HISTORY, CURRENT MARKET, BENEFITS, LIMITATIONS AND THE FUTURE OF PLANT-BASED MEAT ANALOGUES: A REVIEW

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ABSTRACT

Overconsumption of animal proteins has posed threats to the environment, human health, and wildlife. To reduce livestock activities, the consumption of plant-based meat is encouraged. Because of advanced technologies, plant-based meat is more feasible and accessible. The benefits of plant-based meat include less carbon footprint, more conserved wildlife habitats, lowered risks of chronic and infectious diseases. On the other hand, drawbacks are still present. Lack of mineral contents and low preference for plant-based meat would impact the production and innovation of plant-based meat alternatives. In addition to plant-based meat, culture meat and algae-based proteins are likely to be other options to mitigate environmental issues in the future.

BIOGRAPHICAL SKETCH

Hanhang Ying was born on February 11th, 1997 in Ningbo, China. She completed her high school diploma at Whittier Christian High School in California. Hanhang Ying moved to Seattle for her undergraduate studies. She graduated from the University of Washington, Seattle with a degree of Bachelor of Science in Biology (Physiology) major and nutritional science minor. She then started studying at Cornell College of Agriculture and Life Science remotely as a M.P.S. student.

I would like to dedicate this paper to my loving parents, who have offered unconditional support and encouragement, especially in these hard times. I would also like to dedicate this to my dog Citrus, thank you for being my emotional support all the time.

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INTRODUCTION

Protein is one of the macronutrients that are pivotal to human health. The recommended dietary allowance suggests that both men and women should consume 0.8 grams of protein foods per kilogram daily (Dietary Reference Intake). The dietary guidelines for Americans from 2020 to 2025 listed three categories of proteins that are recommended to be consumed, including red meat and eggs, seafood, and nuts and seeds products that are plant-based. Nevertheless, approximately three-quarters of Americans meet or exceed the recommended intake amount for red meat and eggs (Dietary Guidelines for Americans, 2020-2025).

Overconsumption of animal proteins that contain high-fat content has been proven to elevate the risks of type II diabetes, cardiovascular diseases, and cancers (Battaglia Richi et al., 2015; Micha et al., 2012). Moreover, close contact with unregulated food animals could lead to zoonoses (Bidaisee et al., 2014). With the excessive amount of antibiotics used in food animals, antibiotic resistance has become another major challenge posed to humans (Ma et al., 2021; Philips et al., 2004). Meantime, environmental concerns, such as global warming, loss of biodiversity, air and water pollution are also closely linked to the high demand for livestock (Steinfeld et al., 2006).

Because of the rising environmental and health concerns associated with animal proteins, plant-based meat alternatives have become a novel trending source of

proteins that mitigate the threats posed by the environment and animal well-being. Despite the fact that plant-based meat analogues provide adequate amounts of nutrient contents as animal-based proteins do, plant-based protein products have not been fully accepted yet. This paper reviews the history and transitions, current situations, benefits, limitations, and the future of plant-based meat analogues.

CHAPTER 1

History of Plant-based Meat Alternatives

Typical plant-based proteins include seeds, nuts, soy products, and beans (Dietary Guidelines For Americans, 2020-2025). Similarly, plant-based meat alternatives are protein foods made of these common proteins with high protein contents that mimic the taste, texture, appearance, nutrient contents of animal proteins. Additives including oils, food coloring, fat, water, binding materials are commonly used in plant-based meat analogues to increase the gelling ability and improve the appearance (Kyriakopoulou et al., 2021). Though this type of meat analogue seems novel, plant-based meat has a long history since 965 CE (Shurtleff & Aoyagi, 2014).

The history and the evolution of plant-based meat can be categorized into three stages: the traditional plant-based meat that contains plants merely, the traditional plant-based meat that contains ingredients other than plants, and the novel artificial meat. The first plant-based meat that only consists of plants could be dated back to the Liang dynasty which was a thousand years ago (Shurtleff & Aoyagi, 2014; Wang et al., 2020). This form of plant-based meat was made of plants purely through squeezing and steaming. The taste and the texture of traditional pure plant-based meats, such as tofu and seitan, are far distinctive from that of the plant-based meat analogues today. The purpose of inventing this plant-based meat was not to replace animal-based proteins. As technologies develop, this simple form of plant-based proteins could not fulfill the needs of people. Because of the lack of fibration in early plain plant-based proteins

which hinders the production of imitation meat, fibrated plants that are rich in proteins including soybeans have been put into use (Wang et al., 2020).

As the transition of the traditional plant-based meat from the pure plant-based meat takes place, advanced technologies including shearing, spinning, freeze alignment, and 3D printing are adopted to destroy the structure of plant-based proteins, which allows plant-based proteins to resemble the fibration of animal proteins (Manski et al., 2007; Kyriakopoulou et al., 2021). Although the texture and taste are highly identical to that of red meat, the appearance is still quite divergent.

As the awareness of animal welfare and environmental issues arises, people have started considering replacing a portion of animal proteins with plant-based protein foods in the 1970s (Fernandes et al., 2019). Even though the demand for plant-based protein foods has been identified, plant-based meat analogues have not been produced until the beginning of the twenty-first century (Post, 2012). To further mimic the appearance of animal proteins, novel artificial meat that is made of legume hemoglobin has been manufactured (Bohrer, 2019; Wang et al., 2020). Legume hemoglobin (also referred to as leghemoglobin) not only adds color to the plant proteins but also acts as the flavor catalyst, which imitates the flavor of animal proteins (Fraser et al., 2018). Another heme-containing protein, myoglobin has also been investigated and recognized as a novel source of flavor catalyst in plant-based muscles (Carlsson et al., 2020).

Well-known artificial muscle manufacturers, including Impossible Burger© and Beyond Meat©, have not been established until the last few years. Because of that, the studies that focus on the more complex level of plant-based proteins are limited. With the short history and limited researches of artificial meat, it still has a long way to go.

Chapter 2

The current market of plant-based meat

The Agricultural Marketing Act Of 1946 defines meat as the edible part of the muscle of an animal (Schultz, 1981). As the transition to a novel source of protein occurs, plant-based proteins that can serve as an alternative or substitute for animal proteins are commonly referred to as plant-based meat analogues. The primary sources of current plant-based meat are soy, gluten, pea, and fungi isolates, with soy and pea being the predominant sources of plant-based meat (Yuliarti et al., 2021; Kamani et al., 2019). Forms including burgers, sausages, patties, nuggets are prevalent on the market, with burgers being the most popular form of plant-based meat since 2016 (Market analysis report, 2020).

The market size was reported as 592 million US dollars in 2016, and the market size has been doubled since the emergence of industries that produce plant-based meat as their main products (Market analysis report, 2020). According to another report conducted to study the meat substitute market, major countries that currently have high acceptances for plant-based meat based on the survey from 2020 include United States, Canada, Mexico, Germany, United Kingdom, France, Russia, Italy, Spain, China, Japan, India, Australia, Brazil, Argentina, South Africa, and United Arab Emirates (Morder Intelligence, 2019). Among the countries listed, Europe has the largest market for plant-based meat, while the Asia-Pacific region has the market growing the most rapidly due to the influence of western cuisines. As plant-based diets

have been prevalent in multiple developed countries for an extended period, it is understandable that Europe and North America have larger market sizes compared to countries in Asia-Pacific and Africa (Morder Intelligence, 2019).

Although the price of plant-based meat used to be higher than the cost of animal proteins, the reduction in the price allows the market of plant-based meat to expand. For instance, the price of a 12-ounce Impossible Burger© patty has been decreased by twenty percent (Impossible Foods, n.d.). Besides Impossible Foods that have produced impossible burgers, Conabra Brand Inc., Amy's Kitchen Inc., Kellogg Company, and Campbell Soup Company are major companies in the plant-based meat market.

Because of the ongoing pandemic, online stores becomes one of the primary methods for grocery shopping. Since it takes longer for plant-based protein products to be spoiled, the demand and the acceptance of using plant-based proteins as an alternative for animal proteins are also rising. Though people still rely heavily on animal proteins, plant-based meat has become one optimal substitute for consumers when animal meat is not widely available.

CHAPTER 3

Benefits of plant-based proteins

With the growth of the global population and the shortage of foods, seeking a novel source of proteins becomes inevitable (Prasad, 2013). Plant-based proteins become the optimal source of proteins that contains more nutrients. More importantly, it helps mitigate the loss of biodiversity and alleviate the environmental challenges posed by the overconsumption of animal proteins.

BENEFITS ON HUMAN HEALTH

Comparing to conventional animal proteins, artificial plant-based meat contains nearly 50 percent less saturated fats and no cholesterol at all (Ritcher et al., 2015; Wang et al., 2020). Diets high in saturated fats have been proven to increase the risk of cardiovascular diseases while also impairing the cognitive and memory function of brains (Greenwood et al., 1990; Winocur et al., 2005). Besides, a high saturated fat diet also affects the composition of cancellous bones in human adults (Wohol et al., 1998). Though there are unprocessed animal proteins that are low in saturated fat and cholesterol, the majority tend to avoid it because it is less tasty without the presence of a large amount of fat. Plant-based meat would be an ideal alternative option for people who want to have a rich taste of fats while still wish to be healthy because fat mimickers such as hydrocolloids, vegetable gums, starches, and maltodextrins that are plant-based or fruits-based are widely available (Egbert et al., 2006). A study conducted in Canada in which researchers increase the intake of plant-based proteins

by 100 percent and decrease the intake of animal proteins by half suggests that participants have a significantly higher dietary intake of fiber, polyunsaturated fat, and minerals, including magnesium and folate when they transition to plant-based proteins (Vatanparast et al., 2020). The dietary intake of vitamin E has also been escalated (Davey et al., 2003). Based on the model scientists used to calculate the nutrient score, increasing plant-based proteins in diets also results in a higher nutritional quality.

In addition, approximately 9.2 percent of the world population is experiencing food insecurity, which is equivalent to 700 million people (Roser et al., 2019; SOFI, 2019). As conventional food sources could not fulfill the world population's demand, utilizing novel food sources and developing novel technologies would be extremely crucial. Previously, the solutions for food shortages are expanding farmland and exploiting marine resources (Sabaté et al., 2014). Unfortunately, these methods are unsustainable and further exacerbate environmental issues. Transitioning to plant-based diets would be more sustainable because more plant-based resources that human beings can directly consume are freed from livestock. According to Foley et al. 2011, shifting 16 major crop plants to 100 percent human uses only from the ongoing mix of uses would lead to a 28 percent increase in global food production (Foley et al., 2011). Shepon et al., 2018 also corroborates that reduction in the production of food animals can generate two to twenty more times more plant-based foods that contain similar nutrients and fulfill the dietary requirements (Shepon et al., 2018). Replacing animal proteins with plant-based proteins can help feed more than three hundred people that

are starving now. As a result, limiting animal proteins and promoting plant-based diets would dramatically alleviate food insecurity and enhance food availability.

Antibiotic resistance is another threat posed by the consumption of food animals. Antibiotics are commonly used in food animals to prevent diseases and promote growth (McEwen et al., 2002). Although antibiotics are also used in agricultural animals to prevent diseases in humans, more antibiotics are used for non-therapeutic purposes (Landers et al., 2012). Bacteria that have developed resistance to antibiotics are widely found in the environment surrounding livestock and meat products put into the market. Nevertheless, plant-based meat production does not require the presence of antibiotics. Therefore, antibiotic resistance would not become a risk of consuming plant-based meat.

Moreover, zoonoses have become a huge threat to people who have close contact with farm animals. Among all human pathogens, 58 percent of pathogens are zoonotic (Woolhouse et al., 2005). As pathogens have a wide range of hosts, including livestock, livestock becomes the ideal intermediate and amplifier host, allowing pathogens to evolve and transmit to humans (Jones et al., 2013). Although only a small number of zoonotic pathogens are capable of causing major epidemics, the consequences of these epidemics would be detrimental. Shifting to plant-based diets would minimize the close contact with potential livestock, thus lowering the risks of being infected with zoonoses.

BENEFITS ON THE ENVIRONMENT

Although livestock food products count for 33 percent of dietary intakes of proteins, livestock requires extensive farmlands and crops to thrive (Steinfield et al., 2006). More importantly, livestock produces an unbelievable amount of greenhouse gas which deteriorates global warming. A report in 2007 indicates the global temperature would be elevated by 1.1 to 6.4 degrees Celsius by 2100 since 1990 if no practical actions were taken (Solomon, 2007). Since the increase of 2.5 degrees Celsius or more would severely reduce global food availability and contribute to food insecurity, it is urgent to mitigate global warming. Meantime, livestock activities contribute to 18 percent of total greenhouse gas emissions and almost 40 percent of total methane emissions (Steinfield et al., 2006). If the consumption of animal protein continues to rise, people would soon face environmental issues associated with global warmings, such as rising sea levels, extreme weather events, and ocean acidification (Impacts of Global Warming). One solution to mollify global warming would be to transition to plant-based diets, particularly replace a portion of animal proteins with plant-based meat. Plant-based meat alternatives would be more environmentally friendly because it requires less farmland and does not generate as much greenhouse gases as livestock production does. Instead, crops can also reduce greenhouse gas emissions by achieving nutrient management practices such as soil testing, plant tissue testing, and the use of nitrification inhibitors (Smith et al., 2008). In addition to reducing greenhouse gas emissions, 700 million acres of land could be utilized for more sustainable purposes by transitioning to the consumption of plant-based meat (Eshel et al., 2014; Eshel et al., 2015).

Besides, livestock activities have significant adverse effects on water qualities where crop production does not. Although 71 percent of the earth is covered by water, only a small amount of water can be accessed by humans (USGS). Nevertheless, the agricultural sector accounts for 70 percent of water use annually (Steinfield et al., 2006). Within the agricultural sector, livestock has a tremendous impact on water use as an enormous amount of water is needed for feed production. Even though crop plants also require an incredibly vast amount of water for growing, water pollution is a more severe issue associated with livestock activities. The pollution caused by industrial livestock is especially noticeable as it contains high nutrient loads, contaminants, and manures (Steinfield et al., 2006). On the contrary, water used for various purposes could be treated and reused for crop irrigation to mitigate water scarcity (EPA).

Lastly, livestock activities have proven to disrupt biodiversity and cause species extinction. Although it is challenging to conclude livestock activities account for the loss of biodiversity directly, livestock activities still play a pivotal role as loss of biodiversity is caused by a series of environmental degradation, including global warming, environmental pollution, and habitat change driven by overexploitation of lands (Steinfield et al., 2006). Despite the fact that it is difficult to measure the rate of biodiversity loss, species extinction is clearly happening since the Ice Age. Currently, about 10 percent of species have encountered threats posed by livestock due to habitat

loss. As a result, livestock production should be reduced in order to prevent further changes in habitats and thus product animals that are endangered.

In sum, plant-based meat would be a more appropriate approach because food animals have already brought multiple conspicuous and detrimental effects to the environment. Shifting to a plant-based diet would attenuate the situation to some degrees.

CHAPTER 4

Limitations of Plant-based Alternatives

NUTRIENT DEFICIENCY ASSOCIATED WITH PLANT-BASED MEAT

Although replacing a portion of red, processed meat with plant-based meat alternatives indicates an improvement in dietary qualities, studies have also shown plant-based diet would result in a significant reduction in the level of micronutrients and mineral intakes (Vatanparast et al., 2020). Vitamin B12 and zinc are particularly inadequate in plant-based proteins. Vitamin B12 is essential for DNA synthesis and energy production. Because vitamin B12 is commonly found in animal-based foods, it is common for vegetarians to have vitamin B12 deficiency. A long-term deficiency could even affect the eye, cognitive, bone health, and pregnancy (O'Leary et al., 2010).

Meanwhile, zinc deficiency could also lead to severe outcomes. As the consequence of zinc deficiency, growth failure would be reflected in the immune, central nervous, skeletal, epidermal, gastrointestinal, and reproductive systems (Roohani et al., 2013). Even though the lack of zinc and vitamin B12 has been recognized, only 24 percent of products are fortified with vitamin B12, and only 18 percent of products are fortified with zinc (Curtain and Grafenauer, 2019). Because zinc and vitamin B12 are minerals that are indispensable for human health, dietary supplements or more fortification of zinc and vitamin B12 should be encouraged. Additionally, some protein-based isolates have lower essential amino acids contents (Gorissen et al., 2018). Methionine and lysine levels are particularly lower in plant-based proteins when comparing to the

content levels in animal proteins (Table 1). Among the ten types of plant-based proteins studied in this research, five types (oat, lupin, wheat, hemp, and microalgae) do not contain enough essential amino acids that are recommended by World Health Organization, while essential amino acids contents in the remaining five types have met the recommended intake level (Gorissen et al., 2018; WHO, 2007). To ensure an adequate amount of essential amino acids is consumed, a mixture of plant-based protein resources or a dietary supplement of amino acids is crucial to compensate for the lack of essential amino acids in some proteins.

Types of Essential Amino Acid	Methionine	Lysine
Plant-based proteins (percentage)	1.0±0.3	2.5±0.1
Animal-based proteins (percentage)	3.6±0.6	7.0±0.6

Table 1. The differences of methionine and lysine between plant-based proteins and animal-based proteins tested in Gorissen et al., 2018. Plant-based proteins used in the study include oat, lupin, wheat, hemp, microalgae, soy, brown rice, pea, corn, potato, and animal proteins studied are whey milk, caseinate, and egg (Gorissen et al., 2018).

Furthermore, plant-based meat analogues are considered more processed as they require advanced technologies and complex formulations to imitate the appearance, texture, and flavor of animal proteins (Borher, 2019). According to Dietary Guidelines for Americans, 2020-2025, people should consume more unprocessed proteins when available because excessive consumption of ultra-processed food would eventually cause obesity in human populations, especially among women (Dietary Guidelines for Americans; Juul et al., 2018).

LIMITATIONS IN TEXTURE AND SENSORY CHARACTERISTICS

Another problem with plant-based proteins is that plant-based proteins lack some sensory characteristics that are prevalent in conventional animal meat. Although advanced studies and innovative technologies have already made the texture and sensory properties of plant-based proteins highly resemble these of animal proteins, some aspects of animal proteins are still challenging to imitate. Due to the lack of proteinus network, plant-based proteins have relatively lower folding ability as well as adhesiveness (Kamani et al., 2019: Table 2). Moreover, the inclusion of pea proteins increases the product's hardness (Yuliarti et al., 2021). This infers plant-based proteins are more likely to break and be less adhesive compared to animal proteins, although burger patties and processed meat products that are made with a defined percentage of plant-based proteins tend to be juicier and more tender because of their high emulsion stability and low stiffness (Kamani et al., 2019; Taylor et al., 2020).

Sample	A: No chicken inclusion	B: 20% chicken inclusion	C: 60% chicken inclusion
Hardness	1	2	3
Adhesiveness	1	3	3
Folding Ability	1	1	3
Emulsion Stability	1	1	3

Table 2. The ranking of stiffness, adhesiveness, shrinkage, and emulsion stability concluded from Kamani et al., 2019. 1 indicates the lowest level and 3 indicates the highest result. In Kamani et al., 2019, sample A contains no animal proteins. Soy protein isolate and gluten are used in the study as the major sources of protein. Twenty percent of the plant-based proteins are substituted with chicken breast in sample B. For sample C, 60 percent of chicken breast is included with zero plant-based proteins. Emulsion stability is the ability to retain water and nutrients in the meat product. Same numbers indicate the there is no difference or the difference is not statistically significant (Kamani et al., 2019).

SOCIAL CONTRIBUTORS AND CONSUMER PREFERENCES

Another limitation is that people realize it is challenging to adhere to plant-based meat or replace a portion of plant-based meat due to social factors and educational

background (Van Vliet et al., 2020). Studies have shown that red and unprocessed meat-eaters are more likely from families with no undergraduate degrees (Vatanparast et al., 2020). This correlation exists likely because people who have higher education levels are more aware of the harm of saturated fats and cholesterol. Moreover, a study conducted in Europe to understand the preference of meat-eating consumers indicates that meat-eating consumers have more negative attitudes toward plant-based meat products composed of algae or peas, even knowing plant-based meat is not for vegetarians only (Michel et al., 2021). Without even having the actual plant-based patty in the front, the participants strongly believe plant-based meat alternatives are much less tasty by looking at the pictures given. Another study investigating consumer’s preferences on plant-based meat versus conventional animal meat given the same prices and conditions was conducted in 2019. Almost three-quarters of participants have chosen traditional farm-raised beef instead of plant-based meat and cell-based meat (Van Loo et al., 2020). When participants were asked to make decisions after brand names had been revealed, the predilection for animal proteins is more pronounced. Even with significant price reductions in plant-based and cell-based meat alternatives, the inclination remains unchanged. Though researches have shown that consumers are more willing to switch to plant-based products that mimic the taste of animal proteins than traditional plant-based products after recognizing the health benefits of plant-based proteins, consumers still prefer conventional animal meat over plant-based meat analogues generally. As meat consumption has frequently been associated with health, it is reasonable to understand why animal proteins play such an essential role (Modlinska and Pisula 2018).

While the comparison study conducted by Kamani et al., 2019 indicates plant-based meat products and conventional animal meat products have no noticeable differences in appearance and colors, consumers still seem to associate plant-based meat with an unpleasant odor and unsatisfying taste (Kamani et al., 2019).

Even though plant-based meat has been proven to be more environmentally friendly and healthier, the social factors and unchanged preferences for animal-based meat have definitely hampered the development and the acceptance of non-animal-based proteins.

CHAPTER 4

The future of meat alternatives

Because of pandemics that are believed to have animal origins, such as SARS and COVID-19, meat consumption has been significantly reduced in a short period. Long-term influences such as shifting towards lower-meat diets and higher plant-based proteins would likely happen, especially in some high-income countries (Attwood et al., 2020). Even though the majority of meat consumers do not prefer plant-based meat voluntarily, the current scenario might promote a surge in the consumption of plant-based proteins. In addition, cell-based proteins and algae-based proteins could become the new trend as technologies advance.

CELL-BASED MEAT

Besides plant-based meat alternatives, cell-based meat (also referred to as cultured meat) has become a potential protein source that could alleviate food shortages. Cell-based meat alternatives are made of cultured stem cells of animals (Santo et al., 2020). Cultured meat, also known as in vitro meat, has a history of experimental research for nearly twenty years (Stephens et al., 2019). Although this form of synthetic meat is relatively new, cultured meat has drawn much attention and has become more valued. While cell-based meat is not commercially available for purchasing yet, numerous researches and technologies currently focus on cultured meat. According to a 2035 projection, and cost of cultured meat and plant-based meat would be five times lower than animal proteins in twenty-five years. Thus, the demand for plant-based meat and

cultured meat would be significantly increased by reducing the need for animal proteins (Tubb and Seba, 2019). Though the commercial production of cultured meat still requires innovative technologies in tissue engineering and advanced knowledge in stem cell biology, the first cultured meat burger has been created successfully in 2013 (Rubio et al., 2020). It is reasonable to believe cell-based meat would be widely produced and accepted as the nascent protein source in the future.

ALGAE-BASED PROTEINS

Microalgae-based proteins would become the optimal source of protein when crop production reaches the maximum. Similar to plant-based proteins, algae-based proteins are also relatively more sustainable comparing to animal proteins. Algae would likely account for 18 percent of proteins by the middle of this century (Caporgno and Mathys 2018). Even though it has not been utilized as a protein source yet, microalgae act as additives in foods for thousands of years (Spolaore et al., 2006).

Algae are particularly beneficial for the environment and human health because it has a much lower land requirement. Meanwhile, some species of algae are also rich in proteins that contain various amino acids that the human body demands (Caporgno and Mathys 2018). The production of algae-based proteins might not be widely available currently due to underdeveloped technologies and inadequate researches. However, the possibility of utilizing algae-based proteins or meat has become of great interest in the past few years (Caporgno & Mathys, 2018). Therefore, it should not take too long to see the more commercial algae-based protein products.

Even with solid preferences for animal proteins over plant or algae-based products, the transition to novel meat sources seems inevitable because the world is changing rapidly.

Based on Market analysis report conducted in 2020, the market for plant-based proteins is expected to increase continuously from now to 2027 (Market analysis report, 2020). With the uncertainty posed by the pandemic, the demand for plant-based proteins is expected to expedite globally, especially in developed countries (Morder Intelligence, 2020).

CONCLUSION

Due to environmental issues, health concerns, and ecosystem disruption, reducing livestock activities and searching for a nascent protein source that could substitute animal proteins is urgent.

Although plant-based protein products were invented thousands of years ago, plant-based meat that mimics the texture and taste of actual animal proteins was only recently created. Plant-based meat alternatives are generally more environmentally friendly because it does not exacerbate global warming, loss of biodiversity or water pollution severely. It is also less harmful to human health as it lowers the risks of cardiovascular diseases, cancers, and type II diabetes. Promoting plant-based meat analogues would also reduce the risks of zoonoses, antibiotic resistance, and food insecurity.

According to the limited reports available currently, European and North American countries have the largest markets for plant-based meat. Though developing countries in the Asia-Pacific region are considered to have much smaller market sizes, China and Australia have become the most promising countries because of the astonishing growth rates.

Even though plant-based alternatives have proven to be an ideal source of protein that could partially substitute animal proteins, drawbacks are still present. Because zinc

and vitamin B12 are omnipresent in animal proteins, eliminating animal proteins from the diet would result in zinc and vitamin B12 deficiency. As the majority of commercial plant-based meat lack fortifications, this would become a conspicuous limitation. In addition, distinctive structures of plant-based proteins make the imitation of sensory characteristics particularly challenging. If future technologies failed to improve the sensory characteristics of plant-based meat, consumer acceptance is unlikely to change much. More importantly, people who have been meat consumers for a long time find plant-based meat unappealing. Social factors such as wealth and education levels also influence consumers' perspectives on plant-based meat. Though plant-based meat is widely available, negative attitudes toward animal meat alternatives would hinder the transition from animal proteins to plant-based meat.

Luckily, more options, including cell-based meat and microalgae-based proteins, are expected to be accessible soon. With more innovative technologies and advanced researches, animal protein alternatives are likely to be more accepted. Hopefully, threats associated with the overconsumption of animal proteins would soon be alleviated.

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