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Original Research Article

Nutrient content in plant-based protein products intended for food composition databases

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ABSTRACT

The concern about the impact of food consumption on climate change has emphasized the importance of a plant-based diet to reduce the consumption of animal products. Various alternatives are introduced to the market to substitute animal products that are known as a source of protein. This study focused on the nutrient analysis of 58 products with protein derived from egg white, mycoprotein, pea, soy, a combination of pea and soy, and wheat. The products were divided into groups such as cold cuts, minced, pieces, sausages, minced balls, tofu and seitan. The products were collected from the Danish market based on the current purchasing trends with the purpose of including the data in the Danish Food Composition Database (FRIDA). Protein was the most abundant macronutrient (6.6−33 g/100 g), followed by carbohydrate (0.6−18 g/100 g), and fat (2.1−14 g/100), contributing to the energy value of 412−963 kJ/100 g in analysed products. The results included amino acids and fatty acids composition, and content of vitamins and minerals that indicated that these products contain a wide range of nutrients, but there is a need for nutritional guidance to satisfy nutritional recommendations when consuming plant-protein products as a substitute for animal products.

1. Introduction

Increasing concern about the impact of food consumption on climate change has increased the importance of reducing the consumption of animal products (Schiermeir, 2019). Official food-based dietary guidelines (FBDG) taking both health and sustainability into account promote more plant-based diets. Such sustainable national FBDG have been introduced in several countries such as Brazil, Denmark, Germany, Italy, the Netherlands, Poland, Qatar, Sweden, the UK etc. (FAO, 2021; Lassen et al., 2020).

Meat products usually constitute a considerable part of the diets in Western countries. Results from national dietary surveys from Denmark, Czech Republic, Italy and France show an average intake between 100 and 125 g meat (incl. poultry) per 2000 kcal (Mertens et al., 2020) among adults, where men's mean intake ranges between 113 to 175 g per 2500 kcal, and women's mean intake between 85 to 122 g per 2000 kcal (Mertens et al., 2020). In these diets, meat and meat products contribute to the intake of nutrients such as protein, fat and some vitamins and minerals, where protein of animal origin constitutes more than 60% of the protein content in the diets from Denmark, Czech Republic and Italy (Mertens et al., 2018). Protein from non-animal sources has for centuries been the main part of the diet in some regions of the world, e.g. products based on soybean and wheat in China (Rödl, 2019). In some Western countries such as the UK, the number of vegetarians has constituted a considerable part of the population for decades, being around 7% according to Euromonitor's Health and Nutrition Survey (Mascaraque, 2020). Thus, plant-based alternatives to meat have been diverse on the market in the UK since the 1960s, while plant-based products imitating meat products have been increasing more recently also on other markets such as the Danish (Changing Markets Foundation, 2018; Rödl, 2019).

The plant-based protein products are alternative to meat, and may also be named "meat analogues", "meat substitutes" or "meat replacers" containing a protein typically derived from soy, pea or/and wheat, even though protein in these products might derive from non-plant sources such as fungus and egg white. Due to the appearance of flexitarians, a so-

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called consumer group that consumes vegetarian food a few days per week, a popularity of these products on the market is increasing (Dagevos and Voordouw, 2013).

To be able to provide public advice on how to include such products in a healthy and more sustainable diet, and to assess the nutritional adequacy of diets including flexitarian, lacto-ovo vegetarian (diets excluding meat and fish, but including milk and egg products) and vegan (diets excluding all foods of animal origin or containing ingredients of animal origin) that include such meat substitute products, the information about both the environmental and climate impact, and the nutrient content in these products is required.

The American and European food databases contain the data for only few plant-based protein products, mostly including soy products. For those that are presented, the nutrient composition is limited to macronutrients and only iron and riboflavin from the group of micronutrients (Ciqual, 2020; Fineli, 2021; NEVO, 2019; NFCD, 2020; SFAFD, 2021; UK, 2021; USDA, 2019). Furthermore, the documentation of the data presented in food databases is either not accessible, or referring to another food database, or received from the manufacturer. Thus, we aimed to establish representative values for a range of macro- and micronutrients in plant-based protein products sold at the Danish market in 2019/2020. The protein source in these products were primarily from soy, pea, wheat, fermented fungus (mycoprotein), or a combination e.g., soy and pea, but also egg white. The product types selected on the market were cold cuts, minced, pieces, sausages, minced balls, tofu, and seitan. The data is freely available through the Danish Food Composition Database (FRIDA, 2019).

2. Material and methods

2.1. Marked analysis and sampling plan

The samples included in the study reflected the market of plant-based protein products in Denmark in 2019/2020. The products included in the samples were chosen by reviewing data from market analysis based on registration of marketed products from four different online stores (10 visits) and nine different supermarket chains (25 visits) in the Copenhagen area in 2019 (January, February, September and October) and in 2020 (January and February).

The stores included in the market analysis represent store-based supermarket chains accounting for 84% of the total market share from modern grocery retailers (hypermarkets, discounters and supermarkets) in Denmark in 2019 and represent retail groups accounting for 98% of the total market share in Denmark (Euromonitor International, 2020).

Data from product descriptions and photographs (online and in stores) was transcribed into a Microsoft Excel spreadsheet for comparison and analysis. Furthermore, the top-selling brands were identified by analysing Danish brand share data from "meat substitutes" (Euromonitor International, 2020). The most popular products within each brand were identified by collecting information from the four most dominating manufacturers on the Danish market.

The samples were classified according to the combination of a protein source and the product type. Six protein sources were included (egg white, mycoprotein, pea protein, soy protein, wheat protein, and a combination of soy and pea protein), and eight product types (cold cuts, minced, pieces, sausages, minced balls, seitan and tofu).

2.2. Collection of samples

All samples were purchased in the urban area of Copenhagen or online between October 2019 and February 2020. The sampling was performed from eight different store-based supermarket chains and two online supermarkets. Samples were collected from online supermarkets due to the availability of larger amounts of the same product. The samples from online orders were stored at the similar temperature as in the warehouse, i.e. dry samples at ca. 18 °C, refrigerated samples at ca. 2 °C, and the frozen ones at ca. −22 °C. Dry samples were delivered in plastic bags and refrigerated, and frozen ones in thermos boxes in order to ensure a proper storage conditions depending on the storage requirements stated on the products packaging. The delivery was performed within 1−2 hours.

In total, 13 different product types i.e. combination of product type and protein source, were included. Three of the product types were made into composite samples due to financial priorities. These composite samples were made up of 3–8 different products combined on an equal weight basis. See Table 1 for detailed information of the 58 analysed samples. Due to the requirement for a total of minimum 2000 g for the analyses of each sample, the total number of individual packages was between 6 and 49 per sample, and in total 645 packages were included. A full list of all collected samples including specific product information, such as expiry dates and list of ingredients, can be found in the supplementary material (Supplementary Online Material (SOM), Table S1).

2.3. Preparation and homogenization

After collection, the refrigerated samples were stored at max. 5 °C, whereas frozen samples were stored at −20 °C. The sub-samples for each composite sample were packed in individual plastic bags at DTU Food including information on the weight of the sub-samples to be used for each composite sample. The samples were transported at 5 °C to Eurofins Steins Laboratorium A/S, Vejen, Denmark. Within 72 h each individual and composite sample were blended for 30 s, in a blender suitable for the amount (Robot Coupe Blixer 5 plus, Blixer 3 (Robot Coupe, Vincennes France) or OBH Mini chopper (OBH Nordica, Denmark). Heating was avoided by the use of dry ice. Following homogenization the samples were stored in plastic containers (approx. 100 g) at −20 °C. Analysis was performed within 3 months except for sugars and phylloquinone, which were performed within 18 months.

2.4. Analytical methods

The methods used to quantify the content of macronutrients, vitamins and minerals are listed in Table 2, which provide a short description of the method principle, the reference for the method used and the uncertainty including bias. Single determination was applied and all analyses were performed accredited according to ISO17025:2017 by Eurofins-Steins Laboratorium A/S, Vejen, Denmark (DANAK reg. no.

Table 1
Samples involved in the study include product type, number of samples, protein source (declared, %), and explanation about composite sample, and subsamples within each composite sample, if any.

Plant-based product type	Number of Samples	Protein source		Composite sample	
		Declared	%	Yes/No	Subsamples in each
Cold cuts	2	Egg white	8−70	Yes	5
Minced	3	Mycoprotein	92	No	
Pieces	3	Mycoprotein	85	No	
Minced	6	Pea protein	18−22	No	
Sausages	6	Pea protein	16−17	No	
Minced	8	Soy protein	21−32	No	
Pieces	6	Soy protein	25−32	No	
Sausages	4	Soy protein	17	No	
Tofu	2	Soybeans	NA or 13−67	Yes	8
Minced balls	2	Soy protein	22	No	
Cold cuts	6	Soy protein/pea protein	11 (8/3)	No	
Cold cuts	2	Wheat protein	31−33	Yes	3
Seitan	8	Wheat protein	NA or 15	No	

NA-not available.

Table 2
The overview of analytes, method principles, and the uncertainties including bias of the results reported.

Group	Analyte	Principle	Reference	Uncertainty[a] (SD)
Macronutrients	Nitrogen/ Protein	Total amount of organic nitrogen is measured according to the Kjeldahl principle.	NMKL6, 2003	2.5%
	Amino acids	Alkaline hydrolyses used for tryptophane. For cysteine and methionine oxidized with hydrogen peroxide and formic acid at cold temperature prior to the acid hydrolysation. Amino acids are separated in an amino acid analyser using post column derivatisation with ninhydrin reagent. Detection at 440 nm and 570 nm.	EU, 2009; ISO13903, 2005	7.5% tryptophan 5%
	Dry matter	Dried at 102−105 °C for 16−18 hours. The dry matter weighed.	NMKL23, 1991	2.5%
	Ash	Dried and heated at 525−550 °C. The ashes weighed.	NMKL173, 2005	2%
	Dietary fibre	Enzymatic treatment. Two precipitations (water-insoluble dietary fibre (IDF), the water-soluble dietary fibre, including the dietary fibre that precipitates in the presence of 78% aqueous ethanol (SDFP) are collected and assayed. The dietary fibre that remains soluble (SDFS) is quantified by HPLC.	McCleary et al., 2012	11% (total)
	Starch	Prepared according to R-Biopharm kit (No.10207748035). Photometric absorption at 340 nm	R-biopharm, 2021	5%
	Sugars	Extracted with water. Ionic chromatography with sodium hydroxid eluent and pulsed amperometric detection for quantification of fructose, glucose, lactose, maltose, saccharose.	Andersen and Sørensen, 2000	0.3 g/100 (total)
	Fat	Boiled in hydrochloric acid, cooled, filtered, dried, and extracted with petroleum ether. The solvent is evaporated and the residue is dried and weighed.	ISO11085, 2015	5%
	Fatty acids	Boiled in hydrochloric acid and the fat extracted using a mixture of diethyl- and petroleum ether. Treated with sodium hydroxide in methanol followed by boron trifluoride in methanol to form fatty acid methyl esters (FAMES). The FAMES measured using GC-FID, and C17:0 is used as internal standard.	American Oil Chemists' Society, 2009	5%
	Cholesterol	Enxymatic treatment with amylase, saponification, extraction with iso-octane, silylated and determinded by GC-FID.	BVL L 18.00-17:2014-08, 2014	10%
Vitamins	Biotin	Acid hydrolysis at 121 °C. Microbiological growth response of Lactobacillus plantarum (ATCC 8014), and turbidimetrically quantification.	Pharmacopoea Nordica, 1960	12%
	Folate	Extraction in a buffer at 121 °C. Enzymatic treatment with human plasma and pancreas V. Autoclaved. Microbiological growth response of Lactobacillus rhamnosus (ATCC 7469), and turbidimetrically quantification.	NMKL111, 1985	15%
	Niacin	Boiled in weak hydrochlorid acid at 100 °C to extract nicotinic acid and nicotinamide. HPLC-FLD (Ex/Em:322 nm/380 nm) after a post column reaction with hydrogen perioxide catalyzed by Cu(II) ions under UV-radiation (365 nm).	EN15652, 2009	7%
	Pantothenic Acid	Extraction in ammonium acetate buffer solution. UHPLC-ESI-MS/MS.	Martin and Campos-Gimenez, 2015	10%
	Pyridoxine	Enzymatic dephosphorylation followed by reaction with glyoxylic acid in the presence of Fe^{2+} as catalyst to transform pyridoxamine into pyridoxal, which is then reduced to pyridoxine by the action of sodium borohydride in alkaline medium. Pyridoxine quantified by HPLC-FLD (Ex/Em: 290 nm/395 nm).	EN14164, 2014	7%
	Riboflavin	Acid hydrolysis and quantification of riboflavin and riboflavin-5-phosphate by HPLC-FLD (Ex/Em: 468 nm/520 nm).	EN14152, 2003	8%
	Thiamin	Acid hydrolysis and enzymatic treatment. Quantification of thiamin and 2-(1-hydroxyethyl)thiamin by HPLC-FLD (Ex/Em 368 nm/440 nm) after post-column oxidation to thiochrome.	EN14122, 2014	8%
	Cobalamin	Extraction in sodium cyanid at 100 °C. Immunoaffinity clean-up. LC-UV (361 nm)	Campos-Gimenez et al., 2008	5%
	ß-carotene	Alkaline hydrolysation using ethanolic potassium hydroxide, extracted with EtOH: hexane (4:3 v/v) and twice with hexane. HPLC-UV at 452 nm.	EN12823-2, 2000	14%
	α-tocopherol	Alkaline hydrolysation using ethanolic potassium hydroxide, three times with hexane: ethylacetate (85:15 v/v). HPLC-FLD (Ex/Em 290 nm/327 nm).	EN12822, 2014	8%
	Phylloquinone	Treated with lipase, and extracted with n-hexane. HPLC-FLD (Ex/Em 290 nm/327 nm) after post-column reduction with zinc.	EN14148, 2003	10%
Minerals	Arsenic (As)	After pressure digestion, inductively coupled plasma optical emission spectroscopy (ICP-MS)	EN13805, 2014; EN15763, 2009	7%
	Cadmium (Cd)	After pressure digestion, inductively coupled plasma optical emission spectroscopy (ICP-MS)	EN13805, 2014; EN15763, 2009	7%
	Calcium (Ca)	After pressure digestion, inductively coupled plasma optical emission spectroscopy (ICP-OES)	EN13805, 2014; EN/ISO11885, 2009	10%
	Chromium (Cr)	After pressure digestion, inductively coupled plasma optical emission spectroscopy (ICP-MS)	EN13805, 2014; EN/ISO17294-2, 2016	7%
	Copper (Cu)	After pressure digestion, inductively coupled plasma optical emission spectroscopy (ICP-OES)	EN13805, 2014; EN/ISO11885, 2009	11%
	Iodine I	Inductively coupled plasma optical emission spectroscopy (ICP-MS)	EN15111, 2007	10%
	Iron (Fe)	After pressure digestion, inductively coupled plasma optical emission spectroscopy (ICP-OES)	EN13805, 2014; EN/ISO11885, 2009	10%
	Magnesium (Mg)	After pressure digestion, inductively coupled plasma optical emission spectroscopy (ICP-OES)	EN13805, 2014; EN/ISO11885, 2009	10%
	Manganese (Mn)	After pressure digestion, inductively coupled plasma optical emission spectroscopy (ICP-MS)	EN13805, 2014; EN/ISO17294-2, 2016	10%
	Mercury (Hg)	After pressure digestion, inductively coupled plasma optical emission spectroscopy (ICP-MS)	EN13805, 2014; EN15763, 2009	7%
	Molybdenum (Mo)	After pressure digestion, inductively coupled plasma optical emission spectroscopy (ICP-MS)	EN13805, 2014; EN15763, 2009	10%

(continued on next page)

Table 2 (*continued*)

Group	Analyte	Principle	Reference	Uncertainty[a] (SD)
	Nickel (Ni)	After pressure digestion, inductively coupled plasma optical emission spectroscopy (ICP-MS)	EN13805, 2014; EN/ISO17294-2, 2016	15%
	Phosphorus (P)	After pressure digestion, inductively coupled plasma optical emission spectroscopy (ICP-OES)	EN13805, 2014; EN/ISO11885, 2009	10%
	Potassium (K)	After pressure digestion, inductively coupled plasma optical emission spectroscopy (ICP-OES)	EN13805, 2014; EN/ISO11885, 2009	10%
	Selenium (Se)	After pressure digestion, inductively coupled plasma optical emission spectroscopy (ICP-MS)	EN13805, 2014; EN/ISO17294-2, 2016	10%
	Sodium (Na)	After pressure digestion, inductively coupled plasma optical emission spectroscopy (ICP-OES).	EN13805, 2014; EN/ISO11885, 2009	10%
	Zink (Zn)	After pressure digestion, inductively coupled plasma optical emission spectroscopy (ICP-OES)	EN13805, 2014; EN/ISO11885, 2009	13%

[a] Uncertainty including bias.

222). Except for dietary fibre that followed the same principle in the quality control as for an accredited method.

2.5. Statistical analysis and nutritional evaluation of results

The results were statistically evaluated using JMP Statistical Discovery software (version 15.0, SAS Institute Inc. Cary, NC, USA). The content of protein was calculated based on nitrogen (multiplying by averaged factor 6.25), as it is explained in SOM together with other calculations (SOM, Calculations S2). Pearson's correlation coefficient (r) was used to evaluate the correlation between the protein content calculated based on the content of nitrogen and the protein content expressed as a sum of amino acids. Results were divided into groups based on the combination of protein source and the type of product. Data were checked for normality using the Shapiro-Wilk test, and the results were presented as mean and the range, as data were mostly not normally distributed. One-way ANOVA was used to evaluate if different groups based on the combination of the origin of protein and the difference in the product type are significantly different, whereas pooled *t*-test was used to determine significant difference when only 2 food groups were compared (i.e. iodine). The Tukey-Kramer test was used to compare the differences between nutrients per 100 g in various groups of plant-based protein products. Groups with $n \leq 2$ corresponding food products were not included in statistical analysis. When some of detected values within the same group were below limit of quantification (LOQ), 50% of the LOQ values was taken into statistical analysis for these samples. A statistical significance was defined as $p \leq 0.05$.

Nutritional evaluation of results was performed based on the regulations of the European Union on the reference daily intakes of vitamins and minerals for adults and declaration of their significant amount in a given food product (EU, 2011, 2007). For quantified vitamins, the following daily reference intakes were used: biotin (50 μg), folate (200 μg), niacin (16 mg), pantothenic acid (6 mg), pyridoxine (1.4 mg), riboflavin (1.4 mg), thiamin (1.1 mg), cobalamin (2.5 μg), β-carotene (800 μg), α-tocopherol (12 mg) and phylloquinone (75 μg). For quantified minerals, the following daily reference intakes were used: calcium (800 mg), chromium (40 μg), copper (1 mg), iodine (150 μg), iron (14 mg), magnesium (375 mg), manganese (2 mg), molybdenum (50 μg), phosphorous (700 mg), potassium (2000 mg), selenium (55 μg), zinc (10 mg). A product contained significant amount of micronutrients if 15% of the above mentioned reference value was supplied by 100 g of product (EU, 2011). A possibility to make a nutritional claim was also evaluated based on the EU regulations (EU, 2007). Thus, a product could be claimed as e.g. "source of fibre" or "high fibre" if the product contained at least 3 g or 6 g of fibre per 100 g, respectively. In order to claim that a product is "high protein", at least 20% of the energy value of the product should be provided by protein. Special focus was on the evaluation of the nutrients usually deficient in non-animal-based diet such as; protein (essential amino acids), omega-3 fatty acids, β-carotene, niacin, cobalamin, calcium, phosphorus, iodine, iron, selenium and zinc.

3. Results

3.1. Macronutrients composition

Table 3 shows the energy and macronutrient content (carbohydrate, protein, and fat) of the analysed samples, including amounts of sugars, dietary fibre, and saturated fatty acids (SFA). The most abundant macronutrient in these products is protein that accounts for >50% of macronutrients content in mycoprotein-based products, wheat products and most of soy protein-based products. The macronutrient content was significantly different ($p \leq 0.05$) when comparing all food groups, divided by the different product types and protein sources.

3.1.1. Protein and amino acids composition

Mean energy ranged from 412 to 963 kJ/100 g product being the lowest in mycoprotein-based products, where protein content contributed from 6.6 g/100 g in cold cuts based on combined soy and pea protein until 33 g/100 g in wheat protein-based seitan. In general, there is no significant difference between the products within the same group of protein source, except in the products based on soy protein as there is found significantly different content between chopped products and sausages ($p \leq 0.05$). The content and distribution of 18 amino acids including the analysis of 9 essential amino acids (isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, valine and histidine) is presented in Fig. 1, with the values (mg/100 g product) presented in SOM (Table S3).

3.1.2. Carbohydrate

Carbohydrate is the second most abundant macronutrient ranging from 0.6 g/100 g in soy-based tofu to 17.5 g/100 g in wheat protein-based cold cuts. Dietary fibre ranged from 0.8 until 12 g/100 g being the highest in minced soy-based products. Soy and mycoprotein-based products have a high content of dietary fibre, being around 6 g/100 g. Mycoprotein-based products and soy pieces were the only products with sugar content below LOQ (<0.2 g/100 g), whereas the other products contained glucose, sucrose, maltose, and fructose (SOM, Table S4).

3.1.3. Fats and fatty acids composition

Mean fat content ranged from 2.1 to 14 g/100 g being the highest in pea protein-based products, that also contained predominantly the highest level of saturated fatty acids (SFA) being ~6 g/100 g. No significant difference was found in the products within the same protein source, except for soy and wheat. The lowest content of fat and SFA was reported in mycoprotein-based products being 2.0–2.9 g/100 g and 0.26−0.33 g/100 g, respectively. The fatty acids composition (g/100 g) shown in Fig. 2 indicates that fat in the analysed products comes in a form of unsaturated fatty acids (>83%). A level of unsaturated fatty acids <83% was found only in pea protein and minced soy protein-based products. On the other side, legumes and mycoprotein-based products contained high levels of polyunsaturated fatty acids (PUFA), including a

Table 3
Nutrients per 100 g of analysed plant-based products divided by different product types within various plant-based protein sources. The results are expressed as mean with range.

Protein source	Egg white	Mycoprotein		Pea		Soy					Soy and pea	Wheat		p-value
Product	Cold cuts	Minced	Pieces	Minced	Sausages	Minced	Pieces	Sausages	Tofu	Minced balls	Cold cuts	Cold cuts	Seitan	
n	2	3	3	6	6	8	6	4	2	2	6	2	8	
Energy (kJ)	741; 746	458^{e} (452-470)	412^{e} (405-422)	963^{a} (852-1125)	889^{ab} (805-1044)	778^{bc} (640-852)	572^{de} (518-703)	744^{bc} (720-786)	500; 544	719; 725	665^{cd} (602-715)	970; 987	833^{ab} (764-976)	<0.0001
Carbohydrate (g/100 g)	4.6; 4.6	7.7^{ab} (7.1-8.0)	7.4^{ab} (6.7-8.1)	9.5^{a} (3.9-14)	7.2^{ab} (3.9-10)	10.7^{a} (6.6-16)	7.6^{ab} (6.8-8.4)	8.4^{ab} (7.8-9.3)	0.6; 1.4	9.3; 8.2	7.1^{ab} (6.7-7.9)	17.5; 16.7	5.3^{b} (3.5-7.4)	0.0032
Sugars (g/100 g)	1.1; 1.2	< 0.2	< 0.2	1.9^{ab} (0.4-3.4)	1.6^{ab} (0.4-2.3)	2.7^{a} (0.4-4.5)	<0.2	0.8^{ab} (0.6-1.2)	0.2; 0.2	1.2; 1.0	2.7^{a} (2.4-3.3)	5.9; 5.7	0.7^{b} (0.4-1.3)	0.0032
Dietary fibre (g/100 g)	2.3; 2.0	6.5^{abc} (5.0-7.6)	5.5^{bcd} (4.8-5.8)	5.6^{bc} (3.8-7.2)	5.1^{cd} (3.4-6.3)	8.7^{a} (6.9-12)	8.1^{ab} (6.5-10)	6.9^{abc} (6.3-7.4)	1.7; 3.3	7.7; 7.5	2.8^{de} (2.2-3.5)	5.5; 5.5	2.3^{e} (0.8-4.9)	<0.0001
Protein (g/100 g)	8.0; 7.8	14^{cd} (14-15)	12^{de} (12-13)	16^{bcd} (13-19)	16^{bcd} (14-18)	18^{bc} (13-23)	20^{b} (19-24)	12^{de} (12-13)	13.5; 13.1	14.8; 16.0	7.5^{e} (6.6-8.1)	31.1; 31.6	28^{a} (24-33)	<0.0001
Fat (g/100 g)	14.2; 14.2	2.5^{cd} (2.3-2.9)	2.1^{cd} (2.0-2.1)	14^{a} (10-20)	13^{a} (11-18)	7.8^{b} (5.2-10)	2.8^{d} (1.7-4.7)	10^{ab} (9.7-11)	7.0; 8.0	8.4; 8.5	11^{ab} (9.9-12)	4.6; 4.3	7.2^{bc} (4.9-11)	<0.0001
SFA (g/100 g)	0.8; 0.8	0.29^{b} (0.26-0.33)	0.27^{b} (0.26-0.27)	5.6^{a} (3.5-7.4)	6.0^{a} (4.9-8.0)	2.3^{b} (0.49-7.8)	0.16^{b} (0-0.29)	0.61 ± 0.06^{b} (0.54-0.69)	0.99; 1.17	0.51; 0.49	0.63^{b} (0.57-0.73)	0.52; 0.48	0.62^{b} (0.43-0.86)	<0.0001

"n" indicates a number of analysed samples per group of food products. Groups with n ≤ 2 were not included in statistical analysis. Different letters in superscript indicate significant differences ($p \leq 0.05$) in the content between different food products in a row, starting from "a" as the highest mean value. The values below LOQ are shown as e.g. < 0.2.

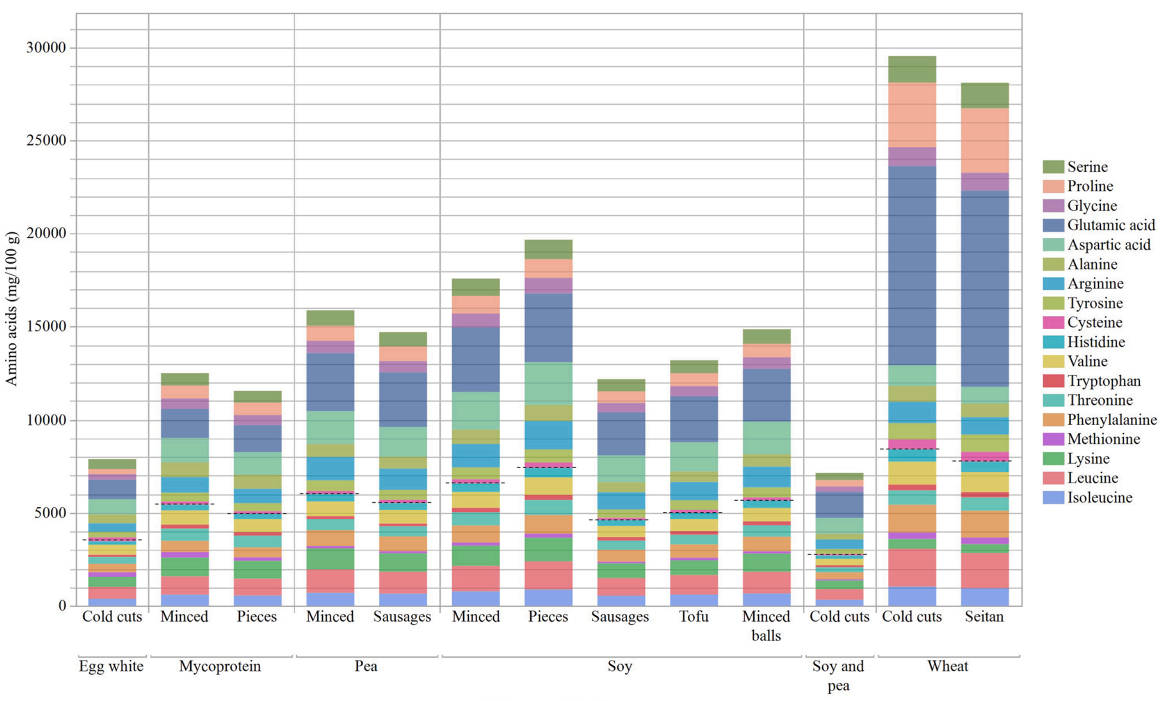

Fig. 1. Amino acids composition (mg/100 g) in analysed samples. The black line divides essential amino acids (bottom of the graph) from the rest of amino acids (upper part).

high content of omega-6 (C18:2, n-6). The amount (g/100 g) of detected and quantified fatty acids is shown in SOM (Table S5).

3.2. *Micronutrients composition*

3.2.1. *Vitamins*

The content of vitamins in the products is shown in the Table 4. Significant differences ($p \leq 0.05$) in the content of vitamins between the

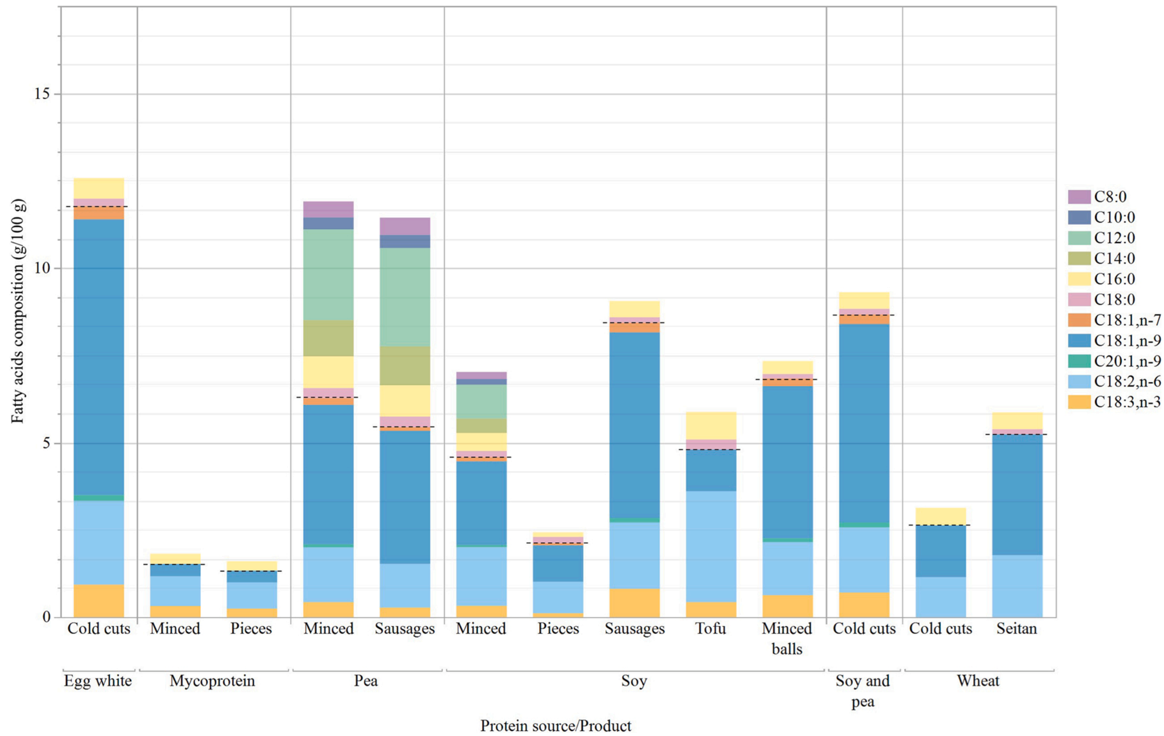

Fig. 2. Fatty acids composition (g/100 g) in analysed samples. The black line divides unsaturated fatty acids (bottom of the graph) from saturated fatty acids (upper part).

products were observed for biotin, folate, niacin, pantothenic acid, pyridoxine, riboflavin and phylloquinone. However, no significant differences in the content of vitamins were observed between products with the same protein source. Significant differences in the content of vitamins were observed for the same product type (e.g. "minced") with different protein sources. No significant differences in the content of vitamins between the products were observed for thiamine, β-carotene and α-tocopherol. All samples were analysed for cobalamin, but the content in all samples was determined to be below LOQ (0.3 μg/100 g) and the results are therefore not shown.

3.2.2. Minerals

The content of the different minerals in the analysed food products is shown in Table 5. Significant differences ($p \leq 0.05$) of the content of calcium, chromium, copper, iron, magnesium, manganese, phosphorus, potassium, sodium, and zinc between the different plant-based products were observed. Significant differences between the products with protein originating from the same source are also observed. Significant differences in the content of minerals in the same product type (e.g. "chopped") with different protein sources were observed. All samples were analysed for arsenic, and mercury but the content in all products were below LOQ being < 0.01 μg/100 g and < 0.5 μg/100 g respectively. Thus, these results are not shown.

4. Discussion

The popularity of plant-based product as substitutes for meat is growing globally because of nutritional, environmental and climate reasons (Mascaraque, 2020). Evidence of lower risk of non-communicable diseases is related to higher intake of plant-origin products such as vegetables, fruits, legumes, whole grain, nuts and seed and lower intake of processed and red meat (Neacsu et al., 2017; Petersen et al., 2018). Epidemiologic studies on the health impact of plant-based meat substitute products in Western diets are not available, since the intake has been relatively low. However, an increase of the intake of these products is expected since FBDG encourage consumption of plant-based food (DVFA, 2021).

Our results show that the content of both macro- and micronutrients varies between the different types of meat substitute products, indicating that the choice of product to include in the diet is important. A modelling study on dietary data from the four European countries shows that it is possible to lower meat intake by substituting with meat substitute products and improve both nutritional quality and climate impact of the diet. However, a substitution with a combination of plant-origin products would lower climate impact of the diets more, since the carbon footprint of the meat substitute products in the study was higher than of plant-origin products, although lower than the carbon footprint of meat and meat products (Mertens et al., 2020).

4.1. Macronutrient composition

Recommendation to increase plant-based foods might lead to the consumption of less healthy plant-based foods that contain refined grains and high sugar content (Cifelli et al., 2016). The results of macronutrient composition of the plant-based protein products enable easier planning of the healthy diet, meeting the daily recommended intake (DRI) range of macronutrients, maximum intake of added sugar and SFA, and recommended intake level of dietary fibre.

4.1.1. Protein and amino acids composition

Macronutrients analysis performed on the plant-based protein products showed that the protein content is highly depended on the protein source, e.g., specific products such as cold cuts, or minced products had highly variable protein content (Table 3). The results for the protein content reported in this study are based on the use of an averaged single factor 6.25 to convert nitrogen content into protein content. A strong correlation ($r = 0.99$) was observed between the protein content calculated based on nitrogen and on the sum of amino acids, confirming the validity of the results of the protein content obtained by Kjeldahl principle. Even though there are specific conversion factors proposed for different food matrices, such as for protein from soy bean being 5.71 (FAO, 2003), we decided to use an averaged factor 6.25

Table 4
Vitamin content per 100 g of plant-based products divided by different products within various plant-based protein sources. The results are expressed as mean with range.

Protein source	Egg white	Mycoprotein		Pea		Soy					Soy and Pea	Wheat		p-value
Products	Cold cuts	Minced	Pieces	Minced	Sausages	Minced	Pieces	Sausages	Tofu	Minced balls	Cold cuts	Cold cuts	Seitan	
n	2	3	3	6	6	8	6	4	2	2	6	2	8	
Biotin (μg/100 g)	13; 10	39^{a} (34-47)	43^{a} (34-48)	9.6^{d} (5.3-14)	12^{cd} (6.6-21)	23^{b} (15-38)	21^{bc} (12-34)	14^{bcd} (11-17)	12; 10	15; 16	4.6^{d} (3.4-5.9)	19; 22	5.7^{d} (1.1-11)	<0.0001
Folate (μg/100 g)	17; 17	45^{ab} (42-51)	53^{a} (45-60)	24^{bc} (13-31)	21^{bc} (13-30)	54^{a} (28-98)	49^{a} (27-69)	34^{abc} (32-37)	7.4; 9.0	33; 27	17^{c} (9.3-23)	56; 63	15^{c} (9.6-26)	<0.0001
Niacin (mg/100 g)	0.37; 0.29	0.69^{ab} (0.61-0.78)	1.4^{a} (0.92-2.2)	0.77^{ab} (0.4-1.2)	0.52^{ab} (0.24-0.71)	0.68^{ab} (0.13-1.8)	0.61^{ab} (<0.1-1.1)	0.35^{b} (0.18-0.54)	0.14; < 0.1	0.19; 0.32	< 0.1	0.31; 1.1	0.23^{b} (<0.1-0.62)	0.011
Pantothenic acid (mg/100 g)	0.13; 0.11	0.19^{ab} (0.18-0.19)	0.25^{ab} (0.22-0.30)	0.01^{ab} (0.068-0.13)	0.08^{ab} (0.06-0.11)	0.27^{a} (0.05-0.77)	0.09^{ab} (0.03-0.15)	0.09^{ab} (0.03-0.23)	0.06; 0.05	0.06; 0.06	0.02^{b} (0.01-0.03)	0.28; 0.31	0.10^{ab} (0.02-0.28)	0.041
Pyridoxine (mg/100 g)	0.04; 0.04	0.06^{ab} (0.058-0.06)	0.09^{ab} (0.08-0.10)	0.04^{ab} (0.02-0.06)	0.04^{ab} (0.03-0.05)	0.09^{a} (0.04-0.2)	0.06^{ab} (<0.01-0.10)	0.04^{ab} (0.04-0.05)	0.02; 0.02	0.05; 0.03	0.02^{b} (< 0.01-0.04)	0.05; 0.04	0.03^{b} (<0.01-0.05)	0.011
Riboflavin (mg/100 g)	0.30; 0.33	0.45^{a} (0.43-0.46)	0.36^{ab} (0.32-0.41)	0.19^{bc} (0.09-0.45)	0.09^{c} (0.05-0.14)	0.18^{bc} (0.08-0.35)	0.16^{c} (0.07-0.26)	0.08^{c} (0.07-0.10)	0.04; 0.04	0.12; 0.16	0.04^{c} (< 0.01-0.10)	0.27; 0.35	0.08^{c} (0.02-0.21)	<0.0001
Thiamin (mg/100 g)	0.04; 0.05	< 0.02	0.10^{a} (0.09-0.11)	0.09^{a} (0.03-0.15)	0.06^{a} (0.02-0.09)	0.11^{a} (0.03-0.27)	0.08^{a} (0.03-0.22)	0.05^{a} (0.04-0.05)	0.03; 0.04	0.05; <0.02	< 0.02	0.22; 0.19	0.06^{a} (0.01-0.11)	0.50
β-Carotene (μg/100 g)	324; 341	< 5	< 5	17 ^{a} (< 5-31)	31^{a} (22-38)	16^{a} (< 5-68)	58^{a} (< 5-144)	71^{ab} (61-76)	< 5; < 5	< 5; < 5	114^{a} (< 5-166)	118; 104	20^{a} (< 5-76)	0.13
α-Tocopherol (mg/100 g)	3.3; 3.3	< 0.1	< 0.1	1.3^{a} (0.24-2.6)	2.0^{a} (1.1-3.7)	1.6^{a} (0.24-3.8)	1.3^{a} (0.55-2.2)	2.3^{a} (2.1-2.5)	0.27; 0.20	1.7; 1.6	2.7^{a} (2.5-3.1)	0.94; 0.98	2.5^{a} (0.37-5.8)	0.29
Phylloquinone (μg/100 g)	13; 14	< 0.8	< 0.8	11^{a} (3.3-21)	5.7^{ab} (3.4-8.2)	5.6^{ab} (<0.4-10)	2.5^{b} (<0.4-5.4)	6.2^{ab} (5.2-7.3)	15; 18	5.7; 6.1	11^{a} (9.2-13)	3.3; 3.4	1.3^{b} (<0.4-3.1)	<0.0001

"n" indicates a number of analysed samples per group of food products. Groups with n ≤ 2 were not included in statistical analysis. Different letters in superscript indicate significant differences (p ≤ 0.05) in the content between different food products in a row, starting from "a" as the highest mean value. The values below LOQ are shown as e.g. < 0.1.

for all food products based on an agreement between these two calculations.

The values in e.g. wheat protein-based products were comparable to protein content of various types of meat, with differences in amino acids composition (Neacsu et al., 2017). The results indicate that the relative content of essential amino acids found in plant-based protein products is comparable with the one found in products based on egg white protein (SOM, Table S3). The relative content of lysine is, as expected, significantly lower in wheat protein-based products (~1.5% of the total protein content) compared to the products based on legumes or egg white protein (~6%) and mycoprotein (~8%). Furthermore, egg white- and mycoprotein-based products had significantly higher relative content of methionine, threonine and valine than legume- and wheat-protein based products (SOM, Table S3).

4.1.2. Carbohydrate

The analysis of carbohydrate showed that they are mostly composed of dietary fibre (>50%), except cold cuts products from various protein sources that besides contain substantial amounts of sugars (SOM, Table S4). As the content of dietary fibre in minced mycoprotein products and all soy protein-based products except tofu exceeds 6 g/100 g, they may be claimed as "high fibre" products, whereas cold cuts may be claimed as "source of fibre", due to a lower content of dietary fibre (EU, 2007). Sugars are found in some of the products as natural components, but they were also added in order to improve the flavor of the cold cuts (SOM, Table S4). Thus, only the products based on mycoprotein, soy-derived pieces and tofu contain < 0.2 g of sugar per 100 g of the sample, the threshold of claiming as "sugar free" (EU, 2007). Presented results indicate that products found on a Danish market in general contain more dietary fibre as part of carbohydrate than plant-based products sold on Australian market (Curtain and Grafenauer, 2019).

4.1.3. Fats and fatty acid composition

As shown in the Fig. 2, the fat content in analysed plant-based protein products is mostly in the form of unsaturated fatty acids, which is in accordance with a recommendation for reduction of SFA (EFSA, 2010). Monounsaturated oleic fatty acid (C18:1, n-9) is the most abundant in products derived from egg white protein, pea, soy, pea and soy combination and wheat protein. Essential fatty acid such as linoleic (C18:2, n-6) called omega-6 fatty acid, is found in high level in all products, except in mycoprotein-based products and soy pieces where no omega-6 fatty acid was detected (Fig. 2, SOM Table S5). As these products contain at least 0.6 g α-linoleic acid per 100 g of product, but not per 100 kcal, they can not be claimed as food "high in omega-3 fatty acids" (SOM, Table S4). However, transition from animal-based protein diet to plant-based protein diet might improve the intake of omega-3 fatty acids, depending on the vegetable oil included in the diet or as ingredients of the products, as described earlier (Lassen et al., 2020; Pereira and Vicente, 2013; Wood et al., 2008).

Table 5
Content of analysed minerals per 100 g of plant-based meat substitutes divided by different products within various plant-based protein sources. The results are expressed as mean with range.

Protein source	Egg white	Mycoprotein		Pea		Soy					Soy and pea	Wheat		p-value
Products	Cold cuts	Minced	Pieces	Minced	Sausages	Minced	Pieces	Sausages	Tofu	Minced balls	Cold cuts	Cold cuts	Seitan	
n	2	3	3	6	6	8	6	4	2	2	6	2	8	
Cadmium (Cd) (μg/100 g)	< 1	< 1	< 1	1.8^{ab} (1.0-3.0)	1.7^{ab} (1.0-2.0)	1.7^{ab} (<1-3.0)	1.0^{b} (<1-2.0)	< 1	< 1	1; 1	< 1	3; 2	2.8^{a} (2.0-5.0)	0.009
Calcium (Ca) (mg/100 g)	39; 37	187^{a} (170-200)	138^{ab} (94-160)	177^{a} (14-280)	192^{a} (45-270)	128^{ab} (50-240)	91^{ab} (62-160)	61^{ab} (59-63)	170; 220	93; 94	15^{b} (14-18)	47; 42	36^{b} (27-49)	<0.0001
Chromium (Cr) (μg/100 g)	17; 7	< 5	< 5	8.1^{b} (<5-11)	8.7^{b} (6.0-12)	6.7^{b} (<5-10)	29^{a} (13-82)	13^{ab} (12-14)	< 5; < 5	< 5; < 5	< 5	9; 9	5.2^{b} (<5-10)	0.004
Copper (Cu) (mg/100 g)	0.02; 0.03	0.30^{ab} (0.23-0.39)	0.28^{ab} (0.19-0.35)	0.30^{ab} (0.20-0.41)	0.25^{ab} (0.21-0.29)	0.38^{a} (0.19-0.79)	0.12^{b} (0.05-0.34)	0.20^{ab} (0.18-0.22)	0.17; 0.14	0.21; 0.21	0.12^{b} (0.10-0.15)	0.31; 0.27	0.28^{ab} (0.17-0.40)	0.0046
Iodine (I) (μg/100 g)	< 5; < 5	< 5	< 5	< 5	10^{a*} (<5-21)	< 5	< 5	< 5	< 5; < 5	< 5; < 5	33^{b*} (25-42)	72; 73	< 5	0.0004
Iron (Fe) (mg/100 g)	0.22; 0.16	0.27^{f} (0.19-0.32)	0.30^{f} (0.13-0.41)	3.5^{c} (3.1-4.2)	3.2^{cd} (2.9-3.6)	2.5^{de} (2.1-3.4)	2.8^{cd} (2.3-3.5)	16^{a} (15-18)	1.7; 2.1	2.2; 2.3	4.6^{b} (4.0-5.3)	2.0; 2.0	1.7^{e} (1.1-2.4)	<0.0001
Magnesium (Mg) (mg/100 g)	11; 11	43^{b} (40-44)	32^{bc} (23-37)	39^{b} (19-58)	28^{bc} (17-34)	83^{a} (53-120)	103^{a} (86-120)	38^{bc} (37-40)	61; 44	53; 54	10^{c} (9.2-12)	40; 35	25^{bc} (16-33)	<0.0001
Manganese (Mn) (mg/100 g)	0.07; 0.07	4.8^{a} (4.3-5.1)	3.8^{b} (3.7-3.9)	0.47^{de} (0.24-0.69)	0.40^{ef} (0.25-0.55)	1.0^{c} (0.76-1.4)	1.3^{c} (1.2-1.4)	0.59^{de} (0.51-0.65)	0.81; 0.78	0.78; 0.70	0.16^{f} (0.14-0.17)	0.86; 0.81	0.71^{d} (0.53-0.99)	<0.0001
Molybdenum (Mo) (μg/100 g)	1.5; 1.5	1.6^{d} (1.6-1.7)	4.1^{cd} (3.3-4.7)	52^{abcd} (27-80)	55^{abc} (27-120)	80^{a} (27-98)	75^{a} (55-130)	68^{ab} (42-120)	25; 33	54; 61	23^{bcd} (18-29)	79; 81	31^{bcd} (15-54)	<0.0001
Nickel (Ni) (μg/100 g)	< 6	< 6	< 6	32^{ab} (9.2-67)	23^{ab} (14-35)	99^{a} (12-350)	13^{ab} (<6-34)	15^{ab} (11-19)	24; 17	26; 27	9.3^{b} (<6-15)	9.8; 7.0	10^{b} (<6-18)	0.024
Phosphorus (P) (mg/100 g)	30; 29	250^{ab} (230-260)	210^{bc} (150-250)	208^{bc} (180-230)	182^{bc} (150-210)	226^{b} (160-330)	318^{a} (270-440)	145^{cd} (140-150)	180; 180	180; 180	75^{d} (67-86)	140; 140	87^{d} (53-120)	<0.0001
Potassium (K) (mg/100 g)	210; 210	79^{c} (74-84)	100^{bc} (69-120)	392^{b} (320-490)	252^{bc} (210-290)	651^{a} (400-1100)	750^{a} (600-1100)	290^{bc} (260-330)	110; 100	450; 460	170^{bc} (150-190)	260; 240	87^{c} (45-180)	<0.0001
Selenium (Se) (μg/100 g)	8.9; 4.8	4.4^{b} (2.5-5.7)	2.0^{b} (1.7-2.4)	4.0^{b} (<0.5-7.3)	7.4^{b} (6.7-8.1)	8.3^{b} (<0.5-11)	5.4^{b} (<0.5-28)	9.8^{b} (6.8-14)	1.8; 2.4	9.3; 8.9	2.5^{b} (<0.5-6.7)	22; 17	32^{a} (11-57)	<0.0001
Sodium (Na) (mg/100 g)	890; 1000	34^{e} (32-37)	233de (180-270)	380^{cd} (230-490)	610^{bc} (490-680)	473^{bcd} (390-810)	643^{b} (500-850)	573^{bc} (520-620)	150; 180	380; 380	993^{a} (890-1200)	1100; 1100	653^{b} (390-1000)	<0.0001
Zinc (Zn) (mg/100 g)	0.12; 0.11	6.2^{a} (5.8-6.7)	5.4^{a} (3.9-6.5)	2.0^{b} (1.5-2.3)	1.7^{bc} (1.5-2.1)	1.2^{bcd} (0.61-2.3)	1.1^{cde} (0.91-1.2)	0.61^{de} (0.54-0.70)	1.2; 1.1	0.63; 0.64	0.27^{e} (0.23-0.31)	1.9; 1.8	1.4^{bcd} (0.81-2.2)	<0.0001

“n” indicates a number of analysed samples per group of food products. Groups with n ≤ 2 were not included in statistical analysis. Different letters in superscript indicate significant differences ($p \leq 0.05$) in the content between different food products in a row, starting from “a” as the highest mean value. The values below LOQ are shown as e.g. < 1. *pooled t-test was performed to test the differences between two products with detected iodine content.

4.2. Micronutrient composition

FRIDA contains data on all relevant micronutrients which enable evaluation of the analysed products in respect to micronutrients such as niacin, cobalamin, β-carotene, calcium, iodine, iron, phosphorous, selenium, and zinc that are normally obtained from animal sources (Pereira and Vicente, 2013).

4.2.1. Vitamins

The content of vitamins varies significantly depending on the protein source of the plant-based products, and some products therefore pose as a better alternative for intake of vitamins otherwise found in meat products (Egelandsdal et al., 2020). Table 4 shows that some products have a substantial (≥15% of DRI per 100 g) content of biotin, folate, riboflavin, α-tocopherol and phylloquinone (EU, 2011, 2007). As seen from our data, the lowest content of vitamins is observed in highly processed products such as tofu and seitan.

As the analysed products are posing as an alternative to animal products, a special focus was put on the content of cobalamin, riboflavin and β-carotene as some of the main dietary sources of these vitamins are meat and dairy products (Lassen et al., 2020). The content of riboflavin is significant (≥15% of the DRI per 100 g) in products with mycoprotein and egg white as the source of protein and in cold cuts with wheat as protein source. The content of β-carotene is varying between the plant-based products with the highest content found in cold cuts with egg white as protein source (>42% of the DRI per 100 g). However, in plant-based products with a source of mycoprotein, no β-carotene is detected.

4.2.2. Minerals

Table 5 shows that products based on pea, soy and wheat protein contain substantial contents (≥ 15% of the DRI per 100 g) of calcium, chromium, copper, iron, magnesium, manganese, molybdenum, phosphorous, potassium, selenium, and zinc. Products based on mycoprotein contain significant amounts of manganese and zinc, whereas the contents of iron, molybdenum and potassium are lower than in the other plant-based products. In general, it was observed that products with egg white protein and mycoprotein show a similar mineral composition.

As plant-based products are posing as an alternative for animal products, a special focus was put on the content of calcium, iodine, iron, phosphorous, selenium and zinc (Lassen et al., 2020). The analysed products had a diverse content of calcium depending on the protein source, with high content ($\geq$ 15% of the DRI per 100 g product) found in products based on mycoprotein and pea protein, varying content in products with soy protein, and low content ($\leq$ 6% of the DRI per 100 g product) in products with egg white, soy and pea, and wheat as the protein source. The iodine content in the plant-based products was in general low except for cold cuts with soy and pea, and wheat as the protein source, which had a content between 22–48% of the DRI. Analysed plant-based protein products present good source of iron (>50% of the DRI per 100 g product), especially in pea and soy protein cold cuts. However, products with egg white and mycoprotein as protein source have a very low content of iron (<9% of the DRI/100 g). The phosphorous content found in the plant-based products ranged from 4 to 45% of the DRI/100 g, with the lowest content found in cold cuts with egg white and a combination of soy and pea as the protein source, and in seitan. Plant-based products with wheat as protein source showed high content of selenium where the content of 100 g was up to 58% of the DRI. Zinc was found in mycoprotein-based products where the content of 100 g of product enabled up to 62% of the DRI.

The sodium content in the plant-based products corresponds to a salt content between 0.085 g/100 g and 2.75 g/100 g. Cold cuts in general, contain more sodium. However, these products are designed for topping on a bread and are not meant to be consumed in high amounts. The high sodium content in these products corresponds to the sodium content found in meat-based cold cuts (FRIDA, 2019). Thus, the same dietary recommendations should be followed, and the consumer should be aware of a potentially high consumption of sodium. Only minced mycoprotein-based products can claim “low sodium content” (<120 mg/100 g) (EU, 2007).

The maximum cadmium levels allowed in food (excluding infant formula, baby foods and supplements) are between 5−100 μg/100 g wet weight, which is well above the levels of cadmium observed in the plant-based products (Table 5) (EU, 2006). Furthermore, the tolerable daily intake of nickel is 13 μg/kg body weight for adults, which is well above the content found in the plant-based products (Table 5). However, for some products, e.g. minced product with soy as protein source, the consumption for young children should be limited based on the high nickel content (Schrenk et al., 2020).

4.3. Strengths and limitations of the study

To our knowledge this is the first study that collected data on the nutrient composition of the plant-based meat substitute products divided into categories based on the protein source and the difference in the product types. It is a strength that the sampling is based on a detailed market survey and that a complete nutrient analyses for all nutrients were performed on the products present on the Danish market. Data on various nutrients are freely available in Danish Food Composition Database (FRIDA, 2019). Similar study was performed on the Australian market (Curtain and Grafenauer, 2019), but it did not contain the information on the specific protein sources and the whole range of nutrients such as amino acids, fatty acids, vitamins and minerals as it is presented here.

Limitations of the study are that we, due to financial constraints, did not collect minimum 6–8 product/samples for every combination of protein source and product type, as we chose to identify differences between product types based on identical protein source.

5. Conclusion

A demand for plant-based protein products is growing globally due to an introduction of new sustainable FBDG that encourage consumption of balanced diet by decreasing animal-origin foods and increasing plant-origin foods. Even though this contributes to sustainability, a careful planning of consumption of plant-based products as substitutes for meat should be done, as it might lead to the lack of essential nutrients.

Some of the plant-based protein products analysed in this study showed nutritional value as can be claimed as “high fibre”, whereas some of them such as pea-based products contain substantial amounts of calcium, iodine, iron, selenium and zinc. However, a precaution should be taken in planning of such diets as the plant-based cold cuts contained high levels of sodium and added sugar, whereas most of the products lack some of the vitamins such as cobalamin, pyridoxine, and β-carotene. As the vitamin and mineral content of the plant-based products varies significantly both depending on the protein source and the product type, a combination of the plant-based meat substitute products might be appropriate in healthy diets. It is also important to emphasize that sustainable FBDG recommend reduction of meat, not exclusion. Thus, a balanced diet with increased amount of fruits, vegetables, legumes whole grain, nuts and seed and a low amount of meat and meat products may also include a certain amount of the plant-based meat substitutes without a risk for human health.

Data availability

Data will be made available on request.

CRediT authorship contribution statement

Petra Ložnjak Švarc: validation, statistical analysis, investigation, visualization, writing – original draft, writing – reviewing and editing. **Marie Bagge Jensen:** validation, statistical analysis, writing – original draft, writing – reviewing and editing. **Marija Langwagen:** conceptualization, methodology, investigation, writing – original draft, writing – reviewing and editing. **Anders Poulsen:** conceptualization, methodology, investigation, writing – reviewing and editing. **Ellen Trolle:** conceptualization, methodology, writing – original draft, writing – reviewing and editing, funding acquisition. **Jette Jakobsen:** conceptualization, methodology, investigation, validation, writing-original draft, writing – reviewing and editing, supervision, project administration, funding acquisition.

Declaration of Competing Interest

The authors report no declarations of interest.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.jfca.2021.104332.

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