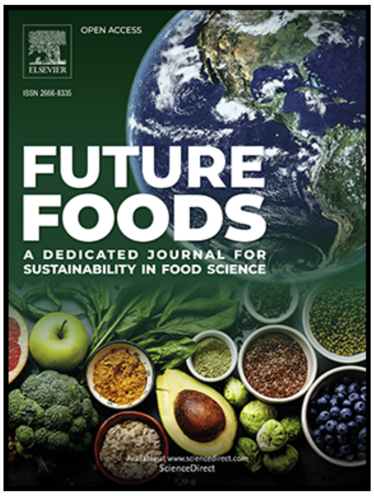

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Plant-Based Animal Product Alternatives Are Healthier and More Environmentally Sustainable than Animal Products

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Abstract

There are increasingly strong reasons to move away from industrial animal agriculture for the good of the environment, animals, our personal health, and public health. Plant-based animal product alternatives (PB-APAs) represent a highly feasible way to reduce animal product consumption, since they address the core consumer decision drivers of taste, price, and convenience. PB-APAs tend to displace demand for animal products, not other plant foods, and are more able to do this compared to whole plant foods alone. This paper reviews 43 studies on the healthiness and environmental sustainability of PB-APAs compared to animal products. In terms of environmental sustainability, PB-APAs are more sustainable compared to animal products across a range of outcomes including greenhouse gas emissions, water use, land use, and other outcomes. In terms of healthiness, PB-APAs present a number of benefits, including generally favourable nutritional profiles, aiding weight loss and muscle synthesis, and catering to specific health conditions. Moreover, several studies present ways in which PB-APAs can further improve their healthiness using optimal ingredients and processing. As more conventional meat producers move into plant-based meat products, consumers and policymakers should resist naturalistic heuristics about PB-APAs and instead embrace their benefits for the environment, public health, personal health, and animals.

WORD COUNT: 9,705

1. Background

1.1. Issues with our current food system

Our food system is an essential component of human society. It provides us with sustenance, nutrition, employment, security, and the opportunity to build society. However, the food system in its current form also causes severe harms to the planet, to human health, and to animals.

Firstly, the environmental case against animal agriculture is increasingly compelling. In a systematic review, Nelson et al. (2016) found that different types of modelling, life cycle analyses, and land use analyses consistently showed that diets higher in animal-based foods caused more harm to the environment than plant-based diets. As well as direct greenhouse gas emissions, animal agriculture drives deforestation, freshwater use, and eutrophication (Djekic et al., 2014; Theurl et al., 2020). Numerous high-profile reports have called for a reduction in meat consumption, especially in developed countries, including the EAT Lancet report on healthy sustainable diets (Willett et al., 2019), the UN's IPCC report on global warming (IPCC, 2018) and, most recently, the Dasgupta Review on the economics of biodiversity (Dasgupta, 2021). Animal agriculture in its current form is unsustainable for the existing population, and this will be exacerbated by the global growth in population and wealth.

Secondly, animal agriculture is a source of several public health concerns.The intensification of animal farming has caused an increase in the prevalence of zoonotic diseases (Jones et al., 2013) due to genetically-similar animals being housed and transported in high densities (Espinosa, Tago & Treich, 2020). These pathogens frequently mutate and pass to humans in close proximity, meaning that wet markets and animal farms increase the chance of zoonotic pandemics (Aiyar & Pingali, 2020). Moreover, years of prophylactic antibiotic use in animal agriculture has created antibiotic resistance in many foodborne pathogens found in animal products. Data from China indicate that 18% of market- and shop-bought meat samples were contaminated with Salmonella; 88% of these contaminated samples were resistant to at least one antimicrobial, while 58% exhibited multi-drug resistance (Xu et al., 2020). Similarly, 88% of Campylobacter identified in poultry samples from Italy were resistant to at least one tested antimicrobial (Di Giannatale et al., 2019). Jaja et al. (2020) have identified similarly alarming rates of multi-drug resistance in E. coli samples found in meat in South Africa. Conventional meat production, therefore, is a source of pandemic risk and antibiotic resistance.

Thirdly, overconsumption of animal products is linked with a range of personal health problems including heart disease and cancer (Al-Shaar et al., 2020; Bouvard et al., 2015; Kahleova, Levin & Barnard, 2018; Zhao et al., 2017). In particular, red and processed meat consumption is implicated in these most acute health problems. In 2015, the

World Health Organisation declared that red and processed meat are carcinogenic; red meat is classified as Group 2A, meaning that there are positive associations and strong mechanistic evidence for a link between red meat consumption and colorectal cancer, while processed meat is classified as Group 1, meaning that there is convincing evidence based on epidemiological studies that processed meat causes cancer. Although this fact seems extremely pertinent to public health, there appear to be no estimates of how much of the meat we eat is processed meat. However, we can construct a rough estimate based on available data. According to the Good Food Institute's analysis of Euromonitor (2021) data from trade sources and national statistics, total global meat sales volume in 2020 was 224 million tons. Global processed meat sales volume was 30 million tons, global beef and veal sales volume was 48 million tons, and global pork sales volume was 66 million tons. Although there is some overlap between processed meat and the beef/pork categories, one could estimate that processed and/or red meat composes roughly half of global meat sales volume. Therefore, a substantial portion of the meat we consume is known to be carcinogenic.

Therefore, industrial animal agriculture is a problematic component of the food system with respect to the environment, animals, and human health. However, although many of these arguments have been well-known for years, meat consumption has grown steadily since the 1960s (Ritchie & Roser, 2019). While some of this growth is attributable to population growth over the same period, it is likely that global demand will continue to rise as more consumers in developing countries incorporate more meat into their regular diets (Delgado, 2003; Whitnall & Pitts, 2019). Many of these issues, especially health-related, are related specifically to meat overconsumption, which is primarily an issue in developed countries (Sans & Combris, 2015).

1.2. Plant-based animal product alternatives

Rising global consumption of animal products in spite of the negative consequences reflects the fact that consumers' food choices are not primarily driven by arguments about the ethical or environmental impacts of their choices. Rather, the primary drivers of food choice are price, taste, healthiness, and convenience (Dikmen, İnan-Eroğlu, Göktaş, Barut-Uyar & Karabulut, 2016; Fotopolous et al., 2009; Januszewska et al., 2011; Onwezen, Reinders. Verain & Snoek, 2019; Steptoe et al., 1995).

One promising avenue for addressing these issues is replacing consumption of animal products with plant-based animal product alternatives (PB-APAs). PB-APAs are products which seek to emulate animal products with respect to their appearance, taste, smell, functionality, and cooking experience. Prominent examples of PB-APAs include Beyond Meat and Oatly oat milk. PB-APAs are differentiated here from whole plant foods, defined as minimally processed plant foods including fruits, vegetables, legumes, nuts, and seeds.

Unlike whole plant foods, PB-APAs seek to emulate the sensory experience of animal products, prioritising the key consumer needs of taste, familiarity, and convenience (Bryant, 2019; Hoek et al., 2011). Consumers can essentially adopt PB-APAs as a way of reducing their meat consumption without sacrificing the cooking and eating experiences they are accustomed to and enjoy (Hoek et al., 2011; Kyriakopoulou, Dekkers & van der Goot, 2019; Weinrich, 2019).

PB-APAs also offer substantial benefits over animal products in terms of both public health and environmental sustainability (see Section 3). However, some critics of PB-APAs claim that they are less healthy and sustainable than a pure whole foods plant-based diet (Al-Heeti, 2019, Scipioni, 2020).

1.2.1. Plant-based animal product alternatives replace animal products, not plant foods

Some critics of PB-APAs have claimed that these products may be preferable to animal products, but that they are not preferable to a straightforward diet of minimally processed whole plant foods. There are at least two points to be made in response to this line of argument.

Firstly, even if it is the case that whole plant foods are preferable to PB-APAs in terms of health or environmental outcomes, the difference between these two options is far smaller than the difference between either option and a regular meat-based diet. This is evident from the orders of magnitude of difference in environmental outcomes: for any analyses which conclude that PB-APAs are at least 50% less destructive than animal products, it must be the case that the gap between PB-APAs and animal products is greater than the gap between PB-APAs and whole plant foods. Most such analyses indicate the efficiency gap between PB-APAs and animal products is, in fact, closer to 90% than 50% (Heller & Keoleian, 2018; Figure 1).

Figure 1: Relative environmental impact of Beyond burgers compared to beef burgers (Heller & Keoleian, 2018).

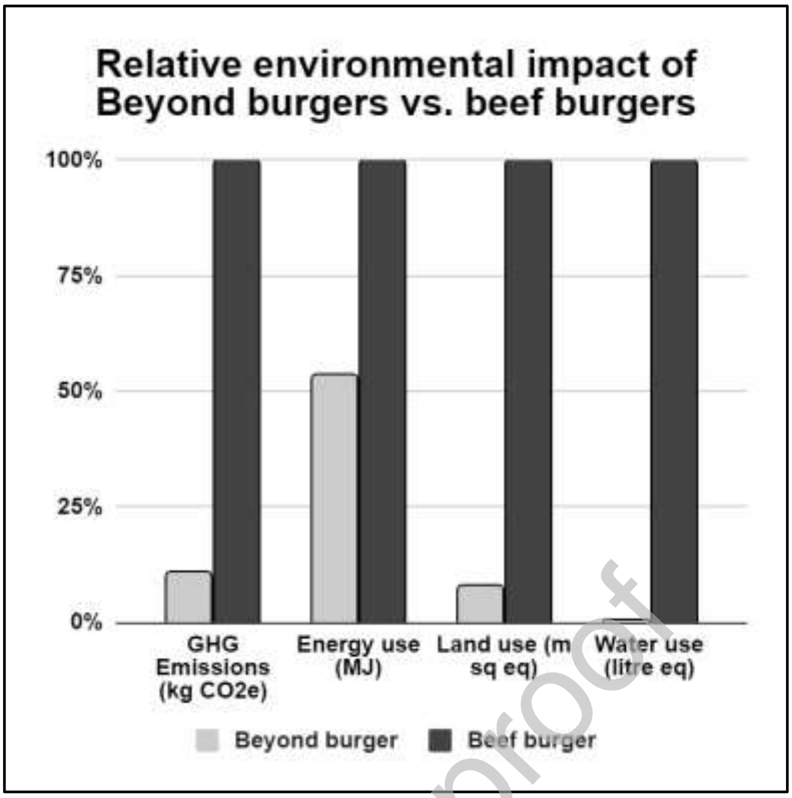


Figure 1 shows data from Heller and Keoleian's (2018) analysis of Beyond meat compared to conventional beef, but such magnitudes of disparity are typical across other similar analyses (see Section 5). As shown, the environmental impact of PB-APAs relative to their animal-based counterparts is close to zero. That is to say, even if whole plant foods had no environmental impact whatsoever (which is not the case), their benefits over PB-APAs relative to animal products would be minimal. Therefore, the argument for whole foods over PB-APAs is about a far smaller potential gain, and will almost certainly lead to worse outcomes overall if it makes PB-APAs less appealing.

Secondly, PB-APAs are intended to be animal product alternatives - not fruit and vegetable alternatives. Their forms, sensory properties, and product labels are similar to those of meat, fish, eggs, and dairy. It therefore seems likely that people buying PB-APAs are eating them in place of animal products, rather than in place of whole plant foods. It seems fairly unlikely that somebody would serve a plant-based burger and a meat burger in the same dish with no sides (see Tonsor, Lusk and Schroder, 2021) - it is much more likely that somebody who eats a plant-based burger swaps out the meat burger, and also eats other accompaniments such as beans or salad.

It is possible that some consumers of PB-APAs would otherwise have eaten whole plant foods, i.e. those who already avoid meat. However, market research suggests that almost 90% of PB-APA consumers are, in fact, meat-eaters (NPD, 2019). Profeta et al. (2021) found that 58.7% of survey respondents said that, on days when they do not eat meat, they substitute it deliberately for alternatives. Additionally, experimental evidence suggests that 21%-23% of consumers select PB-APAs over conventional beef when prices are held constant (Slade, 2018; van Loo, Caputo & Lusk, 2020). Tonsor, Lusk and Schroder (2021) asked consumers of plant-based burgers or plant-based ground beef what they would have purchased if they did not buy these PB-APAs; the most common responses were beef (49%) and chicken (38%). This demonstrates that PB-APAs do, indeed, tend to replace meat, not plant foods.

In economic modelling, Lusk, Blaustein-Rejto, Shah and Tonsor (2022) forecast that reductions in the price of plant-based meat lead to reductions in US cattle production. While the effect they observed was modest, the authors comment that this was offset by a decrease in beef imports and increase in beef exports, implying that the worldwide cattle population would be reduced by an even greater amount. When PB-APAs reach price parity with animal products, the impact on demand will be substantial. Therefore, the comparison between PB-APAs and whole plant foods is not especially relevant, since PB-APAs tend to replace animal products, not whole plant foods. Indeed, given that most PB-APAs take the form of processed meat products (sausages, burgers, nuggets, etc.) it is likely that they are displacing demand for analogous processed meat products.

Overall, therefore, the comparison of PB-APAs to whole plant foods is both irrelevant (since the former is not intended to replace the latter) and myopic (since the difference between the two is many times smaller than the difference between either and animal products). Moreover, a dogmatic insistence that one should only replace animal products with whole plant foods ignores the pragmatic reality that most consumer food choices are driven primarily by taste, price, and convenience, not considerations of animal welfare, public health, or the environment. If we want to achieve goals relating to the latter, we must appeal to appetites consisting of the former.

1.2.2. Plant-based animal product alternatives can displace animal product demand more effectively than whole plant foods alone

Because PB-APAs are specifically formulated to replicate the taste, texture, and overall eating experience of animal products, they can replace animal products directly, and are therefore a more effective tool for displacing animal product demand than whole plant foods alone. One major factor here is pure convenience: Schosler, de Boer & Boersema (2012) found that a lack of familiarity with ingredients and a lack of cooking skill were barriers to people preparing vegetarian meals. The authors recommended a diverse range of meat substitutes to cater for different meat reduction preferences, including reducing meat portion sizes, promoting health-conscious vegetarian meals, and, crucially, providing options for those primarily driven by convenience.

Of course, PB-APAs have developed a lot since 2012, including into ever more convenient purchase locations and product formats (Bryant, 2020). This means that consumers are more able to find plant-based products at the places they shop and in formats that they know how to interact with. A recent review found that convenience was a major factor in acceptance of various alternative proteins, including PB-APAs (Onwezen, Bouwman, Reinders & Dagevos, 2021).

However, even more important than appealing to convenience is appealing to sensory pleasure: the appearance, smell, taste, and texture of PB-APAs offers consumers something that whole plant foods cannot. Michel, Hartmann and Siegrist (2021) found that PB-APAs similar to processed meat had the best chance of replacing meat products, particularly when they have a similar taste and texture and are competitively priced. Similarly, Elzerman, Hoek, van Boekel and Luning (2011) found that PB-APAs were more likely to be considered appropriate if they looked similar to the products they were intended to replace. It is likely to be worth PB-APA producers sacrificing other product traits such as nutritional content or affordability in favour of increased sensory appeal. Indeed, if these products are unappealing, consumers are going to be unlikely to try future iterations which may improve on other points.

Moreover, a systematic review of consumer acceptance of alternative proteins concluded that plant-based meat alternatives are among the most accepted alternative proteins, while people often cite taste barriers to eating diets of purely whole plants (Ipsos Reid, 2010; Onwezen, Bouwman, Reinders & Dagevos, 2021). Survey data suggests that 49% of US consumers have tried a PB-APA, while 44% have not (8% not sure). For those who have never eaten PB-APAs, the most commonly cited reason by far was anticipated taste (cited by 31%) (Food Insight, 2020). While there is certainly room for improvement in the taste profiles of some PB-APAs, Bryant and Sanctorum (2021) found that the consumer appeal of PB-APAs is improving, with the proportion of Belgians saying they were satisfied with existing meat alternatives increasing from 44% in 2019 to 51% in 2020.

Consumers are more likely to choose PB-APAs over whole plant foods because these products better appeal to immediate desires for taste and convenience. As I have argued above, these products are likely to replace animal products and be eaten alongside vegetables, pulses, legumes, and other whole plant foods in a meal context. Moreover, the ability to try more plant-based meals without sacrificing the tastiness and convenience of animal products may mean that more consumers start eating a more plant-based diet, possibly increasing their long-term consumption of whole plant foods. Estell, Hughes and Grafenauer (2021) note that 22.1% of consumers who said they had tried PB-APAs did so to assist them in transitioning to a more plant-based diet. Similarly, Hoek et al. (2011) observed that, the more consumers ate PB-APAs, the more open they were to new plant-based foods. Indeed, we have seen a substantial rise in veganism in recent years in the UK, where such products are popular (Deloitte, 2019; Finder, 2021).

Overall, PB-APAs make more plant-based diets far more accessible to a greater number of consumers. Put simply, more people will choose plant-based options when those options are better. Making products which appeal to the key consumer needs for tasty and convenient food can effectively make it easier for individuals to replace animal products, therefore reducing demand more effectively than whole plant foods alone. If these products lead more people to forgo animal products in the long term, their consumption of whole plant foods is likely to go up, not down.

Thus far, it has been argued that animal products are linked to a number of severe global problems, and that PB-APAs can effectively displace demand for animal products (not whole plant foods) more effectively than whole plant foods alone. The next two sections will review the evidence relating to the health and environmental sustainability impacts of PB-APAs. Namely, are these products healthier and more environmentally sustainable than the animal products they replace?

2. Methods

Thus far, I have reviewed the issues with animal production, and highlighted PB-APAs as a potential solution which tend to replace animal products more effectively than whole plant foods alone. In the following sections, I present the results of a scoping review addressing two questions in more detail:

1) How **healthy** are plant-based animal product alternatives compared to animal products?
2) How **environmentally sustainable** are plant-based animal product alternatives compared to animal products?

A scoping review was chosen as the method to explore the evidence related to these questions due to the method's utility for synthesizing different types of evidence related to a given topic. As both healthiness and sustainability are broad concepts which can be measured and evaluated in a variety of ways, the flexibility and iterative nature of a scoping review enabled a range of relevant issues to be taken into account (Peterson et al., 2017).

2.1. Search terms

To address these questions, I searched Web of Science and Scopus for articles with terms related to plant-based meat and nutrition or sustainability in the title. The specific search terms used were:

Table 1: Terms used in the scoping review.

(**Plant-based meat** OR	((**Nutri*** OR	(**Environment***

Meat analog* OR **Meat alternative*** OR **Meat replace***) AND	**Health***)OR	OR **Sustainab***))

** indicates an incomplete word with multiple possible endings.*

2.2. Inclusion and exclusion criteria

The inclusion/exclusion criteria were defined as follows:

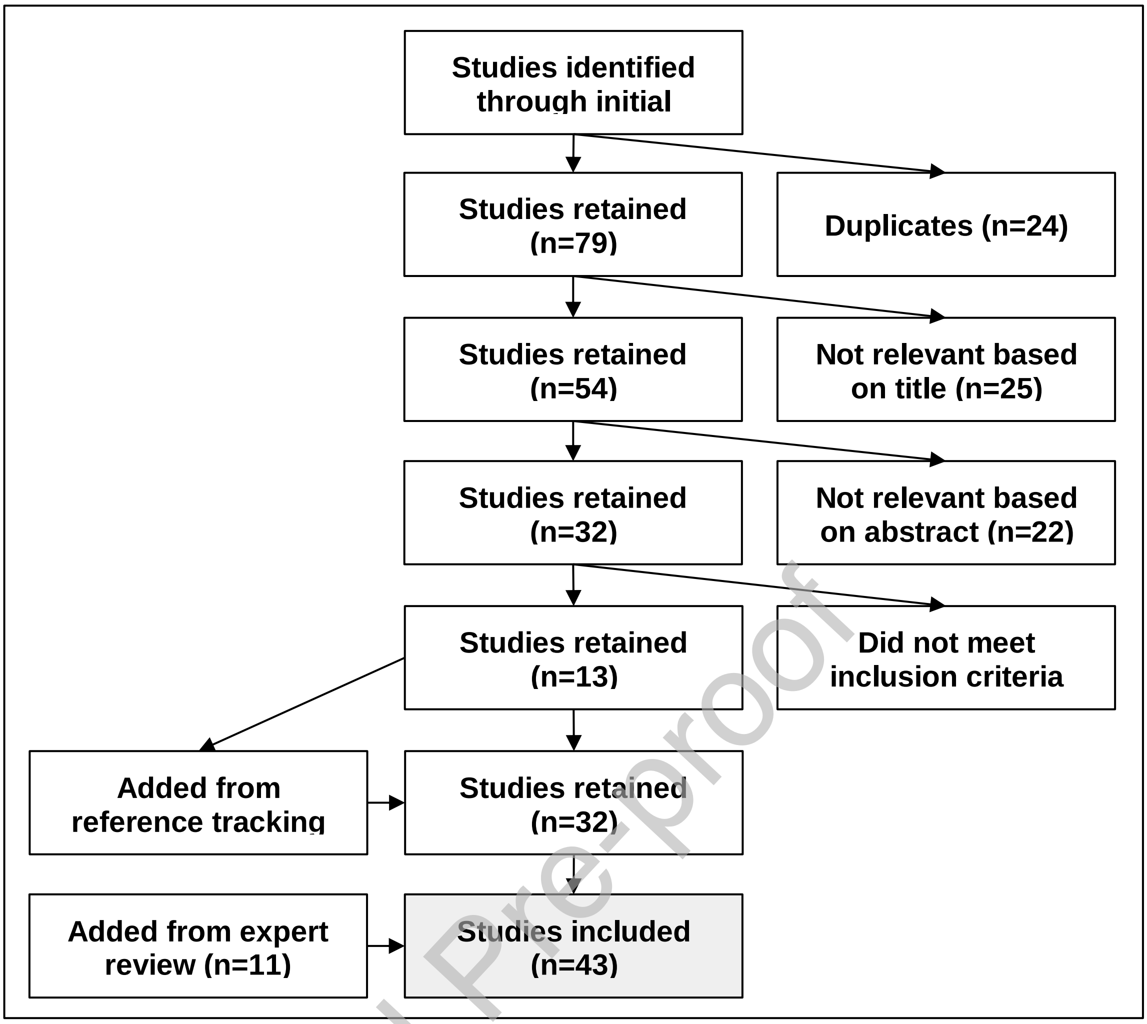
Table 2: Inclusion and exclusion criteria applied to studies.

<u>Inclusion criteria</u>	<u>Exclusion criteria</u>
1. Assess nutritional and/or health aspects of plant-based meat alternatives 2. Published in a peer-reviewed journal 3. Published since 2000 4. English language	1. Opinion, correspondence, or review papers without original data 2. Papers focused on sensory attributes, not nutrition and/or sustainability 3. Papers focused on nutrition or sustainability of whole plant foods, animal products, or processed foods generally – not plant-based meats specifically

2.3. Search and filtering procedure

The initial search identified a total of 103 potentially-relevant articles. The articles were then filtered, and additional articles were added, using the process below. First, duplicates were removed. Studies were then assessed for their relevance based on titles, and then based on abstracts. Studies were then removed if they failed other inclusion criteria on further assessment. Next, reference tracking was performed to identify other relevant studies which met the inclusion criteria. Finally, experts in the field of alternative proteins were consulted to suggest additional relevant studies not captured by the search and reference tracking.

Figure 2: Flowchart showing the scoping review process.



Of the 43 included papers, 33 addressed healthiness and 16 addressed environmental sustainability (6 addressed both health and environmental sustainability). The major themes of the papers were tabled, and prominent findings were noted within each theme. The following sections summarise the literature on the environmental sustainability and healthiness of PBAPAs.

3. Results

3.1. The environmental sustainability of plant based animal product alternatives

In this section, 16 studies assessing the environmental impact of PBAPAs are reviewed. The studies, which are mostly life cycle assessments, evaluate PBAPAs in terms of greenhouse gas emissions, land use, water use, energy use, and other environmental outcomes.

3.1.1. Greenhouse gas emissions

The most common environmental measure was greenhouse gas emissions, or global warming potential. Some of the earliest comparisons were between PBAPA and pork products. Zhu and van Ierland (2010) found that, compared to the PBAPA supply chain, the pork supply chain contributes 6.4 times more to global warming. Similarly, Davis, Sonesson, Baumgartner and Nemecek (2010) found that substituting pork for PBAPAs reduced global warming potential.

Subsequently, more substantial life cycle assessments were performed encompassing a wider range of product categories. Nijdam, Rood & Westhoek (2012) reviewed life cycle analyses of various protein sources, reporting the carbon footprint for each. They found that meat substitutes had substantially lower footprints than animal products. While completely plant-based meat substitutes had a carbon footprint of 1–2 kg CO2e per kg of product, those containing egg had a carbon footprint of 3-6 kg. Comparatively, poultry had a carbon footprint of 2–6 kg, pork had a carbon footprint of 4–11 kg, and beef had a carbon footprint of 9–120 kg. Thus, plant-based products were up to 120 times more carbon-efficient than animal products.

More recent life cycle analyses yield similar findings. Saget et al. (2021a) performed attributional life cycle assessments of pea-protein balls compared to Irish or Brazilian beef. They found that pea protein production was associated with a lower environmental impact across all 16 environmental categories assessed. This included 89% lower global warming potential. The authors argue that replacing just 5% of German beef consumption with pea proteins would reduce CO_2e emissions by 8 million tonnes annually - approximately 1% of Germany's total annual emissions.

Saget et al. (2021b) report that PBAPAs are associated with 82-87% less climate change per nutrition density unit compared to beef burgers. The authors also state that this climate change advantage of PBAPAs is increased by a further 25-44% when accounting for the carbon opportunity cost of land. It is claimed that switching from beef burgers to vegetable patties in the UK could save 9.5–11 million tonnes of CO_2e annually, which is 2.4% of the UK's territorial emissions.

Some assessments use a more applied approach based on existing commercial products, and the effect of integrating them into existing diets. Mejia, Harwatt, Jaceldo-Siegl, Soret, & Sabate (2016) performed life cycle assessments on 39 PBAPAs from two different companies, comparing greenhouse gas emissions. The analysis found that PBAPAs have a much lower environmental impact than animal products, with an average of 2.4 kg CO2e per kg of product – up to 54 times less than animal meat. Mejia et al. (2019) performed life cycle analysis on the outputs from three real PBAPA factories, and found that meat analogues generated relatively low emissions across all categories, factory sizes, and countries of production. They found that meat analogues caused an average of 2.19 kg CO2e/kg compared to 4 kg CO2e/kg for pork products.These studies highlight that currently available meat alternatives can have a substantial impact within our existing food system.

Further exploring the impact of different ingredients, Fresan et al. (2019) compared the emissions footprints of four different plant-based sources of protein, finding no significant difference between products made from soy, wheat, soy/wheat blend, or nuts. Adding egg to any of these products significantly increased their greenhouse gas emissions per quantity of product, protein, and calories, mirroring the findings of Nijdam, Roof and Westhoek (2012).

Some studies have used various methods to model the environmental impact of PBAPA adoption: Mertens et al. (2020) found that diets optimised for emissions reduction entailed a 75% reduction in meat consumption, and argue that instead adopting PBAPAs can reduce dietary emissions. Ritchie, Reay and Higgins (2018) projected that integrating PBAPA into existing diets alongside animal products could reduce $CO2$ emissions by up to 583Mt per year.

Finally, the most recent analyses concur that PBAPAs can yield significant emissions savings. Smetana, Profeta, Voigt, Kircher and Heinz's (2021) found that compared to plant-based burger patties, beef burger patties caused 5.5–8.3 times more greenhouse gas emissions. Saerens, Smetana, Camphenhout, Lammers and Heinz (2021) found that, compared to beef burgers, plant-based burgers were associated with 96%–98% less greenhouse gas emissions, and 43%–63% less ozone depletion. Overall, the evidence is strongly supportive of the view that PBAPAs are associated with significantly less climate change compared to animal products.

3.1.2. Land use

An important component of food system sustainability is efficient land use. Accordingly, agricultural land requirements are an important consideration for sustainability, and several studies compared the requirements for PBAPAs compared to animal products. Zhu and van Ierland (2010) found that, compared to the PBAPA supply chain, the pork supply chain demands 2.8 more land, and leads to 61 times more acification. Davis, Sonesson, Baumgartner and Nemecek (2010) found that substituting pork for PBAPAs reduced land use and acidification. This trend is reflected across the literature, largely due to the higher conversion efficiency.

In a life cycle analysis of various protein sources, Nijdam, Rood & Westhoek (2012) found that meat substitutes had substantially lower land footprints than animal products. While completely plant-based meat substitutes used 2–3 m^2 of land per kg of product, those containing egg used 1–3 m^2 of land. Comparatively, poultry had a land footprint of 5–8 m^2, pork had land footprint of 8–15m^2, and beef had a land footprint of

7–420 m^2. Thus, plant-based products were up to 420 times more land efficient than animal products.

Again, more recent life cycle analyses concur with this view. Shepon, Eshel, Noor and Milo (2018) compared the environmental impact of animal products to their PBAPA counterparts, and found that plant-based foods produce between 2–20 times more nutritionally similar food per unit of cropland compared to animal foods. Smetana, Profeta, Voigt, Kircher and Heinz's (2021) analysis found that compared to plant-based burger patties, beef burger patties required between 2.8–8.9 times more arable land caused between 27–63 times less terrestrial acidification, and caused between 15–56 times less terrestrial toxicity. Saget et al. (2021a) found that pea protein production was associated with 93% lower land burdens per nutritional unit compared to Irish or Brazilian beef. Saerens, Smetana, Camphenhout, Lammers and Heinz (2021) found that, compared to beef burgers, plant-based burgers were associated with 77%–92% less agricultural land occupation. These analyses comparing products like-for-like consistently find that PBAPAs are several times more land-efficient than animal products.

Some studies have modelled the land impact of integrating PBAPAs into existing diets. Temme et al. (2013) assessed the environmental impacts of replacing meat and dairy with PBAPAs in the diets of 398 young Dutch females. They found that replacing these products decreased dietary land use by 51%. Van Mierlo, Rohmer, and Gerdessen (2017) used linear programming techniques to analyse different proteins, seeking to minimise environmental impacts subject to nutritional constraints. Their analysis showed that vegan products had the largest potential for reducing emissions. Overall, the evidence supports the view that PBAPAs require substantially less agricultural land compared to animal products.

<u>*3.1.3. Water use and pollution*</u>

Several studies considered the relative impact of PBAPAs on water use, as well as eutrophication. Zhu and van Ierland (2010) found that, compared to the PBAPA supply chain, the pork supply chain demands 3.3 more water, and leads to 6 times more eutrophication. Davis, Sonesson, Baumgartner and Nemecek (2010) found that substituting pork for PBAPAs reduced eutrophication. Van Mierlo, Rohmer, and Gerdessen's (2017) models found that PBAPAs reduced water use compared to animal products.

More recent life cycle analyses also support the view that PBAPAs are more water-efficient than animal products. Saget et al. (2021b) report that PBAPAs are associated with 92-95% less marine eutrophication per nutrition density unit compared to beef burgers. Smetana, Profeta, Voigt, Kircher and Heinz's (2021) found that compared to plant-based burger patties, beef burger patties caused between 22–44 times more aquatic acidification, and up to 2 times less aquatic eutrophication. Saerens, Smetana, Camphenhout, Lammers and Heinz (2021) found that, compared to beef burgers, plant-based burgers were associated with 67%–97% less freshwater eutrophication, and 83%–92% less marine ecotoxicity. The evidence supports the view overall that PBAPAs require less water and cause less eutrophication compared to animal products.

3.1.4. Energy use

Some studies reported on the energy required to produce animal products in comparison to PBAPAs, though it is worth noting that this is an outcome which was not measured as commonly. Davis, Sonesson, Baumgartner and Nemecek (2010) found that substituting meat for PBAPAs used a similar amount of energy. Smetana, Profeta, Voigt, Kircher and Heinz's (2021) found that compared to plant-based burger patties, beef burger patties required 2.7–4.8 times more non-renewable energy. The evidence seems to suggest that PBAPAs require similar or less energy compared to animal products. That said, the evidence on this point is rather limited, and further research on energy use is warranted.

3.1.5. Other environmental outcomes

There were also a range of other environmental outcomes considered across the papers. Zhu and van Ierland (2010) found that, compared to the PBAPA supply chain, the pork supply chain demands 3.3 times more fertilizer and 1.6 times more pesticides. Van Mierlo, Rohmer, and Gerdessen (2017) showed that PBAPAs reduced fossil fuel depletion compared to animal products. Smetana, Profeta, Voigt, Kircher and Heinz's (2021) found that compared to plant-based burger patties, beef burger patties released 2-4 times more carcinogens into the environment.

Comparing life cycle assessments for a range of protein sources, Smetana et al. (2015) found the lowest environmental impacts across a range of measures for insect- and soy-based substitutes; chicken, as well as dairy- or gluten-based meat substitutes had a medium impact, while mycoprotein and cultivated meat had the highest impacts. The authors comment that many alternative proteins have the potential to become more sustainable with further technological improvements. Notably, this was a study of potentially promising alternative proteins, and therefore considered impacts compared to chicken, but not to higher impact meats like pork and beef.

In summary, many life cycle assessments support the view that PBAPAs are substantially more environmentally sustainable than animal products, producing lower greenhouse gas emissions and other pollution, while requiring less agricultural land, water, and energy inputs compared to animal products. Furthermore, PBAPAs can reduce our consumption of fossil fuels, fertilisers and pesticides, as well as pollution known to harm human health.

3.2. The healthiness of plant based animal product alternatives

This section reviews 33 studies relating to the healthiness of plant-based animal product alternatives identified through the scoping review. Papers investigated the nutritional profiles of PBAPAs compared to animal products, the impact of PBAPAs on weight loss and muscle synthesis, the interaction of PBAPAs with gut health, PBAPAs in relation to specific health conditions, and innovations to improve the healthiness of PBAPAs.

3.2.1 Nutritional profile

There are several studies which systematically compare the nutritional profiles of PBAPAs to their animal-based counterparts based on product nutrition labels. Alessandri et al. (2021) assessed 226 meat products and 207 PBAPAs available from 14 UK retailers. They found that PBAPAs were significantly lower in energy density, saturated fat, and protein, but significantly higher in fiber and in salt. Based on the UK's Nutrient Profiling Model, 40% of meat products were classified as 'less healthy' compared to just 14% of PBAPAs; similarly, 46% of meat products were considered high in total fat, saturated fat, or salt, compared to just 20% of PBAPAs. The authors conclude that PBAPAs have favourable nutritional profiles compared to meat, but there is a need to reduce their salt content. Likewise, Petersen, Hartmann and Hirsch (2021) assessed the healthiness of new meat and meat alternative products in the German market using Ofcom's A-score, which quantifies the presence of several 'nutrients to limit' including saturated fat, sodium, sugar, and overall calories. The analysis found that PBAPAs contained significantly lower levels of nutrients to limit, indicating increased healthiness compared to meat products.

Similarly in the US, Harnack et al. (2021) compared the nutritional profiles of beef and 37 PBAPAs in the ground beef category. They found that the PBAPAs were a good source of dietary fiber, iron, manganese, copper, folate, and niacin, and were low in saturated fat. However, they also found that the products were high in salt, and contained less protein, zinc, and vitamin B12 compared to ground beef. Another paper comparing 7 PBAPA burgers in the US to beef burgers came to similar conclusions (Edge & Garret, 2020). The authors highlight that plant-based burgers have similar macronutrient profiles to 80% lean beef burgers: the PBAPAs compared tended to have similar or higher levels of protein, lower levels of fat and saturated fat, and higher levels of fiber. However, the authors also highlight that PBAPAs have higher levels of salt, as well as less bioavailability of protein, calcium, and iron. These analyses suggest that, while nutritional profiles differ, it is not straightforward to say that either PBAPAs or meat are healthier overall.

Indeed, this view is expressed by Van Vliet et al. (2021). The authors found that, although nutritional profiles of plant-based and animal meats were similar, their metabolite abundancies differed by 90%. While 22 metabolites were found exclusively in beef, and 51 were found in higher quantities in beef, 31 were found exclusively in plant-based meat, and 67 were found in greater quantities. Only beef samples contained omega 3 acids and vitamin B3, while only PBAPA samples contained vitamin C, phytosterols, and several antioxidants. The authors do not argue that one is healthier than the other, but that they have different (and perhaps complementary) metabolomic profiles.

As well as studies comparing commercially available PBAPAs, some looked at the nutritional profiles of plant-based protein sources more broadly. Fresan et al. (2019) compared four different plant-based sources of protein, finding that soy products had significantly higher levels of calories, carbohydrates, fiber, omega 3, zinc, vitamin B1, riboflavin, vitamin B6, and folic acid. Nuts had significantly higher levels of polyunsaturated fatty acids, vitamin A, and niacin. Rodgers (2001) reviewed the nutritional quality of mycoprotein, highlighting that mycoprotein products tended to have less fat, less saturated fat, more fiber, less energy density, and no cholesterol compared to their meat counterparts. Mycoprotein also contains all of the essential amino acids. Smetana, Profeta, Voigt, Kircher and Heinz (2021) compared different alternative proteins in terms of their nutritional quality. They found that insect-, pea-, soy-, and mycoprotein-based burgers all had lower saturated fat and higher dietary fiber compared to beef burgers, and soy-based burgers had the most favourable nutritional properties overall.

There are also several studies which address narrower nutritional claims. An analysis of on-package labelling in the US found that 94% of PBAPAs carried a protein claim, 30% carried a cholesterol claim, 74% carried a GMO-free claim, and 63% carried a plant-based claim (Lacy-Nichols, Hatterslet and Scrinis, 2021). He, Liu, Balamurugan and Shao (2021) found that PBAPAs contained significantly lower levels of trans-fatty acids (associated with coronary heart disease) compared to beef burgers. While PBAPAs contained 2.39%–2.77% trans-fatty acids, beef burgers contained 5.82%–6.06%. Saldanha do Carmo et al. (2019) demonstrated a plant-based snack product made from pea starch, pea protein, and oat fibers. Produced at optimal conditions, these snacks had a high enough protein content to qualify for the EFSA nutrition claim 'rich in protein'. These studies highlight positive health claims that could be made by some PBAPA producers.

Several studies used computer modelling to estimate the nutritional impacts of replacing animal products with PBAPAs in specific populations. Vatanparast, Islam, Shafiee, and Ramdath (2020) modelled the effect of increasing PBAPA consumption 100% while reducing red and processed meat consumption by 50% in Canada. They found that the simulated diet led to increased intake of fiber, polyunsaturated fatty acids, magnesium, and dietary folate equivalents – but a reduction in protein, cholesterol, zinc, and vitamin B12. Based on Nutrient Rich Food scores, the authors conclude that the overall nutritional value of the PBAPA diet was favourable compared to baseline diets. Farsi, Uthumange, Munoz and Commane (2021) modelled the nutritional impact of replacing meat with PBAPAs in the UK. They found that switching to PBAPAs led to increased intake of carbohydrates, fiber, sugars, and sodium, but decreased intake of protein, fat, saturated fat, iron and vitamin B12. The authors conclude that PBAPAs can be a healthy replacement for meat if consumers choose products low in salt and sugar, and high in fiber, protein, and micronutrients. They also suggest that manufacturers and policymakers should consider fortifying PBAPAs with iron and B12, while reducing sugar and salt content.

Finally, several studies simultaneously modelled the environmental and nutritional outcomes of different protein sources. Mertens et al. (2020) found that diets optimised for nutritional quality entailed a 50% reduction in meat consumption, and argue that PBAPAs (especially fortified products) can supplement nutrient quality while reducing environmental impacts. In their assessment of the impact of replacing meat and dairy with PBAPAs in a sample of young Dutch females, Temme et al. (2013) found that replacing these products decreased saturated fat intake by 30% without compromising total iron intake. The authors note that, while the plant-based diet actually contained more iron overall, it tended to be from less bioavailable sources.

Overall, the literature supports the view that PBAPAs, compared to animal products, have lower levels of fat, saturated fat, cholesterol, and calories, but may have less or less bioavailable protein, iron, and B12. Although some products contain high levels of salt, PBAPAs also tend to be higher in fibre and a range of micronutrients. From a nutritional perspective, there are a range of positive health claims available to PBAPAs, as well as several areas where future development can further strengthen overall nutrition.

3.2.2. Muscle synthesis and weight loss

Several studies investigated the effects of PBAPAs on muscle synthesis. Van Vliet, Burd and van Loon (2015) review the skeletal muscle response to various plant proteins, as well as animal proteins. Some evidence has suggested that animal proteins lead to a greater muscle synthetic response than plant proteins, however, the authors noted an absence of studies actually assessing the postprandial muscle synthetic response of plant- vs. animal-derived proteins. They also suggest several strategies for augmenting the anabolic properties of plant proteins, including amino acid fortification of products, selectively breeding plants to improve amino acid profiles, and eating a higher quantity of proteins from multiple complementary plant protein sources.

The review identified two more recent empirical studies on PBAPAs and muscle synthesis. First, Dunlop et al. (2017) found that 40g of mycoprotein (18g protein) was sufficient to mount a robust muscle synthetic response, while 60g of mycoprotein (27g protein) provided an optimal anabolic response. The authors highlight that, gram for gram, mycoprotein and milk protein are equivalent in their amino acid bioavailability. Second, Kouw et al. (2021) found no significant difference in postprandial muscle synthesis rate between a group of healthy young men who ate chicken compared to a group who ate a lysine-enriched PBAPA. The authors concluded that PBAPAs are likely to be as effective as animal proteins to stimulate muscle synthesis. Van Mierlo, Rohmer, and Gerdessen's (2017) models, which optimised for environmental outcomes with nutritional constraints, favoured soy from a range of alternative protein sources due to its favourable amino acid profile.

There were also several studies assessing PBAPAs for weight loss. Rodgers (2001) cites some evidence suggesting that mycoprotein consumption, compared to animal products, can improve blood lipid profiles, reduce long-term hunger, reduce glycemia, introducing potential benefits for obese or diabetic consumers. Three empirical studies addressed PBAPAs for weight loss. First, Douglas, Lasley and Leidy (2015) gave participants either beef or soy based meals, and subsequently observed no significant difference in time before each group requested their next meal, nor in their subjective hunger/fullness, or peptide responses – indicating little difference between the two meals in appetite satiety. Second, Bottin et al. (2016) found that, compared to an overweight group who ate chicken, an overweight group who ate mycoprotein chose to eat significantly less calories (10%). The authors conclude that mycoprotein can reduce energy intake in overweight individuals. Finally, Crimarco et al. (2020) conducted a randomized crossover trial where participants were instructed to eat at least 2 servings a day of PBAPA or animal protein. They observed that plant proteins were associated with significantly lower body-weight. Overall, the evidence suggests that PBAPAs are no different from animal products in terms of muscle synthesis, and may confer benefits in terms of weight loss.

3.3.3. Specific health conditions

The review also identified studies investigating health outcomes of PBAPA consumption related to specific health conditions. Lousuebsakul-Matthews et al. (2013) analysed hip fracture data from the Adventist Health Study-2. They found that daily consumption of PB-APAs was associated with a 49% reduced risk of hip fracture, while consuming meat four times per week was associated with a 40% reduced risk. The trials conducted by Crimarco et al. (2020) found that consumption of PBAPAs compared to consumption of animal meat was associated with a significantly lower level of trimethylamine-N-oxide (TMAO; a molecule linked to cardiovascular disease).

Two studies examined insulin responses to PBAPAs: Bottin et al. (2016) found that compared to chicken meals, mycoprotein meals lead to a significant reduction in insulin responses, arguing that consumption could reduce insulin release in overweight individuals. Similarly, Dunlop et al. (2017) found that, compared to milk protein ingestion, mycoprotein ingestion resulted in slower but more sustained hyperinsulinemia and hyperaminoacidemia. The authors concluded that mycoprotein represents a good bioavailable protein source for muscle synthesis which is also insulinotropic. The product developed by Saldanha do Carmo et al. (2019) contained sufficiently high levels of beta-glucan to qualify for the EFSA health claim that it reduces postprandial glucose response.

Havlik, Plachy, Fernandez and Rada (2010) investigated the purine content of PBAPAs, which is relevant to those with hyperuricemia (abnormally high uric acid in the blood). The authors found that mycoprotein products had the highest purine levels (2,264 mg per kg of protein), while there was significantly less in products made from soy (1,648 mg/kg) and wheat (1,239 mg/kg). The latter, therefore, are preferable for hyperuricemic consumers. Overall, there is evidence to suggest that PBAPAs are appropriate for, and may benefit, those who are at risk of bone fractures, cardiovascular disease, diabetes, and hyperuricemia.

3.3.4. Other health benefits

The literature also contains evidence for other health benefits of PBAPAs, including cholesterol reduction and gut health. Crimarco et al. (2020) found that, compared to meat consumption, PBAPA consumption was associated with significantly lower LDL-cholesterol concentrations. Indeed, the product developed by Saldanha do Carmo et al. (2019) also had a high enough beta-glucan content to qualify for EFSA health claims that it lowers cholesterol.

Some research has assessed the impact of PBAPA consumption on gut health by comparing stool samples of a group who replaced some meat with PBAPAs to a control (Toribio-Mateas, Bester, & Klimenko, 2021). The researchers observed an increase in butyrate production and metabolization in the treatment group, as well as a decrease in the Tenericutes phylum. They concluded that occasional replacement of animal meat with PBAPAs can promote healthy gut microbiomes.

Finally, Ritchie, Reay and Higgins (2018) found that integrating PBAPA into existing diets alongside animal products could prevent up to 52,700 premature deaths each year. Their analysis indicated that more premature deaths are avoided at higher levels of PBAPA uptake, and that over 85% of deaths avoided are attributable to diet-related health risks such as coronary heart disease, cancer, and stroke, as opposed to weight management. The authors recommend a shift towards PBAPAs for public health. Overall, the evidence in this section suggests that PBAPAs can lower cholesterol, improve gut health, and prevent premature deaths.

3.3.5. Innovating to improve healthiness

The review identified several studies presenting formulations or processing methods which improved the healthiness of PBAPAs. These were often focused on addressing the nutritional shortcomings identified in section 3.2.1. Innovations improved overall nutritional profiles, increased vitamin content, reduced antinutrient content, and improved disease-fighting nutrients.

Some specific processes or ingredients may improve PBAPAs' overall nutritional profiles. Hamid et al (2020) demonstrated that PBAPAs which included jackfruit byproducts compared to commercially available plant-based meats had significantly more protein and fiber, arguing that the addition of these byproducts can improve PBAPAs' nutritional profiles.

Vitamins can also be added to PBAPAs. Wolkers-Rooijackers, Endika & Smid (2018) found that adding *Propionibacterium freudenreichii* to *Rhizopus oryzae* could produce Vitamin B12-enriched tempeh without affecting other parameters such as texture and volatile organic compounds. This was found to be a promising way to improve the B12 content of PBAPAs. Similarly, Caporgno et al. (2020) demonstrated that adding microalgae to soy-based PBAPAs could improve the nutritional profile by incorporating vitamins B and E.

Several processing methods show promise in decreasing antinutrient content in PBAPAs. Kaleda et al. (2020) found that treating a pea-oat protein blend with enzymes reduced phytic acid (an antinutrient which inhibits absorption of iron, zinc, and calcium) by 32%, while extrusion further degraded phytic acid up to 18%. Xing et al. (2020) found that solid state fermentation of chickpea products enhanced the nutritional quality by reducing anti-nutritional factors including phytic acid and alpha-galactosides (an enzyme which causes flatulence). Wang, Chen, Hua, Kong and Zhang (2014) found that a phytase-assisted method of processing soy protein isolate yielded lower phytate content, higher protein content, and better in vitro digestibility.

Finally, Palanisamy, Topfl, Berger and Hertel (2019) found that adding spirulina to lupin proteins increased total phenolic content, total flavonoid content, and Trolox equivalent antioxidant activity (all of which are linked to various disease defence properties, including producing antioxidants which may protect against free radicals), but decreased in vitro protein digestibility. Overall, the evidence in this section suggests that further product development of PBAPAs could increase their protein, fibre, vitamin content, and digestibility while reducing phytic acid and alpha-galactosides.

In summary, PBAPAs tend to have favourable nutritional profiles compared to animal products, tend to perform relatively well for weight loss and muscle synthesis, and can be formulated to cater to specific health conditions. They can also provide cholesterollowering benefits, and have benefits for gut health. Research to improve the healthiness of PBAPAs has identified ingredients and processes to optimise protein and fiber content, improve vitamin content, and reduce antinutrient content. Further such research should address ways to increase protein, iron, and Vitamin B12 content while reducing salt content.

4. Discussion

The results of the scoping review above generally support the view that PB-APAs are favourable in terms of environmental sustainability, and a range of measures relating to healthiness. In this section, I discuss these findings in the context of literature on consumer perceptions, explore why perceptions may differ from reality, and how this gap can be addressed.

4.1. Consumer perceptions of healthiness and sustainability of plant-based animal product alternatives

Most consumers correctly view PB-APAs as relatively healthy options. Michel, Knaapila, Hartmann & Siegrist (2021) found that burgers made from pea protein or algae protein were perceived as more healthy than beef burgers, although they were perceived as less tasty. Similarly, Estell, Hughes and Grafenauer (2021) found that 32% of Australian consumers agreed or strongly agreed that PB-APAs were more nutritious than conventional meat, while just 16.3% disagreed or strongly disagreed (38.1% indicated that they neither agree nor disagree, and 13.6% indicated 'Not sure', which may indicate some uncertainty on this question). Furthermore, Sucapane, Roux, and Sobol (2021) found that consumers gave 'meat alternatives' a mean score of 5.18 on a 1-7 scale of perceived healthiness, and gave 'plant-based meat' a mean score of 5.75. The evidence broadly supports the view that consumers tend to view PB-APAs as healthy.

However, some consumers may view PB-APAs as unnatural or overly-processed, and incorrectly infer that they are therefore unhealthy, damaging to the environment, or bad in other ways. Possidonio, Prada, Graca & Piazza (2021) investigated consumer perceptions of five different forms of alternative proteins, and found that perceived healthiness was positively correlated with perceived naturalness, and negatively correlated with perceived degree of processing. The researchers found that legumes were perceived as the most healthy, followed by tofu and seitan, followed by cultivated meat (i.e. meat grown from animal cells). The exception here was insects, which were perceived as more natural than some alternatives, but were still perceived as the least healthy.

Consumers' 'rules of thumb' about additives or degree of processing being related to nutritional profile are not easily supported by current science. Petersen, Hartmann and Hirsch (2021) found that, while 'Natural' labelling such as 'Organic' on meat and meat substitute products was associated with fewer additives, this often did not mean better nutritional quality. In the case of PB-APAs, most evidence suggests they are healthier than animal products, but consumers may infer the opposite to be true if they rely on additives or naturalness as indicators of healthiness.

4.2. The relevance of 'processing' to food healthiness and sustainability

Critics of PB-APAs have labeled these foods 'ultraprocessed' and sometimes point to the study of Hall et al. (2019) as evidence that such foods are unhealthy. The study found that adults who ate a diet of ultraprocessed foods, compared to those who ate unprocessed foods matched for macro-nutrient content, ate about 500 calories a day more when instructed to eat as much as they wanted, and gained weight. However, the ultraprocessed foods in the study (which included Coca Cola, Cheez-Its, and cookies) did not resemble PB-APAs in two important ways.

First, the ultraprocessed diet included 54 percent added sugar, versus 1 percent in the unprocessed group, and second, it included 34 percent saturated fat, versus 19 percent for the unprocessed diet (Hall et al., 2019). But this is not analogous in the comparison of PB-APAs to animal products – we typically see that PB-APAs are lower in saturated fat, and have received positive nutritional evaluations due in part to their low sugar content (Smetana et al., 2021).

Second, the diet examined in this paper was so low in fiber that it had to be supplemented using a drink – whereas plant-based meat contains more fiber than the conventional meat it replaces. This study, therefore, is of little relevance to those who argue against PB-APAs on the basis that they are processed, since the specific elements of the processed foods which lead to negative outcomes in this study are not present in PB-APAs. Indeed, Messina et al. (2022) note that the common criticisms of ultraprocessed foods – that they have high energy density, high glycemic index, hyper-palatability, and low satiety potential – simply do not apply to soy-based meat and dairy alternatives.

Furthermore, there are avenues for PB-APAs to become even more nutritionally robust with future advancements in formulation and processing. As Kyriakopoulou, Keppler, and van der Goot (2021) observe, the main ingredients currently used in PB-APAs have not been optimized for this purpose. PB-APAs are frequently fortified with minerals, vitamins and amino acids which may be difficult to obtain in a plant-based diet (Damayanti et al., 2018), and these ingredients can be more precisely refined in future iterations of these products, including by using more bioavailable sources and by varying or customizing quantities. For example, PATH (2020) assessed the essential amino acid scores of a range of plant protein sources, and identified that chickpeas, soybeans, quinoa, spirulina, duckweed, and potato are all excellent sources of sustainable and highly digestible plant protein.

In many cases, the processing of plant-based ingredients can improve their nutritional profiles. Boukid (2021) highlights how the processing of legumes into PB-APAs can denature naturally-occurring antinutrients and improve protein digestibility. Moreover, the author argues that PB-APA producers may be able to add edible fungi to increase lysine content (Kim et al., 2011), microalgae to balance amnio acid composition (Caporgno et al., 2020), or spirulina to increase phenols, flavanoids, antioxidant capacity, and vitamins B and E (Palanisamy, Topfl, Berger & Hertel, 2019; Caporgno et al., 2020). Future innovations in processing and ingredients are likely to lead to further nutritional enhancements to PB-APAs.

The idea that naturalness equates to goodness, and unnatural things are therefore bad, is known as the naturalistic fallacy (Daston, 2014) and is evident to some extent in alternative proteins (Siegrist & Hartmann, 2020). ProVeg (2020) found that consumers rated taste, texture, and convenience as among the most appealing aspects of PB-APAs, but rated naturalness and nutritional value as among the least appealing. These results indicate that although the sensory properties of PB-APAs are improving, concerns remain about their naturalness, and this may lead to negative inferences about their nutritional quality. Overcoming these concerns could accelerate the adoption of PB-APAs.

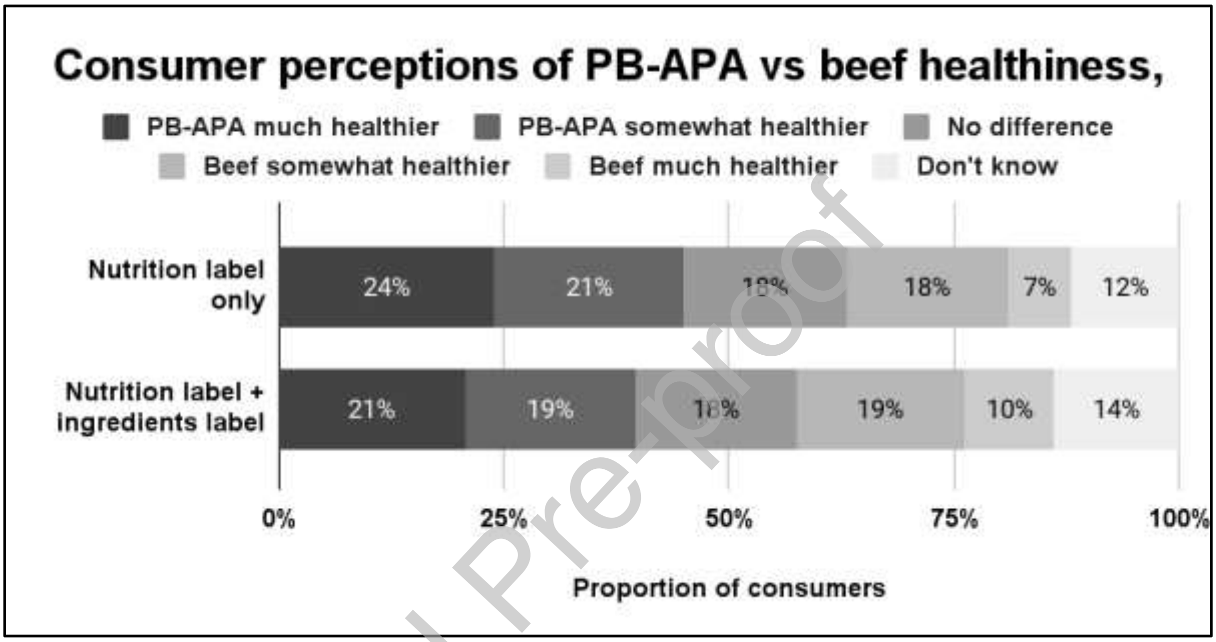
4.3. Messaging around naturalness of plant-based animal product alternatives

This concern appears to have been exacerbated by the conventional animal product industry appealing to consumers' intuitions about 'unnatural' food. In recent years, a lobbying group that used to attack Mothers Against Drunk Driving and fight for fewer restrictions on smoking has taken out expensive advertisements (including full-page adverts in the New York Times and feature adverts during the 2020 Super Bowl) to cast doubt on the healthiness of PB-APAs (Bradley, 2020; Reuters, 2020). Interest groups have started to pursue this strategy in Europe, as well as the US (Parrett, 2020).

In particular, messaging of this kind leans into consumers' intuitions about the relative naturalness of the different products, and can be used to mislead consumers into believing that meat from animals is healthier, simply because it is perceived as more natural. In fact, it is not clear that more natural food is healthier, or, indeed, that today's farmed animals could be called natural. Selective breeding in modern meat production has produced animals which would not be found in nature, and animal products which are higher in fat, lower in protein, and lower in protein quality and functionality (Mudalal, Babini, Cavani & Petracci, 2014).

In one study, 1,000 US participants made blind comparisons of the nutrition labels of beef vs. a beef-style PB-APA, and were asked to assess their relative healthiness. Crucially, participants were not told which label belonged to which product. When evaluating the labels, 45% of respondents said that the PB-APA product was somewhat or much healthier, compared to just 25% who said that the beef product was somewhat or much healthier (12% were not sure and 18% said no difference) (Food Insight, 2020). Interestingly, this 20% gap in favour of PB-APAs fell to just 11% when ingredients were listed (see Figure 2), even though most respondents said the nutritional information was more important than the ingredients list.

Figure 3: Consumer perceptions of PB-APA vs. beef healthiness when seeing the nutrition label only vs. nutrition label + ingredients label



As we can see, although the overall opinion was still in favour of the PB-APA being healthier (40%) compared to the beef (29%), there was a substantial reduction in the number of people judging the PB-APA more positively when the ingredients lists were revealed. This study highlights how faulty consumer intuitions about unfamiliar ingredients can negatively interfere with their judgments about actual nutritional content. PB-APA producers and policymakers should keep this tendency in mind when developing products, or regulations relating to product packaging and labelling.

Two similar studies have investigated different ways of addressing the naturalistic fallacy with respect to a related product - cultivated meat. While cultivated meat is, of course, different from plant-based meat, and related arguments may therefore differ in their persuasiveness, we can likely learn to some extent from empirical studies of naturalistic arguments specifically. First, Bryant et al. (2019) found that arguing either (a) that cultivated meat is natural, or (b) that naturalness should not matter were both ineffective, and did not change opinions of these specific points relative to other experimental conditions. However, arguing that conventional meat, with its artificial breeds, feeds, and practices, is also unnatural did increase acceptance of cultivated meat relative to other experimental conditions. Similarly, Macdonald and Vivalt (2017) found that cultivated meat acceptance was increased more by an argument which embraced unnaturalness-- i.e. that we should focus on the benefits we can reap if we transcend natural processes-- compared to arguments against the naturalistic fallacy or arguments centering on descriptive social norms. Interestingly, these studies concur on the relative efficacy of certain types of argument - focusing attention on clear benefits is better than trying to rebut specific arguments.

4.4. Limitations

There are a number of limitations of the present study worth consideration. First, there were practical constraints to the scope of the review criteria, including limiting the search to the English language, and limiting the search to peer-reviewed publications. This meant excluding some grey literature which may have contained useful data. This approach limited the scope, but may have improved the quality of studies included. Second, due to the variety of study types and evaluation methods included in the review, it was not possible to perform a quantitative meta-analysis relating to specific measures of healthiness and sustainability. The decision was made to favour a broad range of measures. Finally, given the very recent rise in popularity of plant-based animal product alternatives, much of the research on this topic is understandably new, and there remain substantial gaps in the research.

4.5. Future research

In order to capitalise on the many benefits of plant-based animal product alternatives, governments including those of Denmark and Canada, are increasingly investing in research and development in this area. Future research priorities should focus on improving the sensory quality, nutritional profiles, and affordability of plant-based animal product alternatives. Further improvements to these product characteristics will drive long-term consumer adoption, and are within reach given modest investment in research. In particular, the development of new ingredients and processing methods which can make plant-based meat alternatives tastier, cheaper, and healthier for consumers should be prioritised.

5. Conclusion

The problems with our current protein production system are many and severe, affecting the planet, human health, and animal welfare. PB-APAs offer a healthier and more environmentally sustainable solution which takes into account consumer preferences and behaviour. They are consumed in place of animal products, and should therefore be compared with such products. PB-APAs are found to be preferable from an environmental perspective in terms of greenhouse gas emissions, water use, land use, and they do not contribute to the growing global health threats of antibiotic resistance or pandemic risk. They are also preferable from a nutritional perspective in terms of saturated fat, cholesterol, fiber, and a range of other nutrients.

Moreover, with further developments in processing and formulation, PB-APAs have the potential to improve their nutritional profile even further, as well as improving across other metrics such as taste, texture, price, cooking properties, and sustainability. Additional research funding is of paramount importance to making these potential improvements a reality, and also to test early indications that these products offer health benefits when compared to their traditional counterparts. This product category is in its infancy, and products will inevitably improve, particularly if the industry follows its significant growth in sales from recent years (Kantar, 2020).

However, policymakers must be aware of the potential hazards with respect to biased consumer perceptions. Although most consumers correctly view PB-APAs as more nutritionally sound alternatives, their perception as unnatural or overly processed can lead some to incorrectly infer that they are unhealthy and/or harmful in other ways. This perception may be exacerbated by interests in the conventional animal product industry who seek to cast public doubt on these competing products. Consumers and policymakers must resist the heuristic that animal meat is natural and therefore better, and instead listen to the science, which suggests that PB-APAs can be a sustainable and healthy part of our future protein landscape.

Ethical Statement

Ethical review was not required for this study, since there was no original data collected from human or animal participants.

Conflict of Interest Statement

Although there is no specific conflict of interest or funding related to this project, the author is an independent research consultant and works with alternative protein companies.

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