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Meat versus meat alternatives: which is better for the environment and health? A nutritional and environmental analysis of animal-based products compared with their plant-based alternatives

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Abstract

Background: Poor diets lead to negative health outcomes, including increased risk of noncommunicable diseases. Food systems, most notably agriculture, contribute to greenhouse gas emissions (GHGE) that lead to climate change. Meat consumption plays a role in both health and environmental burden. Consumption of meat alternatives may reduce these harms. The aim was to compare meat products and their plant-based alternatives on nutritional parameters, GHGE and price to examine if it is feasible and beneficial for policymakers and health professionals to recommend meat alternatives.

Methods: Data on nutritional information and cost for 99 selected products were collected from five UK supermarkets. Estimates for GHGEs for 97 of these products were found through secondary articles. Median values for nutritional value, GHGE ($kgCO_2e$) and price per 100 g were calculated to allow comparisons between meat products and their alternatives. Mann–Whitney *U* tests were used to look for significant differences for each nutrient, emissions and price.

Results: Meat alternatives contained significantly more fibre and sugar and were significantly higher in price compared to the equivalent meat products. Meat alternatives had a significantly lower number of calories, saturated fat, protein and $kgCO_2e$ than meat products. There was no significant difference in the amount of salt between meat and meat alternatives.

Conclusions: Overall, this paper found that meat alternatives are likely to be better for health according to most parameters, while also being more environmentally friendly, with lower GHGEs. However, the higher price of these products may be a barrier to switching to meat alternatives for the poorest in society.

KEYWORDS

affordability, greenhouse gas emissions, nutritional analysis, sustainability

Key points

Plant-based meat alternatives (PBMA) were compared with meat products on nutrition, environmental impact, and affordability. PBMA contained less saturated fat, protein and calories, more fibre and sugar, and similar salt content. They were more expensive but had less emissions. All plant-based meat alternatives and most meat products were classed as ultra-processed.

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INTRODUCTION

Diet has a direct impact on health and has been the cause of a rise in many noncommunicable diseases (NCD).[1] Poor diet contributes to many negative health outcomes such as obesity, type 2 diabetes, heart disease and some cancers.[2] Poor diet was responsible for over 11 million deaths worldwide in 2017.[3] The climate change crisis is also a public health emergency.[4] Climate change is caused by excess greenhouse gas emissions (GHGE), which can lead to negative health effects such as an increase in heat waves leading to excess deaths, an increased geographical footprint of tropical diseases such as the Zika virus, increased food insecurity and dangerous extreme weather events.[5] Food systems have been shown to be a major contributor to the climate crisis, contributing about 19%–29% of all GHGEs, with agricultural production responsible for 80%–86% of these.[6] This will increase as the demand for food increases with population growth, and consumption of animal products may increase as populations become richer.[7,8]

Animal products are energy dense and contain essential nutrients and amino acids, so are a nutritious food source. In low- and middle-income countries, nutrient-dense foods like meat are particularly important.[9] However, meat consumption is increasing globally, with high per-capita meat consumption in high-income countries.[9] Overconsumption of red and processed meats is associated with increased risk of cardiovascular disease, type 2 diabetes and colorectal cancer.[10,11] The recommended intake varies globally, with the United Kingdom recommending no more than 70 g of red and processed meat per day[12] and the United States recommending 350–500 g of red meat per week and very little processed meat.[13] The production of meat products is additionally responsible for a high proportion of GHGEs attributed to agriculture.[14]

Alternatives to meat include processed plant-based products, which can be categorised as ultra-processed foods (UPFs), designed to replace meat in meals in which meat was a feature, such as 'meat' patties consisting of textured soy protein or pea protein.[15] Recently, the consumption of processed plant-based meat alternatives (PBMAs) has increased, with one reason for the increased consumption being the belief they are healthier than meat and another reason being the belief they are better for the environment.[16] Processed PBMAs are a straightforward substitution for meat, because they fit into existing recipes, which is desirable as cooking knowledge can be poor.[17]

Extensive research has been conducted into reducing consumption of animal products, adjusting diets to focus on a whole-food plant-based approach.[18–20] Aleksandrowicz et al.'s systematic review highlighted the benefits of a whole-food plant-based diet in the reduction of coronary heart disease, stroke and type 2 diabetes. However, this review did not observe PBMAs, and little research has been done on whether replacing meat with these PBMAs is also beneficial to health.[21] The EAT Lancet report in 2019 highlighted the necessity of moving towards a plant-based diet to reduce GHGEs,[22] paving the way for new research in diet, health and the environment. However, only whole-food plant-based diets were considered, not diets including PBMAs. A recent randomised control trial (RCT) studied the effects of swapping meat products with PBMAs; this trial found that those consuming the PBMAs had improved cardiovascular disease risk factors.[21] Another recent systematic review and meta-analysis of controlled trials found that PBMAs can lower your cholesterol.[23] These studies support the use of PBMAs in individual diets as a healthy alternative to some meats; however, more research is needed on these products for health.

Recent media reports stated that that PBMAs, such as plant-based 'beef' burgers and plant-based 'chicken' dippers, are more expensive than animal products, with many of these products being almost double the cost of the animal-based versions.[24,25] It is important to understand the cost of these products in the United Kingdom to understand whether these products could be an accessible option for those facing food insecurity.

As PBMAs are growing in popularity, and meat products can be harmful to the environment and health, the effect of PBMAs must be studied. In addition, whether these are affordable requires further examination. This study aims to understand the nutritional, environmental and affordability differences between meat products and their PBMAs, to support policy change and dietary advice.

METHODS

Product selection

Data were collected on meat and PBMAs from five British supermarkets: Tesco, Sainsbury's, Asda, Morrisons and M&S. These were chosen as they were the most popular supermarkets in the United Kingdom in a YouGov poll[26] available online. The products chosen were sausages, burgers, chicken nuggets, mince, meatballs and battered/breaded fish fillets. These products were chosen as they were identified as the most widely available products across all supermarkets included, allowing for comparison. Supermarket 'own brand' products as well as several other brands available were analysed. Where branded items were available in multiple supermarkets, for price, the modal average was used. In total, 99 products were analysed. However, two products were excluded from the GHGE analysis due to unavailable data in the list of ingredients.

Nutrients

For each product, data were collected on calories, saturated fat, protein, fibre, salt and sugar per 100 g.

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NOVA classification

The level of processing of the products was assessed by examining the list of ingredients. Products were then categorised according to the NOVA classification (group 1: processed and minimally processed foods, group 2: processed culinary ingredients, group 3: processed foods and group 4: UPFs).[27]

GHGE

To assess the environmental sustainability of each product, the GHGEs were studied. This was done by calculating the emissions per 100 g of each item.

The GHGE values for the ingredients were based on published literature, which were used to analyse the emissions for the main ingredient in each product. The values for beef, pork, soy, pea, chicken, farmed fish and soy and wheat were taken from Poore and Nemecek's article.[28] Fresán et al.'s[29] emission values were used for both wheat and soy plus wheat, whereas Robinson et al.'s[30] values were used for mushroom, and the Microbiology Societies (2018) values were used for mycoprotein. In the absence of published carbon footprints for minor ingredients, it was not possible to identify GHGEs for all the secondary ingredients. Therefore, a value of 0.3 kg CO_2/100 g has been assumed for the remaining percentage of ingredients, based on published values for other plant-based ingredients.

Price

Prices were collected from the supermarkets' and Ocado websites and were correct as of August 2020. Promotions were not taken into account, and original prices were used for individual products. For branded items available from multiple supermarkets, the modal average was recorded and used in analysis. Again, the prices were calculated per 100 g to allow a valid comparison. This was done by taking the product cost and converting it to cost per 100 g.

Statistical analysis

To provide insight into the data's spread, scatter plots were generated, which can be used to visually inspect relationships. The plots were generated to show the median and range for each nutrient (calories, saturated fat, protein, sugar, salt and fibre), price and GHGE for each product.

Once all results were obtained, statistical analysis was done to determine whether there is a significant difference between the nutrients, GHGE and prices, for meat versus PBMAs. For this, SPSS Statistics[31] was used to conduct a Mann–Whitney *U* test to examine differences in the average values for each nutrient, GHGE and price between the meat and PBMA groups, with significance decided at the 0.05 level.

RESULTS

For nutrient analysis, 99 products were analysed (sausages, beef burgers, mince, meatballs, chicken nuggets and fish fillets). For nutritional and price analyses, there were 56 meat products, incorporating, where possible, a luxury and budget version (as prices varied so much between different products) and 43 PBMAs. For the GHGEs, 97 products were used, the same 56 meat products and 41 PBMAs, as it was not possible to calculate the emissions from 2 of the products.

Calories

For all products, apart from the fish fillets, the PBMAs had a lower calorie content per 100 g compared to meat products (Table 1). The meat-alternative fish fillets contained 23 calories per 100 g more than the real fish fillets. The largest difference was in sausages: the meat alternatives had 128 calories less than the budget sausages and 130 less than the luxury sausages. The smallest difference is in chicken nuggets: the meat has 9.3 calories more than the meat alternatives (Supporting Information: Figure 2).

Saturated fat

Almost all the PBMAs had less saturated fat than meat products per 100 g (Table 1), with the exception of fish fillets, where the fish alternatives have 0.3 g more. The largest difference was observed in beef burgers, with 6 g less in the alternative products (Supporting Information: Figure 3).

Protein

For all products, PBMAs had lower protein content than meat per 100 g (Table 1). The largest difference was found for sausages, with meat alternatives containing more than 11.4 g less protein than luxury meat brands. The smallest difference is in chicken nuggets, with meat alternatives having only 1.6 g less (Supporting Information: Figure 4).

Fibre

For all products, PBMAs had a higher fibre content than meat per 100 g (Table 1). The biggest difference was in

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TABLE 1 Median values for nutrients per 100 g of product, from combining the values for the products in each category.

Product (per 100 g)		Price (£) (range)	Calories (kcal) (IQR)	Saturated fat (g) (IQR)	Protein (g) (IQR)	Fibre (g) (IQR)	Salt (g) (IQR)	Sugar (g) (IQR)
Sausages	Meat budget ($n = 5$)	0.37 (0.33–0.44)	277 (17)	6.8 (1.4)	15 (1.3)	1.0 (0.8)	1.30 (0.25)	1.80 (0.3)
	Meat luxury ($n = 7$)	0.67 (0.56–0.87)	279 (42.5)	7.5 (1.3)	20 (3.3)	0.9 (0.85)	1.43 (0.44)	0.50 (0.85)
	Plant based ($n = 8$)	0.73 (0.58–1.09)	149 (15.5)	2.5 (2.23)	8.6 (6.55)	6.4 (2.25)	1.27 (0.21)	1.20 (0.68)
'Beef' burgers	Meat budget ($n = 4$)	0.53 (0.44–0.55)	247.5 (35.25)	7.6 (0.68)	20 (1.48)	0.5 (0.28)	0.93 (0.31)	0.40 (0.33)
	Meat luxury ($n = 8$)	0.72 (0.61–1.18)	255.5 (57.75)	7.5 (3.78)	21 (3.9)	0.5 (0.23)	0.77 (0.13)	0.55 (0.38)
	Plant based ($n = 8$)	0.96 (0.39–1.85)	212.5 (48.5)	1.6 (0.8)	16.6 (1.38)	6.1 (1.5)	1.09 (0.27)	1.10 (0.98)
'Chicken' nuggets	Meat ($n = 8$)	0.39 (0.26–1.00)	262.5 (17)	2.1 (0.88)	14.0 (1.15)	1.6 (0.48)	0.77 (0.39)	1.35 (0.52)
	Plant based ($n = 8$)	0.61 (0.55–1.71)	253 (23.25)	0.9 (0.13)	12.4 (0.85)	4.9 (1.78)	0.82 (1.02)	1.00 (0.68)
Mince	Meat medium fat* ($n = 8$)	0.58 (0.47–1.50)	195.5 (33.75)	4.5 (1.83)	20.8 (3.88)	0.0 (0.2)	0.16 (0.10)	0.00 (0.2)
	Plant based ($n = 8$)	0.75 (0.35–1.39)	141 (30.25)	0.9 (2.48)	17.4 (3.48)	5.3 (1.05)	0.71 (0.36)	1.55 (0.85)
Meatballs	Meat ($n = 8$)	0.76 (0.52–1.49)	216.5 (47)	5.4 (2.45)	20.5 (3.38)	0.5 (0.60)	0.69 (0.30)	0.45 (0.35)
	Plant based ($n = 6$)	1.06 (0.44–1.94)	177 (31.75)	1.3 (0.55)	15.6 (2.38)	5.1 (1.53)	1.50 (0.36)	1.30 (0.35)
'Fish' fillets	Fish ($n = 8$)	0.72 (0.60–1.50)	186 (26.5)	0.8 (0.28)	12.6 (1.13)	1.0 (0.23)	0.76 (0.25)	0.95 (0.63)
	Plant based ($n = 5$)	1.31 (1.00–1.50)	209 (16)	1.1 (0.4)	8.9 (5.1)	3.4 (0.6)	1.30 (0.4)	0.90 (0.7)
Mann–Whitney *U* test	Meat compared to plant based	$p = 0.016$	$p = <0.001$	$p = <0.001$	$p = <0.001$	$p = <0.001$	$p = 0.989$	$p = <0.001$

Abbreviation: IQR, interquartile range.

*The options for the animal-based mince were high fat, low fat or medium fat. For analysis, only the medium fat was included.

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meat/meat-alternative beef burgers, and the smallest difference was in in fish fillets. With the exception of burgers, the lowest value for fibre in the meat-alternative products was higher than the largest value in the meat products; this demonstrates the big difference in fibre values (Supporting Information: Figure 5).

Salt

For almost all products, PBMAs have a higher salt content than meat per 100 g, with the exception of sausages (Table 1); however, this was not a significant difference. There is a small difference of 0.03 g between budget sausages and meat-alternative sausages, and a slightly larger difference of 0.16 g between luxury and the meat-alternative sausages. The largest difference was seen in meatballs, with meat alternatives having 0.81 g more salt, and the smallest difference was in chicken nuggets, with meat alternatives having 0.05 g more salt (Supporting Information: Figure 6).

Sugar

There is more variation in the amount of sugar per 100 g between the meat and PBMAs (Table 1), with some meat-alternative products having a higher sugar content than the meat, and others lower. The meat-alternative products with a higher sugar content are burgers, mince and meatballs, as well as luxury sausages, but lower than budget sausages. Meat-alternative versions of chicken nuggets and fish fillets are lower in sugar (Supporting Information: Figure 7). Despite this variation, overall meat-alternative products contained significantly more sugar than meat products (Table 1).

Price

For all products, the PBMAs were significantly more expensive per 100 g than the meat products (Table 1). However, the meat-alternative mince, beef burgers and meatballs all have a large range in price, resulting in a lower-priced meat alternative than the cheapest meat option, despite the higher median. The largest price difference was seen in fish fillets: the alternatives are £0.59 more expensive than real fish per 100 g. The smallest difference in price was seen in the luxury sausages (meat alternatives: £0.06 more) and luxury burgers (meat alternatives: £0.24 more) (Supporting Information: Figure 1).

NOVA classification

All PBMA products were placed in group 4 and classified as UPFs, as they each contained exclusively industrially used ingredients, and undergo industrial processes to create them. Similarly, with the exception of mince, which was categorised as group 1, minimally processed food (as all the animal mince was 100% beef), all of the meat products assessed were in group 4 and classed as UPFs.

Emissions

The data recorded for GHGE, indicating environmental sustainability, are presented in Table 2. Across all categories, PBMAs had a lower CO_2 emission compared with meat products (Mann–Whitney *U* test, $p = <0.001$). The largest difference was seen in products containing beef (meatballs, burgers and mince). Particularly different is the value for mince, which has a 48.41 kg CO_2e difference in emissions between the meat and meat alternatives per 100 g, as meat mince products have a high percentage of beef. This is followed by pork sausages. The smallest difference is between chicken nuggets and fish fillets and their alternatives, fish having the smallest difference at 3.28 g.

Figure 1 shows the spread of data for the kgCO_2e values for all products. For all products, there is a significant difference between meat and PBMA products. All meat products have higher values for kgCO_2e compared to meat alternatives. These data are presented on a log scale (in contrast to the linear scale used for the price and nutritional data comparisons) because of the large differences.

TABLE 2 Median (range) kgCO_2e per 100 g.

Product		kgCO_2e per product
Sausages	Meat budget (5)	5.55 (3.36–5.554)
	Meat luxury (7)	6.87 (5.55–7.38)
	Plant based (7)	0.57 (0.298–1.49)
'Beef' burgers	Meat budget (4)	43.04 (43.04–45.03)
	Meat luxury (8)	46.04 (38.07–47.52)
	Plant based (7)	1.20 (0.31–1.42)
'Chicken' nuggets	Meat (8)	3.11 (2.403–3.54)
	Plant based (8)	0.092 (0.16–1.63)
Mince	Meat medium fat (8)	50 (0)
	Plant based (8)	1.59 (0.31–1.95)
Meatballs	Meat (8)	44.53 (40.06–47.515)
	Plant based (6)	1.29 (0.31–1.49)
'Fish' fillets	Fish (8)	3.58 (3.04–4.01)
	Plant based (5)	0.30 (0.24–1.49)

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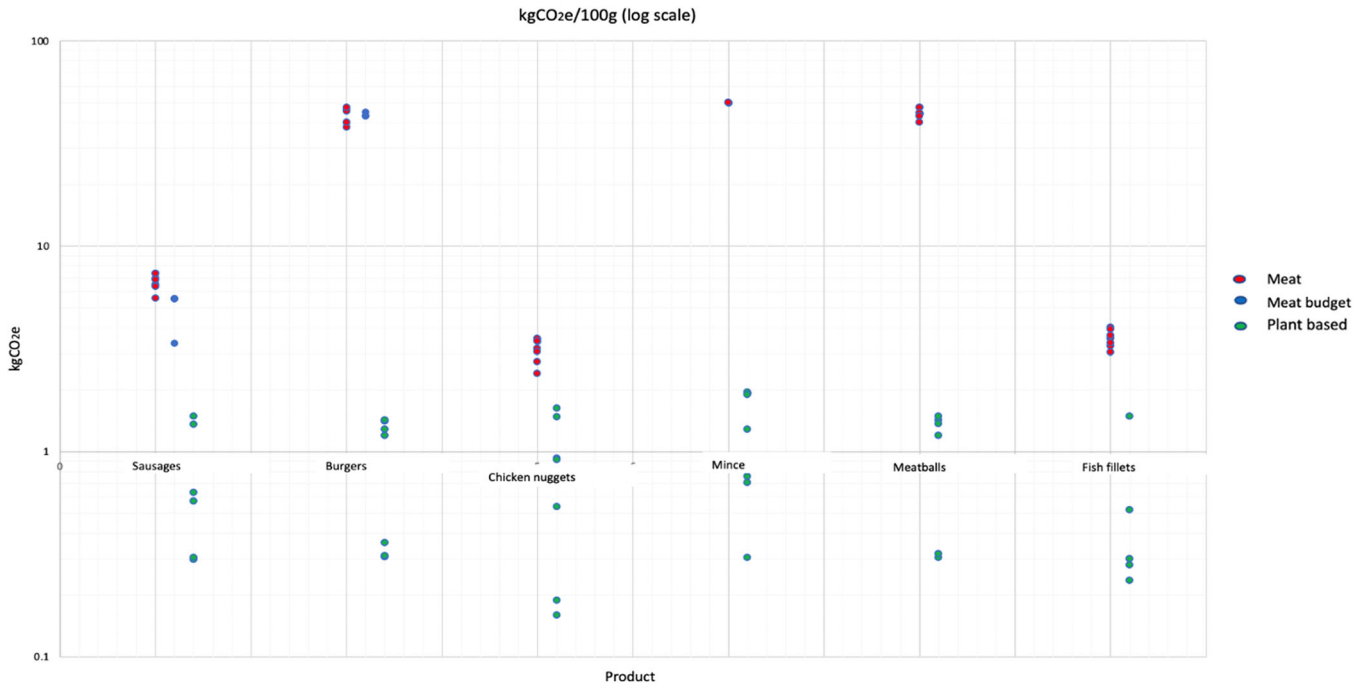

FIGURE 1 Scatter plot of CO_2 emissions ($kgCO_2e$) per 100 g product.

DISCUSSION

Overall, this study shows PBMAs may be healthier than meat products with more fibre, lower calories and lower saturated fat per 100 g. However, they are also higher in sugar and lower in protein. The salt content per 100 g of the products was not significantly different. The study also showed that PBMAs had significantly lower emissions, meaning they are better for the environment than their meat counterparts. However, these products are also significantly more expensive, which means they may not be feasible or affordable substitution to meat for those experiencing food insecurity. All PBMAs were classified as ultra-processed; similarly, all meat products were also classified as UPFs, with the exception of mince, which was minimally processed. This may impact the products 'healthiness'; there is some evidence that UPF may be unhealthy regardless of the macronutrient profile.[27]

These results provide evidence of how healthy PBMAs are compared with meat. The high amount of fibre they contain is beneficial, as consumption of dietary fibre globally is low.[32] Fibre has been consistently shown to reduce chronic disease and proves protective against heart disease, type 2 diabetes and some cancers.[32] A systematic review including 62 RCTs found that a diet high in fibre significantly reduced body weight, particularly in more overweight individuals.[33] As these PBMAs are lower in calories, this could aid weight loss, again proving beneficial for those who are overweight or support maintenance of a healthy weight. A systematic review observing the effect of low-calorie diets on weight loss found them to have a significant effect in individuals losing weight.[34] The PBMAs are also lower in saturated fat; this is beneficial as excess consumption of saturated fat causes obesity.[35]

However, the PBMAs are higher in sugar than meat products. In the United Kingdom, average sugar intake is above the recommended daily amount of 30 g.[36] Consuming too much sugar has been associated with obesity, due to an increased amount of calories[37] and an increase in NCDs.[38] There is also an increased risk of tooth decay in those who consume high levels of sugar.[37] Particularly in the United Kingdom, high intakes of sugar are seen in children, leading to them experiencing the above problems earlier in life.[36] As the PBMAs are higher in sugar, this may be a cause for concern, when the UK population should be looking to reduce their sugar intake. However, the amounts found in these foods are not excessive, so these products may be okay as part of a balanced diet, if individuals consume lower sugar elsewhere, particularly 'free sugars' found in foods like biscuits, chocolate, flavoured yoghurts, breakfast cereals and fizzy drinks.[37]

A common assumption with PBMAs is that they contain less protein than meat. This analysis confirmed this, as meat products have a significantly higher amount of protein per 100 g. Plant-based protein consumption is associated with lower-muscle protein synthesis[39] due to lower digestibility and lack of essential amino acids. This is a particular cause for concern in the older population where muscle depletion is higher.[40] This will need to be considered in places that have an ageing population, as recommending PBMAs to this population group may

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not be beneficial. This issue could be overcome by consumption of a wider variety of plant proteins to ensure a sufficient amount of all amino acids are consumed.[41] These contradicting health issues make recommendations difficult for policymakers to implement. More research into plant proteins may be needed to explore how these could be altered to improve protein availability.

It is well documented that excess salt in the diet can lead to high blood pressure[42,43]; however, there was no significant difference in the salt content of meat and PBMAs per 100 g. Therefore, a recommendation of PBMAs would not impact individuals' salt intake. Although it is reassuring that PBMAs are not higher in salt, it is disappointing that they are not lower in salt as this is one crucial nutrient that we know is particularly high in processed meat products and might be a mediator between consumption of processed meat products and adverse health outcomes.[44]

In the United Kingdom, UPFs account for over 50% of total energy intake.[45] UPFs are generally higher in salt, saturated fat, calories, sugar and carbohydrates, while being lower in fibre.[46] Studies have shown that those who have a higher proportion of UPFs in their diet are more likely to be obese and contract NCDs.[46,47] The products in this study were all UPFs, both animal products and PBMAs, except animal-based mince. This suggests that it would be best for individuals to minimise consumption of all of these products. However, although UPFs are often high in these nutrients, unusually, the PBMAs were low in saturated fat and calories and high in fibre, therefore potentially less likely to lead an individual to becoming obese.[47] However, they were higher in salt and sugar (although the sugar content was still relatively low compared with many other UPFs). Further understanding of the effect of processing of food on health outcomes, independent of nutritional composition, will help to further understand the place for PBMAs in the diet.

The results showed that PBMAs were significantly more expensive than meat. This is a cause for concern and may be a barrier for policy and professionals recommending these products, or for lower-income groups to take up a recommendation if it were made. Although some plant-based diets are affordable,[48] these are whole food diets, which may require individuals to have more cooking knowledge. Although switching to PBMAs would not require more knowledge, the expense of the products should be taken into consideration. One reason for the increased expense is the unestablished supply chains due to historically lower demand.[49] As demand increases, it is likely that supply chains will develop, and creating these products should become cheaper. It is also worth noting that the cheapest PBMAs in three categories were less expensive than the cheapest meat version. However, there are other products which can be substituted for meat which may not be as expensive, for example, lentils and tofu.

In some countries, like the United Kingdom, animal agriculture is subsidised by the government to support meat farmers. Similar subsidies could be introduced for production of PBMAs, which would also prove beneficial for the economy.[50] Cheaper PBMAs, along with recommendations to eat these, would likely encourage their consumption and therefore reduction in meat consumption. Alternatively, products could be taxed based on GHGEs, which Briggs et al. recommend, making the PBMAs likely more affordable than the meat products, increasing revenue while improving health.[51]

Although this study focused on substituting equivalent products by weight, because it is likely that this is how the PBMAs would be used by most consumers, it is possible that people may want to substitute to maintain another specific parameter – most likely protein consumption or price. If using these meat products or PBMAs as the only source of dietary protein, an adult would need to consume a larger amount of the PBMAs to meet requirements. For example, if a person wanted to eat plant-based mince, rather than meat, and wished to consume 30 g of protein in a meal, he or she would need to consume 172 g of the plant-based mince, compared to 144 g of animal mince. In this situation, consuming the plant-based mince would lead to consumption of 2.7 g more sugar and 0.99 g more salt than consuming the meat. However, it would still mean consuming 4.93 g less saturated fat, 39 fewer kilocalories and 9.11 g more fibre. It would be considerably more expensive. Another possibility is that a fixed grocery budget would be the constraint – for example, if an individual had £3 to spend, he or she could purchase 517 g of animal mince or 400 g of plant-based mince, therefore getting more for the money when buying the animal products. If meat is purchased, the individual would consume 446.7 more calories, 19.7 g more saturated fat and 37.9 g of protein. The person would also consume 21.2 g less fibre, 2 g less salt and 6.2 g less sugar.

The climate emergency necessitates reducing emissions. Because almost a quarter of all emissions are from the food industry,[6] a change in diet would support this need. The EAT Lancet 2019 report[22] highlighted that policymakers are key in sustaining change to mitigate climate change and promote health. Canada, for example, has changed its dietary guidelines to increase the sustainability of dietary recommendations.[52] This was a recommendation made by Tichenor Blackstone et al.[53] in the *Lancet Planetary Health*. There have been further calls for targets on meat and dairy consumption, for example: the Institute for Public Policy Research recommended adopting the Eating Better target of a 50% reduction in meat and dairy consumption by 2030.[54] However, many countries have not adopted this approach to dietary guidelines.

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This study is the first to assess the price, nutrition and emissions of meat and their PBMAs. The study provides evidence that can be used when making dietary recommendations regarding these meat alternatives, which may prove beneficial for health and the environment. Dietary recommendations need to be equitable, so as not to increase health inequalities; this study shows the price of PBMAs are higher than meat products, therefore being less affordable for all.

However, there were some limitations of this study:

- Micronutrients were not assessed. As plant-based diets may be deficient in some micronutrients, this could be the focus of future research, particularly B12, iodine and iron. However, although micronutrients were not assessed, macronutrients are extremely important for health, and they are frequently labelled for ease on packets; therefore, understanding the difference in these nutrients is a priority.
- The value of GHGE is an estimate, as a value was calculated only for the main ingredient and an estimate of 0.3 kg CO_2/100 g drawn for the remaining ingredients. Having assessed the main ingredient in the products for GHGEs gives a strong idea of those products that are better for the environment; variation was extremely wide, and the secondary ingredients that were estimated will not impact the overall values that much.
- The product samples (sausages, burgers, chicken nuggets, mince, meatballs and fish fillets) were limited, and small numbers were analysed. This could be expanded to draw a more widely applicable conclusion. Those that were examined were the most popular products from the most popular supermarkets which were available across them all.
- The prices of products were collected in August 2020. Prices in the United Kingdom at that time may have been affected by COVID-19, which will have affected processing for both meat and their PBMAs. Brexit may have also impacted pricing, particularly of meat products. Since 2020 products may also have been reformulated, particularly the PBMAs as they are new and undergoing frequent changes in recipe and production.
- Lidl and Aldi were also among the most popular supermarkets, but it was not possible to collect data on their products online, and as this study was conducted during restrictions associated with the COVID-19 pandemic, it was not possible to collect data in stores.
- These PBMAs are UPFs. UPFs may have adverse health consequences over and above their macronutrient formulation. This might mean there are additional negative effects for health other than what we have reported (although not when compared with other ultra-processed products, e.g., chicken nuggets).

Overall, this study finds that there are challenges to consider when making recommendations on PBMAs. Although overall PBMAs are healthier, with less emissions, they are lower in protein and higher in sugar, which may not be advisable for some population groups (depending on age or health status), and are more expensive, so recommending them may not be equitable. Both the meat products and PBMAs were found to be UPFs; therefore, regarding the products studied in this paper, it would be best to reduce them generally in your diet. This study provides evidence that PBMAs could be recommended in the UK guidelines or by health professionals; however, more research is still needed, particularly surrounding the micronutrient availability in the products.

AUTHOR CONTRIBUTIONS

Alice A. Coffey performed statistical analysis and wrote the manuscript. Oyinlola Oyebode supported with the critical appraisal of the manuscript, and Robert Lillywhite contributed to statistical methods in GHGE assessment.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request. Data can be supplied by the corresponding author on request.

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PEER REVIEW

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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