Nutritional assessment of plant-based meat analogues on the Swedish market

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ABSTRACT

Nutritional quality of 142 plant-based meat analogues (PBMAs) on the Swedish market were assessed by nutritional contribution (NC) to recommended nutrient intake, three labelling systems (Keyhole, Nutri-Score, nutrition claims) and comparisons to meat references. Based on median (min-max) NC for macronutrients, PBMAs in general appeared as healthy options to meat due to higher NC per 100 g for fibre [PBMAs: 15% (1-33%) vs meat: 0% (0-2%)] and lower NC for saturated fat [PBMAs: 4% (0-59%) vs meat: 15% (1-51%)]. The NC per 100 g for salt was substantial for both PBMAs [25% (5-52%)] and meat [24% (2-55%)]. Limited data for micronutrients indicated that PBMAs are higher in iron compared to meat. Nutrition quality varied both between and within product categories. Mince, bite/fillet and nugget analogues were the main healthier categories, according to labelling systems. Bioavailability of iron, protein quality and effects of processing are important future aspects to consider.

INTRODUCTION

Transition towards more plant-based diets is identified as a key measure to promote health and limit environmental impact of diets. Increased intake of vegetables, fruits, pulses, whole grains, and a limited intake of red and processed meat is emphasised in Nordic official dietary guidelines (Nordic Council of Ministers 2014). However, meat has a central role in many food cultures, and factors such as taste, texture, convenience, and social pressure may hinder consumers from replacing meat with plant-based foods (Aschemann-Witzel et al. 2021; Collier et al. 2021; Onwezen et al. 2021). Plant-based meat alternatives provide an option for consumers striving for reduced meat intake but are not willing to compromise desirable attributes in meat. Two main types of meat alternatives can be defined: meat analogues that strive to mimic meat, for example taste, visual appearance and cooking methods, and other meat alternatives, that do not strive to mimic meat (Bohrer 2019).

Plant-based meat analogues (PBMAs) are commonly based on concentrates or isolates of plant-based protein, while other meat alternatives more commonly are based on whole vegetables and legumes. The market of plant-based meat alternatives has been rapidly growing in recent years and is predicted to advance even more in the coming years (Curtain and Grafenauer 2019; Aschemann-Witzel et al. 2021). In Sweden, the annual growth of plant-based meat alternatives has been about 15% for the last 5 years, and the product group is predicted to be as large as today’s chicken segment within 5 years (Växtbaserat Sverige [Plant-foods Sweden] 2021). As PBMAs become more common in the diet, the importance of their nutritional quality is increasing, in relation to both the recommended intake of nutrients and the meat replaced.

It has been reported that replacing animal protein, especially processed red meat, with plant-based protein sources is associated with reduced overall mortality (Song et al. 2016). However, the potential health benefits of conventional plant-based foods cannot directly be extrapolated to PBMAs due to the potential effects of processing on nutritional quality. So far, few clinical trials have studied the health effects of PBMAs. Two intervention studies on PMBAs concluded that these alternatives may promote positive changes in the gut microbiome and cardiovascular disease risk factors, but also emphasised the need for...
further research to confirm these findings (Crimarco et al. 2020; Toribio-Mateas et al. 2021). On the other hand, concerns regarding the role of PBMAs in a healthy and sustainable diet have been raised, underpinning the need for further assessment of these products from a nutritional, health and environmental perspective (Wickramasinghe et al. 2021; Tso and Forde 2021; Santo et al. 2020). In the scientific literature, a limited number of recent studies reported on the nutritional quality of PBMAs (Bohrer 2019; Fresán et al. 2019; Curtain and Grafenauer 2019; Alessandrini et al. 2021; Cole et al. 2021; Harnack et al. 2021; De Marchi et al. 2021; van Vliet 2021). Only a few of these studies reported systematically collected data on a broader range of PBMAs (Curtain and Grafenauer 2019; Alessandrini et al. 2021). None of the studies reports data on PBMAs on the market in the Nordic countries.

Within the European Union (EU), the nutrition quality of PBMAs is not regulated. However, there is a large interest by politicians, authorities and food companies in guiding consumers towards healthier and more sustainable diets (European Commission 2020). Different nutrition labelling systems have been developed globally, during the last decades. Within EU a harmonised regulation on nutrition and health claims was launched in 2006 (European Commission 2006). In some EU countries, nutrient profiling systems for front-of-pack (FOP) nutrition labelling are also authorised, for example the Keyhole (Livsmedelsverket 2015) and the Nutri-Score (Chantal and Hercberg 2017). Nutrition claims and nutrition profiling systems offer possibilities to communicate the nutritional quality of foods to consumers and it is therefore interesting to use them as nutritional indicators when assessing foods from a nutritional perspective. To our knowledge, only two studies in the scientific literature have investigated the application of the FOP nutrition labelling system to PBMAs (Curtain and Grafenauer 2019; Alessandrini et al. 2021). None of the studies has applied the Keyhole and Nutri-Score as nutrition indicators on PBMAs.

Considering the mentioned limitations in the PBMAs research and the absence of studies on the nutritional quality of PBMAs in Sweden, this study aims to assess the nutritional characteristics of PBMAs available on the Swedish retail market. It provides an overview of the PBMAs nutritional profile and evaluates their nutritional content in relation to Nordic Nutrition Recommendations (NNR) and compares them to meat-based products. Furthermore, this study assesses the nutritional quality of PBMAs in relation to three labelling systems used in EU (the Keyhole, Nutri-Score and nutritional claims as defined within the EU).

Materials and methods

Identification and classification of PBMAs

In this study, PBMAs on the Swedish retail market were identified through searches of websites of the main Swedish retailers (coop.se, ica.se, willys.se, hemkop.se) and e-shops (mathem.se, mat.se) between March and April 2021. Searches were made for foods classified as ‘vegetarian’, ‘vegan’ or ‘green alternatives cuisine’. Products included were those available for consumers on the Swedish retail market, designed to mimic red meat or chicken products, in which plant-based protein concentrate or isolate constitutes the main protein fraction. In addition, products having egg protein or egg white as the main protein fraction were included for sausages and cold cuts (see categories below), based on the assumption that these products are vegetarian foods and considered as meat-free option by consumers. Products available only for food service, designed to mimic fish and seafood were excluded, as were products based on whole legumes and vegetables, and products not specifically designed to mimic meat products, such as tofu, tempeh and falafel. Composite meals and alternatives to liver paste were not included. All identified products were classified as one of ten different categories: bacon, ball, bite/fillet (incl. steak, strips, skewers), burger, cold cut, mince, nugget, sausage, schnitzel and others (including kebab and pulled). The classification was based on their appearance, FOP information (text and pictures), and their assumed culinary use.

Data collection

For the nutritional quality assessments, information on ingredients (according to the ingredients list) and nutrient content (according to the nutrition declaration for nutrients mandatory and non-mandatory to declare) were extracted based on FOP information and the manufacturers’ or retailers’ websites. In addition, information on the content of animal ingredients, added vitamins and minerals (incl. fortified ingredients) was collected to identify vegan products and assess the extent of product fortification. The data on FOP labelling for nutrition and health claims (European Commission 2006) and the Keyhole symbol (Livsmedelsverket 2015) were also extracted. Claims and Keyhole symbols presented as part of
communication provided on websites only, i.e., not used as FOP labelling, were not included.

**Meat references**

For comparison, nutritional data on selected comparable meat references were collected from the Swedish National Food Composition Database (Livsmedelsverket 2021) and the Finnish National Food Composition Database for schnitzel (Finnish National Institute for Health and Welfare 2019) (Supplemental material, Table S1). The selection of meat reference products was based on informal discussions with main retailer companies, to identify products that represent the main selling conventional meat product on the Swedish market, within each category.

**Nutritional quality assessment**

Nutrition quality was assessed by calculating the products nutritional contribution to NNR and by evaluating the PBMA's using three selected nutritional labelling systems; Keyhole labelling (Livsmedelsverket 2015), nutrition claims (European Commission 2006) and Nutri-Score (Chantal and Hercberg 2017). The three labelling systems are described in the Supplemental material (Table S2).

**Nutritional contribution in relation to NNR**

The percentage of nutritional contribution (NC) to NNR for 100 g of PBMA's and meat references was calculated. The calculation was based on the percentage of daily reference value (energy), recommended intake (fat, protein, carbohydrates, fibre, iron, vitamin B12, folate and riboflavin) and maximum recommended intake (saturated fat and salt) according to the NNR (Supplemental material, Table S3). The median NC per 100 g was calculated for all PBMA's and meat references, and for each category of PBMA's separately (except for the 'other analogues' category). The NC per estimated portion sizes was also calculated. Portion sizes for PBMA's (100 g for sausage, 125 g for bite/fillet, burger, mince, ball, schnitzel, 75 g for cold cuts, 90 g for nuggets and 75 g for bacon) were estimated based on portion sizes for the comparable meat references, provided by a common dietary assessment software used by Swedish dietitians (Dietist ProNet, version 20220118) and complementary information from a brand-independent meat organisation (Svenskt Kött [Swedish meat] 2022). All categories of PBMA's, including cold cuts, were assumed to replace meat 1:1 in a composite meal.

**Statistical analyses**

For statistical analyses, the normality of data was tested, and the results of Shapiro-Wilk were significant for all nutrients except riboflavin. Therefore, a Mann–Whitney U test was used to compare the NC of all PBMA's and all meat references. The statistical analyses were conducted in SPSS (Version 25, SPSS Inc., Chicago, IL), and statistical significance was set at \( p < 0.05 \).

**Results**

In total, 142 PBMA's from 24 different brands (Supplemental material, Table S4) were identified. Sausages (\( n = 31 \)), bites/fillets (\( n = 20 \)) and burgers (\( n = 19 \)) were the three largest categories, followed by mince (\( n = 16 \)), cold cuts (\( n = 16 \)), ball (\( n = 12 \)), schnitzel (\( n = 11 \)), nugget (\( n = 7 \)), bacon (\( n = 5 \)) and others (\( n = 5 \)). Soy and pea were the two main protein sources while rapeseed and sunflower were the two main fat sources, for PBMA's (Supplemental material Table S5). Most products were vegan (\( n = 110, 77\% \)), i.e., they were free from animal ingredients. In total, 14 products were fortified (added vitamins and minerals) with one or several nutrients: iron (\( n = 12 \), whereof five from fortified flour), vitamin B12 (\( n = 8 \)), niacin (\( n = 5 \), from fortified flour), thiamine (\( n = 5 \), from fortified flour), riboflavin (\( n = 4 \)) and vitamin D2 (\( n = 1 \)). The majority of the fortified products were vegan (\( n = 10 \)).

**Nutrition profile of PBMA's**

Tables 1a and 1b present the median (min-max) energy and nutrients content per 100 g of product for the 10 PBMA categories. For all nutrients a variation was found, both within and between categories. Non-mandatory nutrients were not declared on all products. For example, fibre was the most frequently reported nutrient (\( n = 96, 68\% \)) and iron was reported on 18 products (13%) (Table 1b). Very few PBMA's reported their folate (\( n = 8, 6\% \)), vitamin B12 (\( n = 8, 6\% \)) or riboflavin (\( n = 4, 3\% \)) content. One of the products in the ball analogue category declared vitamin D2 in its ingredient list; however, no further information regarding the vitamin D content was provided. Niacin and thiamine from fortified flour, that was used in some PBMA's (as specified in the ingredients list, \( n = 5 \)), was not declared on any product.
Table 1a. Median (min–max) of energy and nutrients (mandatory to declare) in 100 g plant-based meat analogues (PMBAs).

| Category | Fibre (g) | Fat (g) | Saturated fat (g) | Carbohydrate (g) | Total sugar (g) | Protein (g) | Salt (g) |
|----------|-----------|---------|-------------------|------------------|----------------|-------------|----------|
| Sausage  | 2.08 (1.15–2.44) | 15.40 (2.00–20.00) | 1.20 (0.32–15.80) | 4.70 (1.00–12.50) | 1.50 (0.30–3.00) | 13.00 (3.40–20.30) | 1.90 (1.08–3.10) |
| Burger   | 2.08 (1.15–2.91) | 13.00 (4.40–23.00) | 1.50 (0.58–13.00) | 8.00 (3.10–20.00) | 1.10 (0.50–3.00) | 14.00 (9.90–21.00) | 1.20 (0.78–2.30) |
| Cold cut | 1.71 (9.43–24.67) | 13.10 (2.30–18.00) | 1.00 (0.30–6.70) | 4.15 (0.90–14.00) | 0.80 (0.30–3.80) | 11.00 (6.90–27.00) | 2.40 (1.30–2.70) |
| Mince    | 1.71 (10.05–246) | 9.70 (2.00–17.50) | 1.05 (0.30–7.90) | 2.30 (0.50–7.50) | 0.80 (0.00–1.60) | 15.55 (13.00–20.00) | 0.80 (0.30–1.20) |
| Ball     | 1.26 (190–240) | 11.35 (4.60–17.00) | 1.10 (0.60–2.70) | 9.05 (3.90–15.00) | 1.30 (0.70–3.60) | 13.60 (8.60–20.00) | 1.40 (1.00–1.90) |
| Schnitzel| 1.23 (103–305) | 11.00 (5.60–17.00) | 1.20 (0.80–4.50) | 17.00 (11.00–26.00) | 0.90 (0.30–3.30) | 12.00 (9.50–17.00) | 1.40 (0.93–2.20) |
| Nugget   | 2.17 (195–320) | 10.00 (2.70–20.00) | 1.10 (0.30–1.40) | 16.00 (9.70–27.00) | 1.50 (0.20–2.40) | 14.00 (11.00–19.00) | 1.20 (1.10–1.50) |
| Bacon    | 1.80 (130–237) | 13.00 (3.20–18.30) | 1.50 (0.50–1.70) | 5.00 (3.70–9.00) | 0.70 (0.50–3.10) | 18.00 (6.00–18.00) | 2.00 (1.50–2.70) |
| Other7   | 2.00 (129–247) | 6.00 (0.50–13.10) | 0.70 (0.20–1.10) | 5.80 (2.30–8.60) | 1.00 (0.00–1.70) | 27.20 (15.00–30.50) | 1.70 (0.80–1.95) |

Table 1b. Nutrients (non-mandatory to declare) in 100 g plant-based meat analogues (PMBAs)1.

| Category | Fat (g) | Iron (mg) | Folate (ug) | Vitamin B12 (ug) | Riboflavin (mg) |
|----------|---------|-----------|-------------|-----------------|----------------|
| Sausage  | 2.57 (2.75–2.75) | N/A | 49.45 (49.40–54.10) | N/A | 1.25 (1.25–1.25) | 0.23 (0.23–0.23) |
| Burger   | 2.75 (2.10–3.40) | N/A | 104.00 | N/A | N/A |
| Cold cut | 2.40 (0.30–3.30) | N/A | N/A | N/A |
| Mince    | 2.63 (2.46–2.80) | 74.00 | N/A | 0.38 |
| Ball     | 2.10 | N/A | 0.38 |
| Schnitzel| 2.10 | N/A | 0.38 |
| Nugget   | 2.10 | N/A | 0.38 |
| Bacon    | 2.10 | N/A | 0.38 |
| Other7   | 2.90 | N/A | 0.38 |

N/A: not available.

1Data presented as median (min–max) when the selected nutrient was reported in more than one product.
2Number of products reported fibre content: bacon (n = 2), ball (n = 8), burger (n = 15), bite/fillet (n = 15), mince (n = 9), sausage (n = 22), nugget (n = 4), cold cut (n = 9), schnitzel (n = 9), others (n = 3).
3Number of products reported dietary iron content is one except for burger (n = 2), bite/fillet (n = 5), mince (n = 2), sausage (n = 4).
4Number of products reported dietary folate content is one except for bites/fillet (n = 4).
5Number of products reported vitamin B12 content is one except for sausage (n = 4).
6Number of sausages reported dietary riboflavin content is 4.
7Other: kebab and pulled meat analogues.

**Nutrition quality of PMBAs in relation to recommended intake and comparable meat-based products**

The NC to recommended intake of energy and nutrients per 100 g of PMBAs and meat references, is presented per category in Table 2a (nutrients mandatory to declare) and Table 2b (nutrients non-mandatory to declare). Figure 1 illustrates the median NC from 100 g of PMBAs and meat references using combined data for all PMBAs and meat references, respectively.

**Nutrition quality of PMBAs in relation to NNR**

The NC of PMBAs and meat references to the NNR is presented in Tables 2a and 2b. The median NC to energy from PMBAs varied between 7% and 10%. For fat and saturated fat, the median NC from PMBAs varied between 7–18% and 3–6%, respectively, with examples of PMBAs providing as much as 26% of the recommended daily intake for fat (a burger analogue) and 59% for saturated fat (a sausage analogue). For carbohydrates and proteins, the median NC varied between 1–6% and 13–21%, respectively, while the variation for sodium and fibre were between 13–40% and 8–23%, respectively. When iron, folate and vitamin B12 were reported (few samples), the NC for individual PMBAs varied between 18–28%, 14–30% and 19–63%, respectively.

By considering portion sizes, the results regarding NC were similar for sausage, 25% higher for bite/fillet, burger, mince, ball and schnitzel, 10% lower for nugget and 25% lower for cold cut and bacon compared to per 100 g (Supplemental material Table S6).

**Nutrition quality of PMBAs in comparison to comparable meat references**

The comparison of all PMBAs and meat references at an aggregated level is presented in Figure 1. The overall NC per 100 g for saturated fat from PMBAs was significantly lower than meat references (4% versus 15%, p = 0.003). The median NC for carbohydrate and non-mandatory nutrients (except vitamin B12) were higher for PMBAs compared to meat references (carbohydrate: 2 versus 0%, p = 0.012; fibre 15 versus 0%, p < 0.001; iron: 23 versus 12%, p < 0.001; folate: 15 versus 2%, p < 0.001; riboflavin: 18 versus 11%, p = 0.004). There were no significant differences in the overall NC for energy (8 versus 9%, p = 0.674), fat (13 versus 15%, p = 0.527), protein (16 versus 21%, p = 0.050), salt (25 versus 24%, p = 0.784) and vitamin
Table 2a. Percentage of nutritional contribution (NC)\(^1\) (nutrients mandatory to declare) of 100 g of plant-based meat analogues (PBMAs) and meat references to the Nordic Nutrition Recommendations (NNR)\(^2\).

| Nutrient       | NNR\(^2\) | Sausage analogues | Bite/fillet analogues | Fillet, pork | Fillet, chicken | Burger analogues | Burger, beef | Cold cut analogues | Cold cut, smoked ham | Mince analogues | Mince, beef | Ball analogues | Schnitzel analogues | Nugget analogues | Schnitzel analogues | Schnitzel, pork | Nugget, chicken | Burger analogues | Bacon analogues | Bacon, pork |
|---------------|-----------|------------------|-----------------------|--------------|----------------|----------------|--------------|-------------------|-------------------|----------------|-----------|---------------|-------------------|----------------|---------------------|-----------------|----------------|----------------|----------------|------------|
| Energy (% NC) | 2366 kcal | 87g              | 27g                   | 306g         | 87g            | 6g             | 9 (5–10)     | 7 (3–10)          | 5                 | 4               | 9         | 6 (6–12)      | 7 (4–10)           | 6                 | 4                   | 6               | 8               | 8 (5–10)      | 15           | 18 |
| Fat (% NC)    |           | 18 (2–23)        | 4 (1–59)              | 2 (0–4)      | 15 (4–23)      | 18 (13–29)     | 7 (3–10)     | 7 (0–15)         | 3 (0–10)          | 2 (0–7)         | 18 (15–23) | 7 (4–10)      | 15 (3–21)          | 6 (1–29)         | 10                  | 7               | 11              | 15 (5–20)     | 13           | 22          |
| Saturated fat (% NC) |        | 4 (1–59)         | 3 (0–10)              | 2 (0–7)      | 18 (13–29)     | 16 (11–24)     | 7 (3–10)     | 7 (0–15)         | 3 (0–10)          | 2 (0–7)         | 18 (15–23) | 7 (4–10)      | 4 (1–25)          | 4 (1–29)         | 10                  | 7               | 11              | 16 (1–29)     | 23           | 31          |
| Carbohydrate (% NC) |     | 2 (0–4)          | 2 (0–7)               | 0            | 24             | 27             | 5             | 10               | 0                 | 17             | 25         | 8             | 1 (0–5)           | 1 (0–2)          | 0                   | 2               | 8               | 23            | 15           | 55          |
| Protein (% NC) |            | 15 (4–23)        | 18 (13–29)            | 24           | 10 (4–5)       | 21 (11–24)     | 10           | 24               | 24               | 40             | 22         | 60            | 13 (8–31)         | 18 (15–23)      | 60                  | 24              | 13              | 15 (3–50)    | 25           | 55          |
| Salt (% NC)   |            | 32 (18–52)       | 24 (10–45)            | 2           | 2              | 3              | 2            | 24               | 24               | 40             | 22         | 60            | 40 (22–45)        | 13 (15–23)      | 24                  | 24              | 13              | 60 (5–20)    | 25           | 55          |

N/A: not available.
\(^1\) Data are based on median (min–max) nutrient content for all meat analogue groups (Table 1a) and nutrient content of selected meat references (Supplemental material, Table S1).
\(^2\) Daily reference value for energy, recommended intake for fat, protein, and carbohydrates, and maximum recommended intake for saturated fat and salt (Supplemental material, Table S3). NNR does not have any recommendation for total sugar intake. Average of daily requirements for men and women aged 31–60 years, with moderate physical activity. NNR does not have any recommendation for total sugar intake.

Table 2b. Percentage of nutritional contribution (%NC)\(^1\) (nutrients non-mandatory to declare) of 100 g of plant-based meat analogues (PBMAs) and meat references to the Nordic Nutrition Recommendations (NNR).\(^2\)

| Nutrient       | NNR\(^2\) | Sausage analogues | Bite/fillet analogues | Fillet, pork | Fillet, chicken | Burger analogues | Burger, beef | Cold cut analogues | Cold cut, smoked ham | Mince analogues | Mince, beef | Ball analogues | Schnitzel analogues | Nugget analogues | Schnitzel analogues | Schnitzel, pork | Nugget, chicken | Burger analogues | Bacon analogues | Bacon, pork |
|---------------|-----------|------------------|-----------------------|--------------|----------------|----------------|--------------|-------------------|-------------------|----------------|-----------|---------------|-------------------|----------------|---------------------|-----------------|----------------|----------------|----------------|------------|
| Fibre (% NC)  | 30g       | 14 (1–20)        | 12mg                  | 350ug        | 63 (63–63)     | 18 (18–18)     | 15           | 12 (2–15)         | 11 (7–15)         | 13 (2–15)     | 15 (3–15) | 15 (15–25)    | 12 (1–14)         | 12 (1–14)      | 15 (15–25)         | 13 (2–15)     | 15 (3–15)     | 16 (16–21)    | 13           | 18          |
| Iron (% NC)   |           | 23 (23–23)       | N/A                   | 14 (14–15)   | 14 (14–15)     | 10 (10–20)     | 1          | 25 (25–28)        | 25 (25–28)        | 25 (25–28)   | 23 (23–25) | 25 (25–28)   | 25 (25–28)        | 25 (25–28)   | 25 (25–28)         | 25 (25–28)    | 25 (25–28)    | 25 (25–28)   | 25 (25–28)   | 25 (25–28) |
| Folate (% NC) |           | N/A              | N/A                   | 5            | 5              | 5              | 5          | 5                 | 5                 | 5              | 5          | 5              | 5                 | 5              | 5                   | 5              | 5              | 5              | 5            | 5           |
| Vitamin B12 (% NC) |       | 63 (63–63)       | N/A                   | N/A          | N/A            | N/A            | 2          | 7                 | 7                 | 7              | 7          | 7              | 7                 | 7              | 7                   | 7              | 7              | 7              | 7            | 7           |
| Riboflavin (% NC) |          | 18 (18–18)       | N/A                   | N/A          | N/A            | N/A            | 1.35ug      | 9                 | 9                 | 9              | 9          | 9              | 9                 | 9              | 9                   | 9              | 9              | 9              | 9            | 9           |

N/A: not available.
\(^1\) Data are based on median (min–max) nutrient content for all meat analogue groups (Table 1b) and nutrient content of selected meat references (Supplemental material, Table S1).
\(^2\) Daily recommended intake for fibre, iron, vitamin B12, folate and riboflavin (Supplemental material, Table S3). Average of daily requirements for men and women aged 31–60 years, with moderate physical activity.

B12 (41 versus 42%, \(p = 0.472\)) of these two groups. However, Tables 2a and 2b shows that the nutritional quality of PBMAs and meat references are category dependent, with the following main results (median NC per 100 g):

- **Energy**: Bacon analogues show a substantially lower and bite/fillet and schnitzel analogues a slightly higher contribution compared to meat references.
- **Fat**: Bacon, ball, burger and nugget analogues show a lower contribution, and bite/fillet, cold cut and schnitzel analogues show a higher contribution compared to meat references.
- **Saturated fat**: All PMA categories show a substantially lower contribution compared to meat references, except for bite/fillet analogues that had similar contribution.
- **Protein**: Bite/fillet, mince, nugget, cold cut and schnitzel analogues show lower contribution, while
bacon analogues show a higher contribution compared to meat references.

- Salt: Bacon, burger and cold cut analogues show a lower contribution, and bite/fillet and mince analogues show a higher contribution compared to meat references.
- Fibre: All PMBA categories show a higher contribution compared to meat references.
- Iron, folate, vitamin B12 (limited data): PBMAs show a higher contribution for iron and folate compared to meat references, while the contribution to vitamin B12 is lower for bacon, ball and schnitzel analogues, similar for nugget analogues and higher for sausage analogues compared to meat references.

Similar findings were observed when PBMAs and meat references were compared based on portion sizes rather than 100 g (Supplemental material, Table S6).

**Nutrition quality of PBMAs assessed by the Keyhole labelling system**

In total 10% of the PBMAs (mince n = 9; bite/fillet n = 3; burger n = 2; ball n = 1) met all conditions of use for the Keyhole symbol (Table 3). Most of the PBMAs (93%) met the Keyhole criteria on sugars (95%) and saturated fat (84%), while fewer products met the criteria on total fat (39%) and salt (17%). For six categories of PBMAs (sausage, cold cut, schnitzel, nugget, bacon and others), no products met all the Keyhole-criteria. Eight PBMAs (6%) were labelled with the Keyhole symbol (mince n = 6; ball n = 1; burger n = 1) (Supplemental material, Table S7).

**Nutrition quality of PBMAs assessed by Nutri-Score**

PBMAs varied in nutritional quality when assessed with Nutri-Score (Table 4). About one third (35%) of the PBMAs showed the highest quality score A, followed by C (30%), D (19%) and B (17%). No PBMAs showed the lowest quality level (score E). Variability in quality was also observed within categories of PBMAs. Bite/fillet was the PBMAs-category most frequently scoring A (n = 12, representing 60% of
Table 3. Number of plant-based meat analogues (PMBAs) meeting criteria for the Keyhole symbol and nutrition claims (% of number of products reporting the necessary data, within that category).

| Nutrition claims | Keyhole | Protein | Fibre | Low in sat. fat | Low in salt | Source of iron | Source of vit. B12 |
|-----------------|---------|---------|-------|----------------|------------|--------------|------------------|
|                  | Sausage | Source of | High in | Source of | High in | 21 (68) | 4 (100) | 4 (100) | 4 (100) |
|                  | Bite/fillet | Source of | High in | Source of | High in | 16 (73) | 4 (18) | 0 (0) | 4 (100) | 5 (100) | N/A |
|                  | Burger | Source of | High in | Source of | High in | 13 (87) | 4 (27) | 10 (53) | 0 (0) | 2 (100) | N/A | N/A |
|                  | Cold cut | Source of | High in | Source of | High in | 16 (100) | 2 (20) | 5 (25) | 0 (0) | 2 (100) | N/A | N/A |
|                  | Mince | Source of | High in | Source of | High in | 9 (100) | 1 (100) | 2 (100) | 1 (100) | N/A | N/A | N/A |
|                  | Ball | Source of | High in | Source of | High in | 5 (100) | 1 (100) | 1 (100) | 1 (100) | N/A | N/A | N/A |
|                  | Schnitzel | Source of | High in | Source of | High in | 6 (30) | 2 (10) | 5 (25) | 0 (0) | 2 (100) | N/A | N/A |
|                  | Nugget | Source of | High in | Source of | High in | 2 (100) | 1 (100) | 1 (100) | 1 (100) | N/A | N/A | N/A |
|                  | Bacon | Source of | High in | Source of | High in | 2 (100) | 1 (100) | 1 (100) | 1 (100) | N/A | N/A | N/A |
|                  | Other | Source of | High in | Source of | High in | 0 (0) | 1 (100) | 1 (100) | 1 (100) | N/A | N/A | N/A |
| Total | 45 (47) | 101 (71) | 1 (1) | 18 (100) | 8 (100) |

1Total number of products reporting all necessary data was 142; sausage (n = 31), bite/fillet (n = 20), burger (n = 19), mince (n = 16), cold cut (n = 16), ball (n = 12), nugget (n = 7), bacon (n = 5), other (n = 5).
2Total number of products reported fibre content was 96; bacon (n = 2), burger (n = 15), bite/fillet (n = 15), mince (n = 9), sausage (n = 22), nugget (n = 4), cold cut (n = 9), schnitzel (n = 9), others (n = 3).
3Total number of products reported iron content was 18; for all categories n = 1, except for burger (n = 2), bite/fillet (n = 5), mince (n = 2), sausage (n = 4).
4Total number of products reported vitamin B12 content was 8; for all categories n = 1, except for sausages (n = 4).

Table 4. Number of plant-based meat analogues (PMBAs) scoring A–D*, according to the Nutri-Score labelling system.1 Presented as number of products (% of total number of products within that category).

| Nutritional Profile | A | B | C | D |
|---------------------|---|---|---|---|
| Sausage (n = 31) | 2 (6) | 1 (5) | 1 (3) | 6 (19) |
| Bite/fillet (n = 20) | 12 (60) | 3 (15) | 4 (20) | 0 (0) |
| Burger (n = 19) | 7 (37) | 3 (16) | 2 (11) | 0 (0) |
| Cold cut (n = 16) | 3 (19) | 2 (13) | 1 (6) | 0 (0) |
| Mince (n = 16) | 9 (56) | 4 (25) | 0 (0) | 0 (0) |
| Ball (n = 12) | 2 (17) | 4 (33) | 0 (0) | 0 (0) |
| Schnitzel (n = 11) | 5 (45) | 3 (27) | 0 (0) | 0 (0) |
| Nugget (n = 7) | 4 (57) | 0 (0) | 0 (0) | 0 (0) |
| Bacon (n = 5) | 1 (20) | 1 (20) | 2 (40) | 0 (0) |
| Other* (n = 5) | 3 (60) | 1 (20) | 1 (20) | 0 (0) |
| Total (n = 142) | 49 (35) | 24 (17) | 42 (30) | 27 (19) |

1A is the highest quality, D is the second lowest quality. No PMBAs scored E (lowest quality).
2Other includes kebab and pulled analogues.

bit/fillet analogues), followed by nugget (n = 9, 57%) and mince analogues (n = 4, 56%). Cold cut and bacon analogues most frequently scored D (69 and 40%, respectively).

Nutrition quality of PMBAs assessed by nutrition claims

Almost all (97%) PMBAs met the required protein content to claim 'source of protein', and the majority also met the criteria to claim 'high in protein' (Table 3). Most PMBAs (71%) complied with the nutrient criteria to claim 'low in saturated fat', while only one product (a mince analogue) met the criteria to claim 'low in salt'. Most of the PMBAs (83%) reporting fibre content met the nutrient criteria to claim 'source of fibre', and about half met the criteria to claim 'high in fibre'. Few PMBAs reported their content of iron and vitamin B12, but of those that did, all met the nutrient criteria for claiming to be a source of iron or vitamin B12. More than half of the PMBAs (73%) actually used one or more FOP nutrition claims on the product (source of/high in protein n = 67; source of/high in fibre n = 27; source of iron n = 6; and source of vitamin B12 n = 4) (Supplemental material, Table S7). Protein and fibre FOP claims were used on products in all PMBA categories (except cold cut analogues that did not have a fibre claim).

Discussion

This study reported nutritional data for 142 PMBAs on the Swedish market. A comprehensive overview of the nutritional profile of PMBAs was provided and assessed in relation to NNR, compared to meat references, and based on three nutritional labelling systems. Our findings showed that PMBAs on the Swedish market have potential strengths and limitations, in terms of their ability to contribute to a healthy diet and as a nutritious alternative to meat products. On the positive side, PMBAs are generally higher in fibre and lower in saturated fat compared to meat references (median NC: for fibre 15 versus 0% and saturated fat 4 versus 15% per 100 g). On the downside, the contribution to salt intake may be substantial from both PMBAs and meat references (median NC: for fibre 15 versus 0% and saturated fat 4 versus 15% per 100 g). The contribution to protein intake was generally similar in PMBAs and meat references (median NC: for fibre 15 versus 0% and saturated fat 4 versus 15% per 100 g).
(all non-fortified, soy-based). Vitamin B12 content (all fortified, few products) were lower, similar or higher for PBMA compared to meat references, depending on category. The majority of PBMA on the Swedish market met the nutrient content required to claim high in protein, source of fibre and lower in saturated fat, while only one PBMA could claim to be low in salt. Substantial variations in nutrient content were found for all nutrients, between and within categories of PBMA. Mince was identified as a healthier PBMA option according to both Nutri-Score and Keyhole. Nutri-Score also highlighted bite/fillet and nugget as healthier options among PBMA.

**Comparisons to other studies – nutrient content**

Studies on PBMA in other countries, such as the UK (Alessandrini et al. 2021), US (Bohrer 2019; De Marchi et al. 2021; Cole et al. 2021; Harnack et al. 2021) and Australia (Curtain and Grafenauer 2019) reveal generally the similar nutritional pros and cons as identified in this study. Based on studies using systematically collected data, published in the scientific literature, a closer comparison can be made primarily for burgers (Curtain and Grafenauer 2019; Alessandrini et al. 2021; Harnack et al. 2021; Cole et al. 2021), mince (Curtain and Grafenauer 2019; Alessandrini et al. 2021) and sausages (Curtain and Grafenauer 2019; Alessandrini et al. 2021).

For plant-based burgers both higher (mean 19.8 g/100 g) (Cole et al. 2021) and lower (median 7.1 g/100 g, lowest value 2.9 g/100 g) (Curtain and Grafenauer 2019) protein content has been reported, compared to our findings. One study also reported a higher protein content for plant-based mince (mean 20.8 g per 100 g) than for meat (Alessandrini et al. 2021), which contrasts with our findings. Other studies report a lower median or mean fat content compared to our findings for burgers, mince and sausages, but also show a large within group variation, similar to our findings (Curtain and Grafenauer 2019; Alessandrini et al. 2021; Harnack et al. 2021; Cole et al. 2021). For example, an Australian study reported a median fat content of burger, mince and sausage analogues of 7, 3.8 and 7.3 g/100 g, respectively (Curtain and Grafenauer 2019). However, for mince and sausages, the same study reported a higher median content of saturated fat (2.8 and 2.2 g/100 g), compared to our findings.

For salt, lower content has been reported for plant-based burgers (median 0.8 g/100g) and sausages (median 1.2 g/100 g) on the Australian market (Curtain and Grafenauer 2019), as well as for plant-based sausages on the UK market (mean 1.4 g/100 g) (Alessandrini et al. 2021), compared to our findings. In contrast to our findings, some studies also reported plant-based burgers to have a higher (Alessandrini et al. 2021; Cole et al. 2021; Harnack et al. 2021) or similar (Curtain and Grafenauer 2019) salt content compared to meat references. Differences in salt content could be due to cultural differences or national salt reduction initiatives. For example, in the UK salt reduction targets are defined specifically for some categories of PBMA (Alessandrini et al. 2021).

**Healthy attributes of PBMA**

Our results show that PBMA in general have a higher fibre content and lower content of saturated fat compared to meat references. Substituting meat by PBMA may in this perspective provide positive health effects in countries like Sweden where a majority of the population have low fibre and high saturated fat intake in relation to dietary recommendations (Amcoff et al. 2012; Lemming et al. 2018). Salt content of PBMA is also highly relevant from a health perspective as populations in many industrialised countries, including Sweden, have high salt intake (Amcoff et al. 2012, Lemming et al. 2018). Our results show that PBMA have lower salt content compared to meat references for some categories, especially bacon and cold cuts. However, the NC per 100 g was substantial for both meat references and PBMA and only one (mince analogue) out of the total 142 PBMA met the criteria for nutrition claim on low in salt. Reduced salt content in PBMA is desirable but may affect taste as many plant proteins have an off-flavor that needs to be masked. This is an area where future product development will be of great importance.

**Nutritional aspects of substituting meat by PBMA**

**Iron – bioavailability**

For some nutrients, including iron, comparisons between plant-based foods and meat are not feasible without considering bioavailability. In this study, 13% of the products declared their iron content, indicating a higher quantity of iron in PBMA compared to meat references. However, nutrition declarations provide no information on the content of bioavailable iron (i.e., iron that can be absorbed in our bodies). In meat, iron is present in the form of haem iron,
well-known to be more readily absorbed than iron of plant-based foods (Collings et al. 2013). There are examples of novel PBMAs that contain haem iron produced by yeast encoded with the soy leghemoglobin gene (van Vliet et al. 2021), but they are limited. The bioavailability of iron in plant-based foods may also be hampered by the presence of antinutrients, e.g., phytic acid (Schlemmer et al. 2009; Collings et al. 2013). In legumes, phytic acid is stored within the protein bodies in the endosperm of the seed (Erdman 1979). Therefore, phytate may attach to protein when the protein is extracted/fractionated for protein isolates/concentrates production. Almost 11% phytic acid has been reported in soy concentrates (Lehrfeld 1994). Phytate may be degraded during processing, e.g., extrusion and fermentation, leading to improved iron absorption (Hurrell 2004; Rousseau et al. 2020). However, to ensure a meaningful increase in iron absorption, a molar ratio of phytate:iron below 1, or even less than 0.5, is recommended (Hurrell 2004; WHO, FAO 2006). A recent study estimated the phytic acid content of PBMAs to be between 7.6 and 501 mg per 100 g (median 228 mg/100 g), with the lowest content in PMBAs based on mycoproteins (Harnack et al. 2021). Therefore, the phytate:iron ratio of PBMAs would vary between 0.03 and 4.12 (median 1.7), implying that the iron absorption from many PBMAs could be limited.

Iron deficiency is the most common nutritional disorder in the world and is a public health problem in both industrialised and non-industrialised countries (WHO, FAO 2006). Young women and elderly are vulnerable groups. About 30–45% of Swedish teenage girls is reported to be iron deficient (Sjoberg and Hulthen 2015; Lemming et al. 2018). The relevance of iron bioavailability calls for more thorough assessments of PBMAs in parallel with product development to enhance absorption of iron in the future products.

Protein quality

Protein quality is another aspect to consider when comparing plant-based and meat-based foods. Our results showed that the majority of PBMAs on the Swedish market could claim to be high in protein with a similar or lower content compared to meat references, except for plant-based bacon (higher contribution). However, from a nutritional perspective, animal proteins generally have higher quality (containing all essential amino acids) and higher digestibility compared to plant-based proteins (Adhikari et al. 2022). A detailed characterisation of plant-based burgers showed that they were 21-fold lower in methionine, compared to beef burgers (De Marchi et al. 2021). However, some protein concentrates and isolates used for PBMAs may have similar digestibility as animal-based proteins (Rutherfurd et al. 2015). Processing can affect the digestibility of protein in a positive or negative direction (Pasqualone et al. 2020). In general, the digestibility of protein is increased by extrusion (Singh et al. 2007), which is commonly used to manufacture PBMAs.

On a population level, protein intake in Sweden is well within the recommended range (Amcoff et al. 2012; Lemming et al. 2018). However, this situation may change depending on future dietary patterns and food choices. For individuals substituting part of or all meat for plant-based foods, protein quality will be an important aspect. Recently, Canada introduced a legislation on ‘simulated meat’, including criteria for protein content and protein quality, as well as minimum content of a range of vitamins and minerals such as iron and vitamin B12 (Government of Canada, Minister of Justice 2022).

**Fortification – focus B12**

In this study, 6% (all fortified) of the products declared their vitamin B12 content. Compared to meat references, the content of vitamin B12 was lower, similar or higher, depending on the category. Since vitamin B12 is known to be absent (or present in unavailable forms) in plants, it is unlikely that unfortified plant-based products contain vitamin B12. Considering that PBMAs are intended to replace meat, surprisingly few products were fortified with vitamin B12. Fortification frequency of the Swedish PBMAs with vitamin B12 was lower compared to PBMAs on the Australian market (24%) (Curtain and Grafenauer 2019).

Modelling studies indicates that fortification can be an important factor, for PBMAs to serve as nutritionally adequate alternatives to meat-based products (Van Mierlo et al. 2017; Mertens et al. 2020; Tso and Forde 2021). The intake of vitamin B12 is well above the recommended levels in Sweden (Amcoff et al. 2012; Lemming et al. 2018), thus the risk of deficiency is mainly related to vegans avoiding vitamin B12 supplements, and the elderly with the reduced absorption of the vitamin.

**Nutritional quality of PBMAs based on labelling systems**

Considering that consumers tend to perceive PBMAs as healthy options (Onwezen et al. 2021), it is
intriguing that only 10% of PBMAs on the Swedish market met the Keyhole criteria mainly due to salt content. It is worth mentioning that the Keyhole system has a higher cut-off for salt in meat products compared to PBMAs. For example, the upper limit for meat-based sausages is 2.0 g salt per 100 g, while it is 1.0 g per 100 g for plant-based sausages (Livsmedelsverket 2015).

The assessment based on Nutri-Score confirmed that PBMAs is heterogeneous when it comes to nutritional quality. Bites/fillets, nugget and mince analogues were generally ranked with higher nutrient quality compared to e.g., cold cut and bacon analogues. Considerable differences were also found between PBMAs within the same category. For example, among bite/fillet analogues, some products scored A \( (n = 12) \) and some D \( (n = 3) \) on a five-degree score (A–E). This variation indicates a potential for improving nutritional quality of PBMAs via further product development.

Most PBMAs met the required nutrient content to claim high in protein, low in saturated fat and source of fibre, whereas almost no products could claim to be low in salt. All products reporting iron met the iron content required to claim source of iron. However, from a nutritional perspective, it could be relevant also to consider protein digestibility and iron bioavailability of products claiming the content of these nutrients. In other regions, e.g., the US, both protein quantity and quality must be considered for protein claims (US FDA [Food and Drug Administration] 2013).

**Limitations and uncertainties**

This study systematically collected nutritional data for a broad range of PBMAs, allowing to compare the nutritional quality of PBMAs within and between categories, as well as in relation to meat references. Nutritional assessments were performed by several methods, that strengthens the conclusions on the nutritional performance of different categories of PBMAs, in relation to nutritional recommendations. However, this study also has some uncertainties and limitations.

First, it is not certain that all PBMAs available on the Swedish market were identified. However, websites of all main retailers were screened to identify the vast majority of PBMAs available on the Swedish market at the time being, to obtain representative nutritional data. The selection of meat references is also critical for conclusions on the relative performance of PBMAs. To obtain comparisons representative from the average consumer perspective, nutritional data from the national food composition database were used for meat references representing main selling meat products. The outcome of comparisons between PBMAs and meat references might have been different if only main selling PBMAs had been included (similar approach as meat references). However, required PBMAs sales statistics were not available for this study to undertake such a comparison.

For the meat references, data was mainly used for raw (uncooked) products. This is not an obvious choice, since comparable PBMAs are pre-processed. However, similar cooking losses have been reported for plant based-burgers, as for meat-based burgers (De Marchi et al. 2021). Moreover, this study reported nutritional data for pre-packaged PBMAs and did not account for possible nutritional effects of home preparation. Home preparation could influence many nutritional parameters. In respect to our results, an awareness of possible addition of salt during home preparation is especially warranted.

Since information on portion size was not consistently available for the commercial products (on pack or on websites), it was assumed that PBMAs will replace meat-based references 1:1 for the comparison purposes, even though portion sizes may vary depending on product type, and country (Cole et al. 2021). Finally, the calculation of Nutri-Score has some uncertainties since the content of fruit, vegetables, legumes, nuts and oils was available only for three products. For all the other products, the ratio of fruit, vegetables, legumes, nuts and oils was assumed to be under the minimum threshold of 40%. Although in a few cases this could lead to an underestimation of the nutritional quality of the product, this approximation is assumed to have minor impact on results.

**Future perspectives**

To assess the nutritional quality of PBMAs more in depth, studies with reliable data on vitamins and minerals are needed, as well a better understanding of their bioavailability. Further elucidation of differences in other bioactive components between plant-based and meat-based products is also of interest. The health effects of such components are less well established compared to nutrients but may nevertheless be important for a more complete understanding of the health effects of PBMAs. More knowledge is also required on the quality of the present nutrients. In particular, it is highly warranted to further examine
the protein quality of PBMAs, using different plant-protein sources. It is also interesting to examine the dietary fibre type (soluble/insoluble) of PBMAs, since fibre is promoted as a nutritional benefit of PBMAs compared to meat-based products. More research is also needed to better understand the nutritional effects of processing of PMBAs, both from industrial and home preparation point of view. Finally, suggested health effect needs to be confirmed by human studies. According to our knowledge, there are only two published intervention studies on PBMAs (Crimarco et al. 2020; Toribio-Mateas et al. 2021), meaning that many questions on health effects of PBMAs remain to be answered.

Conclusions

Our findings show that PBMAs on the Swedish market have potential strengths and limitations, in terms of their ability to contribute to a healthy diet and as a nutritious alternative to meat products. In terms of macronutrients, most categories of PBMAs are healthy options to meat references, primarily due to their higher content of fibre and lower content of saturated fat. For salt, many PMBAs are healthy alternatives to processed meat references, but often less healthy options to unprocessed meat references. For vitamins and minerals, data were very limited but indicated that PBMAs in general are higher in total iron and folate, while the content of vitamin B12 varied depending on category. The overall nutritional quality varies substantially between products, indicating that the development of healthier PBMAs is possible. Bioavailability of iron, protein quality and the role of fortification and processing are important nutritional aspects to consider in future research and product development of PBMAs.

Disclosure statement

The authors report no conflicts of interest.

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Data availability statement

The data that support the findings of this study are available from the corresponding author (SB), upon reasonable request.

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