluten which poses a health concern for individuals with celiac disease. The use of soy protein in meat analogues can also be harmful to individuals who suffer allergic reactions to cow's milk as this portion of the population (10%–14%) also tend to have similar reactions to soy products (Sun et al., 2021). Consumer concerns are further seen with respect to genetically modified organisms (GMOs) and their use in food production. Soy, commonly cultivated as a genetically engineered crop, plays a major ingredient role in many meat analogues. To incorporate heme in meat analogues industry utilizes genetically modified yeast to produce the protein. Heme is important in meat analogues as it is pertinent to mimicking meat attributes and improving nutritional content. Although GMO crops have advanced significantly in recent years and have undergone composition analyses to assure safety, consumers are still wary of food products containing GMOs (Sun et al., 2021). As for GMO produced heme, further safety testing is needed to affirm that it can be safely consumed at appropriate levels. On the other hand, it is important to note that development of gluten-free meat analogues is already underway and not all meat analogues rely on soy proteins or GMOs (Sun et al., 2021).

To summarize, consumers of both traditional meat and meat analogues agree that an ideal meat alternative product will be comparable to meat in taste and texture but be cheaper and have a more desirable nutritional makeup (Michel et al., 2021).

Industry considerations

While consumer demand, perspective, preferences, and opinions influence purchasing power of meat analogues, industry and manufacturing practices make up the other half of parameters determining meat analogue success in the marketplace. Regardless of consumer desires, if industry is unable to produce the product effectively and efficiently, it will not make it to the shelves. In the specific context of meat analogues, there is an argument that farming and sustainable practices can ease concerns related to traditional meat production and thus render a shift towards meat analogues unnecessary. On the contrary, mass manufacturing of plant-based proteins at the scale experts expect to see in the future is, at present, poorly understood. There are both environmental benefits and drawbacks of producing more meat analogue products for the global market.

Farming and sustainable practices

As consumer demand for meat grows around the globe and consumers focus on more sustainably sourced products, the meat industry is in search of new ways to keep up. While commercialization and industrialization of livestock farming has solved this problem in the past, limitations including water, land availability, and concerns surrounding sustainability and animal welfare, limit this solution moving forward (Lee et al., 2020). However, while meat analogues offer one solution, it is important to consider various sustainable farming practices. A shift in how traditional meat is produced from farm to table can shift consumer perspective and impact the success of meat analogues.

One example of sustainable farming that can open the door for farmers moving forward is management-intensive rotational grazing, or MIRG (Oates et al., 2011). Under MIRG farming, livestock is rotated between pastures on a schedule, during which the pastures are given time to regrow and recover from grazing. Studies of this farming method in Kentucky show that MIRG, in comparison to other grazing methods, had improved forage production and quality but showed no difference in root production of pasture foliage (Oates et al., 2011). Other management techniques farmers may choose to utilize can sequester carbon and offset or diminish the GHG emissions of livestock production. Soil organic carbon (SOC) can be stored in agricultural soils, and photosynthesis by agricultural crops and pastures can convert some carbon from the air into SOC,

thus storing it in the soil and sequestering it from the air (Kragt et al., 2012). Adjustments made by farmers can affect and improve the amount of carbon that is sequestered into the soil via management practices including grazing of livestock and pasture rotation. However, this practice comes at a cost. A study in Western Australia estimated that farmers would forfeit approximately $80 in profit for every ton of carbon dioxide stored in the soil (Kragt et al., 2012). To put this cost into perspective, in 2012 when the study was conducted, the carbon tax per ton of carbon emissions was only $23, significantly lower than the profit farmers would forgo to practice more sustainable and environmentally friendly farming via carbon sequestration (Kragt et al., 2012).

Finally, just as it is important to scrutinize and evaluate the flaws in traditional meat farming and production, the same is true of the crops used to formulate the plant-based protein utilized for meat analogues. One of the most popular and common agricultural crops cultivated for meat analogues is soy (Sun et al., 2021). A life cycle analysis of the carbon footprint produced from the process of growing soy to transform it into an edible food component is between eight and eighty times lower than that of comparable animal-based protein products (Thrane et al., 2017). Additionally, soy can be grown in a wide range of climates and geographic locations due to development of varieties that can produce high yields under various conditions. A life cycle analysis of a specific product of soy and soy protein isolate has been conducted by investigating sixteen major impact areas that could possibly affect sustainability (Thrane et al., 2017). Of these categories, isolated soy protein had the smallest resource consumption of water and land in comparison to other protein sources such as chicken, pork, beef, and skim milk powder. Due to growing concern regarding resource limitations, in the context of traditional meat practices, isolated soy protein meat analogues provide a more sustainable option than conventional meat. Just as with nutritional content, there is no ‘one size fits all’ comparison between meat analogues and conventional meat with respect to environmental impacts. While growing crops for meat analogues is typically less resource intensive, factors such as transportation may offset benefits if industry is not conscious of these limitations.

Processing and mass manufacturing of meat analogues

Moving forward, mass production is a large area of concern surrounding meat analogues. As many consumers associate meat analogues to be like ultra-processed meats (meats that are highly manipulated and contain multiple additives, for example hot dogs), there are questions surrounding whether the production and manufacturing of the products will compromise and offset the sustainability gains from the products (Michel et al., 2021).

Production of meat analogues can be done via various approaches (Dekkers et al., 2018). Of the possible methods, the two most common production techniques for meat analogues are ‘bottom-up’ and ‘top-down’ (Dekkers et al., 2018). The bottom-up procedure encompasses the structural assembly of necessary polymers and their subsequent combination into a meat analogue product. Some techniques or structural ingredients that can be used for the bottom-up strategy include tissue-engineering (*in vitro* cultured meat), mycoprotein, wet-spinning of fibrous proteins, and electrospinning. For the top-down approach, a force field is used to blend previously structured biopolymers and direct them to form desirable structures, such as extrusion, freeze structuring, shear cell technology of plant-based materials, and mixing proteins and polysaccharides. Although these two methods both create meat analogues, the bottom-up process is typically considered to have the most potential to create analogues that effectively mimic the structure of traditional meat. This is due to the hierarchical placement and assembly of the individual proteins and structural components allowing for a more accurate recreation of meat structure (Dekkers et al., 2018). Alternatively, the top-down approach generally uses resources in a more efficient manner and is a more robust process. This creates a dilemma for industry, as meat analogue consumers are typically highly conscious about the sustainability of the products they consume (Fiorentini et al., 2020).

Market trends

Though meat and poultry still dominate the world protein market today, the market for meat analogues is steadily rising (Fig. 3). It is projected that consumption of meat analogues will increase by 36% in the next year (Lee et al., 2020). This increase in popularity can be attributed to consumer perceptions about meat analogues being healthier, better for the environment, and decrease animal welfare issues (Lee et al., 2020). However, this increase in consumption of meat analogues is not due to a rise in the vegan or vegetarian diets, it is more so due to

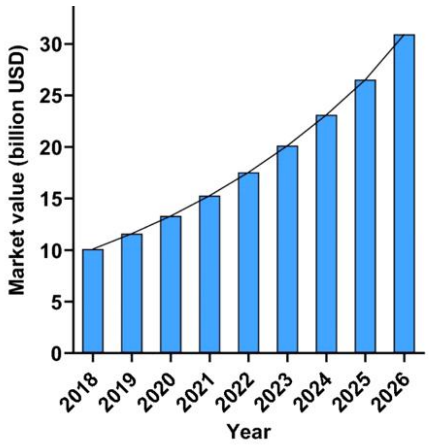

Fig. 3. Projected global market value of plant-based meat analogues from 2018 to 2026 in Billion US Dollars. Adapted from van Vliet et al. (2021) with CC-BY.

meat-eating consumer incorporating some of these meat analogues into their diet (Joseph et al., 2020).

A major concern with the meat analogues market is the affordability and accessibility of these products. In general, meat analogues are more expensive to purchase when compared to traditional meat products. As technology continues to evolve, prices of plant-based meat analogues could decrease to lower than the price of traditional meat prices, which would greatly increase the market popularity of these products.

Conclusion

On the surface, it may seem easy to determine the parameters that dictate the potential success of meat analogues. However, consumer perspectives and industry considerations are closely intertwined. Key parameters include sustainability, price, sensory evaluation, competition with traditional meat products, and nutrition. Sustainability can represent a double-edged sword for the success of meat analogues. While consumers who commonly purchase meat analogues are typically concerned about the sustainability and environmental impact of their food products, these individuals are often reluctant to purchase the GMOs as well. Furthermore, sustainability has impacts on the meat industry. Emissions of GHGs for animal products are much higher than plant protein alternates, but sustainable farming practices can serve to mitigate the environmental impacts to a certain extent. Sensory evaluation is potentially the biggest parameter of success for meat analogues as consumers have the expectation that these products will taste, smell, and feel like traditional meat products. Mimicking sensory traits influences what methods the industry utilizes when producing meat analogues. Failure to meet expectations of product quality can also prevent consumers from purchasing meat analogues, as food neophobia may act as a significant barrier. Overall, these parameters represent components that will challenge or bolster the success of meat analogues. As research and development moves forward, it is likely meat analogues will occupy a larger share of the retail space along with traditional meat products.

Conflicts of Interest

The authors declare no potential conflict of interest.

Acknowledgments

This work was also supported by the USDA National Institute of Food and Agriculture, Hatch-Multistate project 1006773.

Ethics Approval

This article does not require IRB/IACUC approval because there are no human and animal participants.

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Date Received Jun. 24, 2022
Date Revised Jul. 1, 2022
Date Accepted Jul. 1, 2022