



Iodine in plant-based dairy products is not sufficient in the UK: A market survey

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ABSTRACT

Background: Following a well-balanced diet ensures that a person gets all the essential elements for health sustenance. However, in the United Kingdom an increasing proportion of people are transiting to become vegans who exclude animal-based products in their diets. Consequently, people may have a deficit of essential elements such as iodine which is not present in most plant-based meals, additionally iodide fortified table salt is not commonly used in the UK. Without iodine people consuming a vegan diet risk developing iodine deficiency and diseases like goiter.

Methods: The objective of this study is to determine the difference in iodine content and iodine speciation between plant-based and dairy products. More than 100 market samples of plant-based and dairy milk products were collected in Scotland, UK.

Results: Iodine concentrations in dairy milk is ten times higher compared to plant-based milks. Similar differences were also apparent for butter, yogurt and cheese. A total of 20% of plant-based milk products were fortified with iodine, however these products had lower iodine concentrations compare to the equivalent dairy products. In this study we calculated that people with average diet have an iodine intake of $226 \pm 103 \mu\text{g day}^{-1}$ from dairy products which satisfies the WHO recommended intake of adults and 90% of the recommend intake for pregnant and breast-feeding women. A diet from substituted dairy products gives only $21.8 \mu\text{g day}^{-1}$ for the respective WHO guideline intake values, which accounts only 15% of the iodine intake for adults and 9% for pregnant and lactating women. Iodine fortified diet could increase the iodine intake to 55% or 33% of the WHO recommended daily intake respectively.

Conclusion: Plant-based dairy consumers are encouraged to use iodine fortified dairy products or use of iodized salt in the UK for home cooking, otherwise there are at risk to get iodine deficient.

1. Introduction

Food is closely linked to critical aspects of consumers' health and wellness. The residents and citizens of the United Kingdom are minimizing their meat intake in favour of a vegan diet. Research shows that there has been a 2% increase in the number of people who eat a vegan dinner between 2014 and 2019 [1]. In 2020, the world vegan food market reached a value of USD 15.4 billion [2]. In the United States, the vegan market grew by 20% in one year (2018) to reach \$3.3 billion in sales [3]. Thus, the statistics show that there is a shift in the eating pattern where more people are choosing to eat non-animal products.

Notably, people who are committed to a vegan diet prohibit the

consumption of meat, eggs, dairy products, and other animal-derived ingredients. There are new products, such as plant-based meat alternatives (PBMA), which have been developed to satisfy these new food demands [4]. People choose to change their eating patterns to plant-based meals due to various influences. The main reasons for the shift to plant-based food products is health and environmental concerns [2,5].

The primary problem with this shift in diet is that plant-based products cannot provide all the essential nutrients the body needs for its development. For instance, dairy products and fish are the main sources of iodine in the United Kingdom [6]. Particularly, dairy sources contribute to 25–70% of all the iodine consumed in the country [7].

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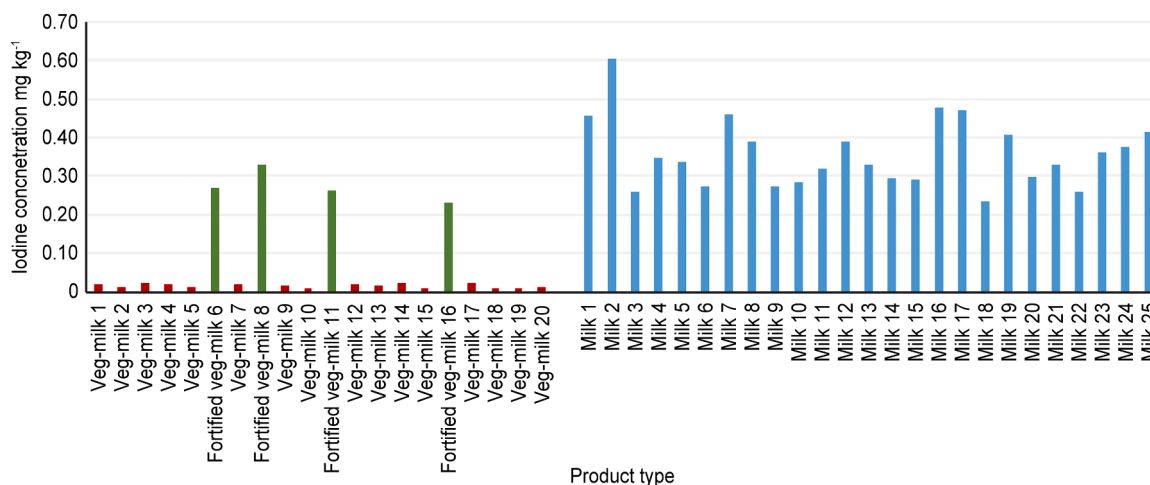


Fig. 1. total iodine concentration in dairy milk and plant-based milk). Red bars are plant-based dairy alternative samples; Green bars are iodine fortified are plant-based dairy alternative samples; Blue bars are dairy milk samples.

Iodine helps in maintaining vital functions in the body [8]. It is essential for the regulation of thyroid hormones in the body [9]. With diseases such as goitre, mental retardation and sluggishness associated with iodine deficiency [10,11]. The implication of moving to vegan diets is that iodine deficiency is reemerging in Europe [12].

The World Health Organization (WHO) recommends the use of iodized salt to correct iodine deficiency in populations [13]. In fact, many countries have increased iodine intake in their populations by adding iodine to table salt to form iodized salt. However, this has never been the case for the UK where iodine fortification of salt was not introduced and iodized salt is therefore not readily available in the UK [14]. Availability of iodized salt in the UK supermarkets was reported to be 21.5% [13]. Goitres had been reported in the UK until the iodine level in milk has increased [7]. In the UK iodine intake was increased through changes in the dairy farming industry [15], with iodine being added to cattle feed to improve cattle health and the cross contamination through the use of iodine for disinfection of the tits. This in turn increased the iodine concentration in milk. As a consequence, milk and dairy products became the major sources of iodine, and since milk consumption is high in the UK, increased milk-iodine concentration meant increased iodine intake [11]. However, vegans can improve their iodine intake by consuming iodine-rich plant-based foods such as seaweed, which is a good source of iodine. Other plant-based sources of iodine include iodized salt, fortified plant-based milk, and some types of bread [26].

In the UK vegans may be at risk of developing iodine deficiency which may lead to serious medical repercussions [10]. The objective of this study was to conduct a market survey on the most common dairy and plant-based dairy products and to determine the iodine concentration and speciation, with a focus on the consequences of an increased vegan diet on iodine intake in the UK.

2. Material and methods

2.1. Sample collection

A total of 103 milk, cheese, yogurt and butter dairy products and plant-based products were collected from stores in the city of Aberdeen, Scotland, UK from the 1st to 14th of September 2020. The products purchased represent national brands. The dairy milk and plant-based milk samples were collected based on the number of purchases in Great Britain from 2014 to 2020 (statista.com). The top selling products were sampled. Information about the products in [supplementary material \(Table S1-Table S8\)](#).

2.2. Iodine extraction method

Iodine analysis was performed by inductively coupled plasma-mass spectrometry (ICP-MS) Agilent 8800 triple quad, no gas mode (for instrument settings see [Table S9](#)). For the analysis of dairy milk and plant-based milk 200 μ L of milk samples was transferred to 15 mL plastic tubes (Corning centrifuge tubes). The sample was diluted to total of 10 mL by 2% (v/v) tetramethylammonium hydroxide, ((CH₃)₄NOH) 25%, Aldrich, that was prepared in ultrapure water (18.2 M Ω cm). The sample were manually shaken for 10 s than transferred into 10 mL luerlock syringe and filtered through a 0.45 μ m filter (Fisherbrand™ Sterile PVDF Syringe Filter 33 mm diameter 0.45 μ m PVDF w/pp filters). For cream, cheese, and yogurt products 200 g was freeze dried for 16 h before grinding to powder using a pestle and mortar. A total of 50 mg of ground sample was transferred into 10 mL Pyrex® glass test tubes. To this 0.5 mL of 25% TMAH and 1 mL of 5% Triton X-100 was added, before heating the samples for 1 h at 90°C. After the digestion sample were diluted to 10 mL with ultrapure water (18.2 M Ω cm). Butter sample was melted at 40°C, by placing the samples in a container in a water bath, once melted 200 μ L was transferred into the Pyrex® glass tube and then underwent the same digestion method as above.

2.3. Speciation method

The HPLC system used for the analysis was an Agilent 1260 Infinity II composed of a quaternary pump and using the Agilent LC connection kit for ICP-MS. The column was a Hamilton PRP-X100 Anion Exchange HPLC column (4.1 mm inner diameter \times 150 hardware length, 10 μ m particle size polyhydroxymethacrylate base resin) (HPLC operating conditions are detailed in [Table S10](#)).

Milk samples were diluted (1:5) than filtered through 0.45 μ m PVDF filter before the analysis. For yogurt, cream and cheese, 0.5 g of freeze-dried sample was dissolved into 2 mL of with ultrapure water (18.2 M Ω cm) and shaken for 1 min before diluting to 10 mL with water. The samples were filtered through 0.45 μ m PVDF before the analysis.

2.4. Reference standards and quality control

Certified Reference Material (CRM) ERM BD-150 was used to validate the method for total iodine. The reference milk powder is certified to contain an iodine concentration of 1.73 mg I kg⁻¹ (\pm 0.14 mg kg⁻¹). For analysis 1 g of skimmed milk powder was dissolved to 10 mL of distilled water to yield a homogenous solution containing 173 μ g L⁻¹ of iodine. The CRM underwent the same extraction procedure as the milk samples. After the optimized digestion method ([Fig. S1](#)) the measured

Table 1

Summary of the of the dairy products and plant-based products analysed for iodine content in mg/kg.

	Dairy milk	Plant-based milk	Dairy yogurt	Plant-based yogurt	Dairy cheese & cream	Plant-based cheese & cream	Dairy butter	Plant-based butter
Count	25	19	14	7	17	11	6	4
Mean	0.36	0.016	0.261	0.029	0.510	0.059	0.0396	0.0207
SEM	0.02	0.002	0.035	0.004	0.074	0.008	0.0071	0.0037
Median	0.34	0.017	0.194	0.031	0.477	0.069	0.0394	0.0198
SD	0.08	0.005	0.129	0.010	0.305	0.025	0.0175	0.0075
Minimum	0.23	0.007	0.151	0.012	0.118	0.025	0.0157	0.0130
Maximum	0.61	0.025	0.522	0.041	1.204	0.090	0.0696	0.0301
Variability^a	2.7	3.6	3.5	3.4	10.2	3.6	4.4	2.3

^a factor between min and max.

value was $1.68 \pm 0.045 \text{ mg kg}^{-1}$ ($n = 3$) which is a recovery of 97%. Additionally, quality control for total iodine analysis was performed using spiked additions for every 10 samples. Briefly, $10 \mu\text{g L}^{-1}$ of iodine was spiked into a set of milk, cheese and butter samples (Fig. S1, S2 and Table S11, S12). The iodine average recovery was 90% which indicated that there is no major loss of iodine by using the digestion method above. Hence of adequate quality for this study.

To determine if there was any species conversion in the analysis of iodine species $50 \mu\text{g L}^{-1}$ of iodide and iodate were spiked in ultrapure water ($18.2 \text{ M}\Omega \text{ cm}$) and the recovery of both species was 42 and $47 \mu\text{g L}^{-1}$ and recoveries of 85% and 94% respectively (see Table S13), which indicate that the used methodology of the study was appropriate.

2.5. Data analysis

Data were analysed using Minitab 19. One way ANOVA was applied to determine differences between the iodine concentration in dairy milk product vs plant-based product in the same category of produce. (Supplementary information Table S14 and Table S15).

3. Results and discussion

3.1. Iodine in dairy milk and plant-based milk

When comparing the concentration of iodine in dairy milk and plant-based milks there is significantly higher iodine concentrations in the dairy milk compared to the plant-based milk (p value < 0.01); with average iodine concentration of $0.36 \pm 0.08 \text{ mg kg}^{-1}$ in the dairy milk products $0.067 \pm 0.109 \text{ mg kg}^{-1}$ in the plant-based milk products (Fig. 1, Table 1, Table S1 and S2). While the iodine level in the milk varied by max factor 2, the plant-based milk samples showed larger variability. While most samples (16 out of 20) of the plant-based milk

products were below 0.05 mg kg^{-1} , 4 samples have iodine concentrations around $0.2\text{--}0.3 \text{ mg kg}^{-1}$ (mean $0.273 \pm 0.073 \text{ mg kg}^{-1}$). Those higher-level plant-based products had been fortified with additional iodine according to the product declaration. The iodine concentration of non-fortified plant-based milk was therefore even lower $0.016 \pm 0.005 \text{ mg kg}^{-1}$ ($n = 16$). The results are consistent with an American study which shows that the average iodine concentration in non-fortified plant-based milk ($n = 30$) was $0.012 \pm 0.10 \text{ mg kg}^{-1}$ [16]. Similarly, a study based in the United Kingdom established that iodine content in alternative milk products was 0.007 mg kg^{-1} and was lower than that of cow milk 0.438 mg kg^{-1} , resulting in daily intake of iodine of 94 versus $129 \mu\text{g d}^{-1}$ for a non-dairy diet (not necessarily vegan) vs a diet that contained dairy products [17]. The implication is that people who rely only on the plant-based products are at risk of developing iodine deficiency. In a separate UK study, the findings show the concentration of iodine in unfortified plant-based products ($n = 44$) was lower than this study finding at a mean of 0.007 mg kg^{-1} [18], where iodine mean in the fortified products ($n = 3$) was 0.28 mg kg^{-1} . The differences from the present study could be as a result of product selection or the variation in products used to create the plant-based products.

Vegan diet could mean that there will be a re-emergence of serious diseases and health conditions. Efforts are being made to ensure that plant alternatives can offer the same nutrients, but findings reveal that most of the plant-based products have little if any iodine. For example, soya, coconut, and almond milk have lower values of calcium, iodine, and carbohydrates compared to dairy milk [19]. While plant-based products may be high in fibre and a few elements, they are lacking in some essential nutrients even when fortified [20,21].

Although, iodine concentration in plant-based product is much lower than that of cow milk, it has been demonstrated that iodine fortified plant-based milk can have higher concentration of iodine content compared to dairy [22], however that observation was not supported in

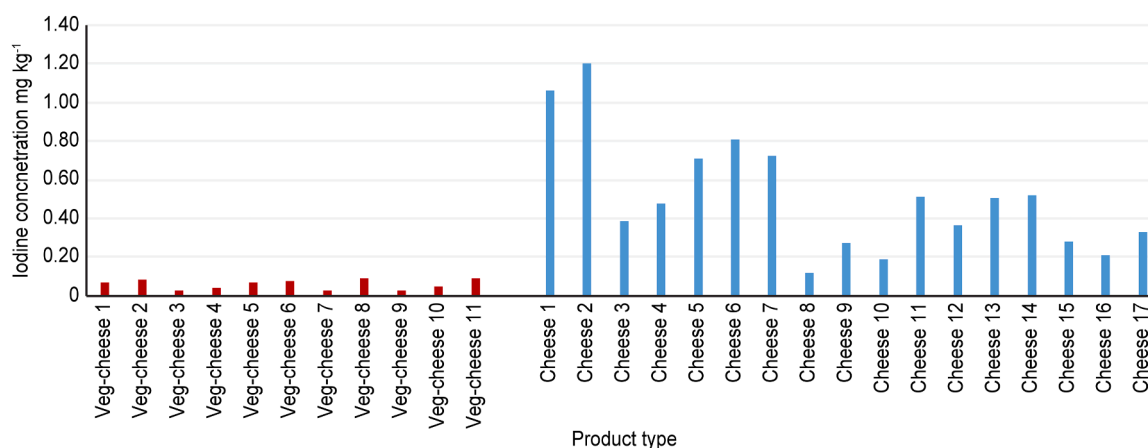


Fig. 2. Iodine concentration in various kind of cheese and cream in dairy and plant-based diet. Red bars are plant-based dairy alternative samples; Blue bars are dairy samples.

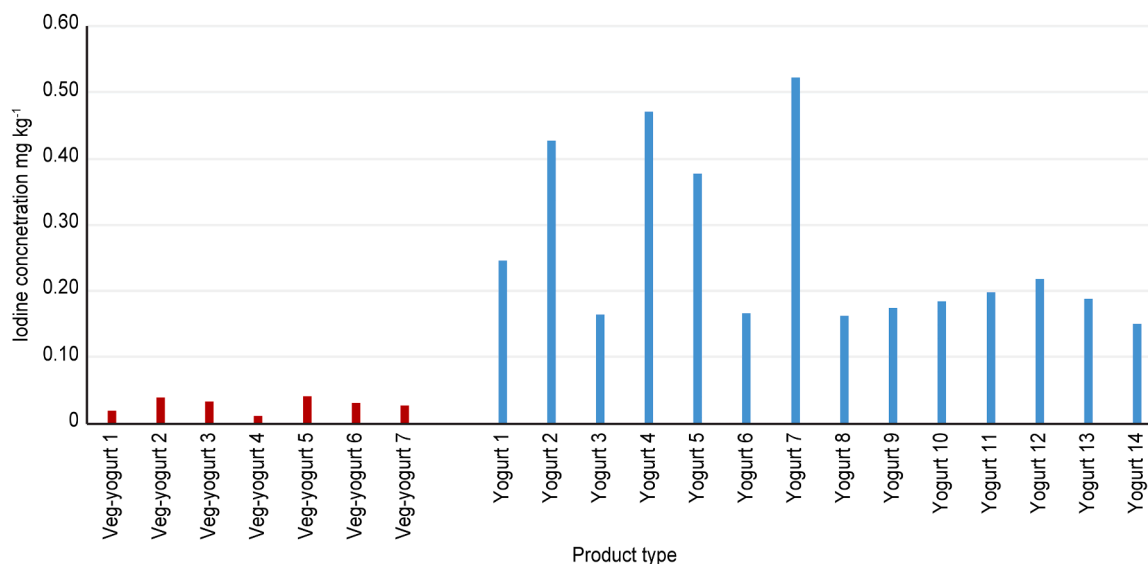


Fig. 3. Iodine content in dairy yogurt and plant-based yogurt. Red bars are plant-based dairy alternative samples; Blue bars are dairy samples.

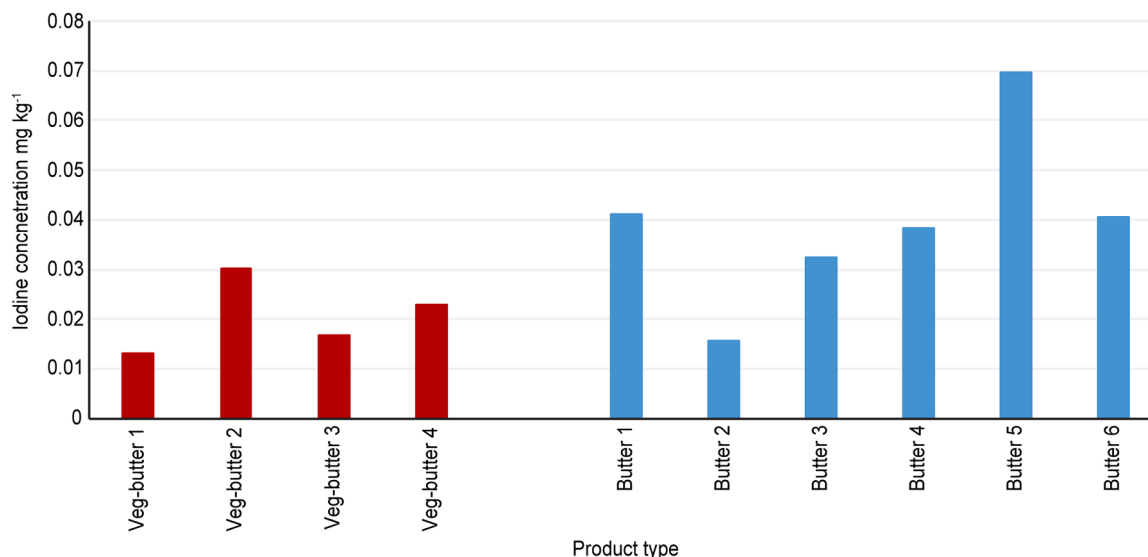


Fig. 4. Iodine concentration in dairy butter and plant-based alternatives. Red bars are plant-based dairy alternative samples; Blue bars are dairy samples.

this study (Fig. 1). Our fortified plant-milk was also significantly lower than the dairy milk products (p value < 0.01).

3.2. Iodine in cream, cheese, yoghurt and butter of dairy and plant-based products

Cheese and cream have the highest concentration of iodine, with the maximum value observed to be 1.2 mg kg^{-1} with a mean value of $0.510 \pm 0.305 \text{ mg kg}^{-1}$ ($n = 17$), (Fig. 2, Table 1, Table S3 and S4). During the production of cheeses at the curd separation step, 75–84% of iodine content is lost in whey [23]. Nevertheless, the iodine concentration in the final product is increased due to moisture loss (about 80% for fresh cheeses and 90% for semi-hard cheeses). Therefore, the iodine levels in cheese can increase 1.6–2.3 times after curdling [23]. The iodine concentration in yogurt is lower (mean $0.261 \pm 0.129 \text{ mg kg}^{-1}$, $n = 14$) compared to milk (Fig. 3, Table 1, Table S5 and S6). With concentrations in cream and cheese products being statistically higher (p -value 0.007) than milk. For the comparable non-fortified milk, cream and cheese plant-based products the concentrations of iodine were 0.016

$\pm 0.006 \text{ mg kg}^{-1}$ and $0.059 \pm 0.025 \text{ mg kg}^{-1}$ ($n = 11$) respectively. All significantly lower than the respectable dairy products. Dairy butter has the lowest concentration of iodine of any dairy products ($0.040 \pm 0.017 \text{ mg kg}^{-1}$ ($n = 6$)), but still significantly higher than the plant-based alternatives ($0.021 \pm 0.007 \text{ mg kg}^{-1}$ ($n = 4$)) (p value < 0.03) (Fig. 4, Table 1, Table S7 and S8).

3.3. Iodine speciation

Investigating the iodine species is important to give an understanding of iodine behaviour in plant-based products, especially to know which iodine species is present in fortified products, and which molecular form is in animal dairy products. Notably, most iodine analysed in the dairy products are in the form of inorganic iodine. Detected speciation of the sum of iodide (I^-) or iodate (IO_3^-) compared to total iodine (digestion) gives organoiodine compounds. A total of 19 dairy and plant-based product was studied (Table S13), the recovery of the iodine in the form of iodide species was around 82%. Meanwhile, only iodide was detected in the samples (dairy, plant-based and plant-based fortified

Table 2

daily iodine consumption from dairy products for average daily intake and mean and median (in paraphrase) concentration from this market survey for people with normal diet and vegans. The error is given as one standard deviation.

Commodities	Dairy based diet Iodine ($\mu\text{g day}^{-1}$)	Vegan diet	Fortified Vegan diet ^a
Milk	86 +/- 21 (81)	3.8 +/- 1.4 (4.0)	65 +/- 10 (64)
Yogurt	10.4 +/- 5.2 (7.8)	1.7 +/- 0.4 (1.2)	1.7 +/- 0.4 (1.2)
Cheese	127 +/- 76 (119)	14.9 +/- 6.2 (17.2)	14.9 +/- 6.2 (17.2)
Butter	2.8 +/- 1.2 (2.8)	1.4 +/- 0.5 (1.4)	1.4 +/- 0.5 (1.4)
Sum 1 /day from dairy products	226 +/- 103	21.8 +/- 8.5	83 +/- 17
% WHO guideline normal person	151%	15%	55%
%WHO guideline for pregnant and breastfeeding women	90%	9%	33%

^a where no iodine fortified products were available the mean concentrations of the non-fortified commodities were used.

samples). The findings from the current study are a confirmation that the iodide species is the dominant species. This confirms a previous study where fortified infant formula contained $1.31 \pm 0.04 \text{ mg kg}^{-1}$ of iodide and no detectable iodate and no organoiodine species [24]. Our mass balance suggests that no significant organoiodine species can be expected in neither the dairy nor the plant-based dairy products.

3.4. Iodine intake from dairy products and plant-based products

In the UK it is estimated that the number of vegans in the United Kingdom quadrupled to 600,000 between 2014 and 2018, which is about 1 per cent of the total population [25]. To make sure that the alternative products available to people on a vegan diet is meeting daily requirements the concentrations of iodine in dairy and non-dairy alternatives were used to determine the daily in iodine intake from those commodities. Iodine concentration in milk varies from one country to another depending on the farming method practiced by the farmers.

For this case, UK milk has been found to have a relatively high concentration of iodine with an average concentration of $427 \pm 16 \mu\text{g L}^{-1}$. According to World Health Organization, adults' iodine intake is recommended at $150 \mu\text{g day}^{-1}$. In cases where the adult is pregnant or lactating, WHO recommends iodine intake should increase to $250 \mu\text{g day}^{-1}$ [26]. According to UK Department for Environment Food & Rural Affairs the usage of milk was found to be 0.24 L day^{-1} and $0.04, 0.07, 0.25 \text{ L day}^{-1}$ of yoghurt, butter, cheese respectively (DEFRA Sept 2022). Using the average concentrations in the different commodities the iodine consumption for both a dairy based diet and a vegan diet were determined (see Table 2).

People with a diet that contains dairy products consumes a significant higher iodine intake from dairy products than vegan consumers from the plant-based alternatives with an average iodine intake of $226 \pm 103 \mu\text{g day}^{-1}$ from dairy products, which accounts for approximately 150% of WHO recommended amount of $150 \mu\text{g day}^{-1}$ for adults. Pregnant and nursing mothers would need to increase the quantity of dairy products above the national average to meet the required WHO standard of $250 \mu\text{g day}^{-1}$. The UK Scientific Advisory Board Committee on Nutrition stated that $140 \mu\text{g day}^{-1}$ is even sufficient for pregnant and lactating woman [7]. However, iodine intake from dairy products usually accounts only for half of the daily iodine intake; 34% for adults, 51% for school children, 62 for children below 5 years depending on their milk consumption [7]. On the other hand, people on a vegan diet have an average iodine intake of $21.8 \mu\text{g/day}$ from plant-based dairy products, which accounts only for less than 15%

of WHO recommended amount and only 9% of the WHO recommended daily intake for pregnant and breastfeeding women. While fortified plant-based products contribute 55% of recommended daily intake set by WHO iodine for adults and 33% for pregnant and lactating women. Hence, the use of fortified plant-based milk might be adequate for vegan if iodine in the other consumer products is similar concentration than the normal diet.

Although here only dairy products have been considered a shift from dairy to plant-based product consumption could lead to iodine deficiency in countries in which table salt is usually not fortified with iodide and not readily available at supermarkets. A shift to ready meal products and whether those vegan products in the UK have also lower iodine levels than in countries where iodized salt is used needs to be studied in the future. Therefore, it is recommended that people that consume a vegan diet either consume iodine fortified products or utilize iodine fortified salt for home cooking.

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Ali Alzahrani received his scholarship from the Saudi Arabian Cultural Bureau.

CRediT authorship contribution statement

Ali Alzahrani: Laboratory work, ICPMS analysis, sampling, methodology, writing- original draft preparation. **Rainer Ebel:** Supervision, help with manuscript writing. **Andrea Raab:** supervision of laboratory experiments. **Gareth Norton:** Conceptualisation, methodology, supervision, help with manuscript writing. **Jörg Feldmann:** Conceptualisation, methodology, supervision, help with manuscript writing.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests Ali Alzahrani reports financial support was provided by Saudi Arabian Cultural Bureau.

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Declaration of interest

All authors have no conflict of interest. Declaration of generative AI and AI assisted technologies in the writing process. No AI was used in the writing process and in the final manuscript. One artistic image was generated using AI technology as part of the graphical abstract.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.jtemb.2023.127218](https://doi.org/10.1016/j.jtemb.2023.127218).

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