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Contribution of different vitamin D forms and fortified foods to vitamin D intake in Europe: A narrative review

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ABSTRACT

In the current narrative review, the bioavailability of the main vitamin D forms is evaluated. The mean intakes and main contributing forms of vitamin D in the European diet are estimated, as well as the major contributing dietary sources. The literature is reviewed for studies reporting on the proportion of users and non-users of fortified food with vitamin D intakes below reference intakes. In addition, the availability of vitamin D-fortified prepackaged retail products and fortification levels in the European market is assessed. Previously, vitamins D2 and D3 forms were considered the primary forms in the diet. Recent analytical methods suggest that dietary 25(OH)D3, when adjusted for higher bioequivalence, significantly contributes to total vitamin D intakes. When also considering 25(OH)D3 from foods, the estimated vitamin D intake from an average European diet was 3.8 μg/d of total Vitamin D Equivalents: vitamin D3, vitamin D2 and 25(OH)D3, contributing about 71 %, 2 %, and 27 %, respectively. Animal foods, fortified fats and spreads contributed most to total intakes. Literature suggests that 94–100 % of Europeans aged $\geq$ 13 y fail to meet the vitamin D reference intake of 10 μg/d. About 98–100 % of vitamin D-fortified food users and 99–100 % of non-users in the UK and Netherlands consumed less than 10 μg/d of vitamin D. About 1.2 % of prepackaged foods and drinks were voluntary fortified with vitamin D, margarine and plant-based drinks providing most of the daily vitamin D. Encouraging fortification and other strategies may support closing the gap between current and recommended vitamin D intakes.

1. Introduction

Vitamin D is crucial for calcium and bone homeostasis, but no global definition of inadequacy exists. Due to complexity most guidelines assume minimal sunlight exposure [1–3]. Optimal 25(OH)D intake levels in the absence of sunlight exposure remain debated, due to differences in dose-response models, varying between intake guidelines, varying study types and target outcomes included in establishing target levels. While early vitamin D recommendations focused on rickets prevention, later ones aimed at musculoskeletal health. However, recent studies provide little new insight, likely due to high baseline 25(OH)D levels in participants.

The prevalence of adults in Europe with serum 25(OH)D concentrations < 45 or 50 nmol/L and < 25 or 30 nmol/L ranged from about 28–67 % [3] to 9–26 % [4], respectively. The intake data from 21 European surveys among adults pointed to generally low vitamin D intakes, with males and females consuming on average 2.7 and 3.3 μg/day, respectively [3–5].

The EFSA highlights the challenge of obtaining sufficient vitamin D in Europe [6]. While national policies are expected to address inadequacies, fortification remains limited, except in Finland. In the UK mandatory vitamin D fortification is considering mandatory to combat deficiencies [7]. In the EU, fortification is less common due to a focus on whole foods, lack of perceived need, and concerns about overconsumption.

Policy-based national concerns in establishing vitamin D fortification guidelines may arise from lack of data. It is essential to evaluate the current landscape of vitamin D intake and fortification in Europe. It is also important to assess vitamin D intakes considering analytical detection of new vitamin D forms. Therefore, the main objectives of the present narrative review are to:

- Describe the main forms and bioavailability of vitamin D in the diet, fortified foods, enriched foods, and supplements in Europe
- Estimate the vitamin D intake from an “average” European diet, the main contributing vitamin D forms and food sources
- Review the prevalence of inadequate vitamin D intakes in fortified food and non-fortified food consumers in Europe

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- Evaluate the availability of prepacked vitamin D-fortified products and vitamin D fortification

levels in Europe

2. Results

2.1. Main forms and bioavailability of vitamin D in the Europe diet, fortified and enriched foods, and supplements

Vitamins occur in the diet in a variety of related molecular forms that together contribute to the vitamin activity in the body. Vitamins in foods originating from animals are generally more bioavailable than vitamins originating from plants [8]. To correct for the differences in their bioavailability and their relative contribution to biological activity, regulatory authorities have established conversion factors relative to a reference form. The main forms of vitamin D traditionally considered in food composition data and for food labelling are cholecalciferol (vitamin D3) and ergocalciferol (vitamin D2); the term "vitamin D" referring to the sum of these two forms.

While vitamin D2 and vitamin D3 have long been considered the primary forms of vitamin D in supplements and fortified foods, recent research suggests that other forms of vitamin D may be more prevalent or have different biological effects than previously thought. Several analytical studies reported that the hydroxylated form of vitamin D3, 25(OH)D3 (calcifediol) is among the main forms present in the diet [9–12]. It can be found in animal source foods such as eggs, fish and fish oil, milk, cheese, meat, organs like liver [9–12]. Animals mainly obtain 25(OH)D3 from vitamin D3 or 25(OH)D3 added to their feed, or 25(OH)D3 produced from UVB exposure. Adding 25(OH)D3 to feed is allowed for ruminants, poultry and pigs in both EU and the United States. The use of added 25(OH)D3 for food is not reviewed for safety or registered so far. Fortification of feed can result in higher levels of 25(OH)D3 in meat, eggs, and milk, hence improving the total vitamin D content of foods generated from animals. Despite that 25-hydroxyvitamin D3 is widely present in the diet, only a few national dietary composition tables worldwide contain calcifediol as part of the three main forms of vitamin D in foods [13–15]. The 25(OH)D3 form of vitamin D has been approved as a novel food for use in food supplements in for instance the UK [16], Brazil [17], Australia [18], and EU [19] (Table 1).

The half-life of 25(OH)D2 is probably around 10 % shorter than that of 25(OH)D3 due to the vitamin D binding protein's slightly lower affinity for vitamin D2 metabolites than for vitamin D3 [20]. The vitamin D2 and D3 forms are currently treated as bioequivalent. However their relative bioavailability likely differs; vitamin D3 being more bioavailable compared to D2 in raising total serum 25(OH)D concentration [21]. In a recent review of studies with supplements and fortified foods, vitamin D2 was found to be not different from, or 0.4-fold to 0.8-fold less efficient than cholecalciferol, in increasing total serum 25(OH)D concentrations [22] (Table 1). The heterogeneity between the studies makes it difficult for authoritative bodies to establish a relative bioavailability conversion factor of vitamin D2 compared to D3 [23].

The 25(OH)D3 form of vitamin D is considered more bioavailable than the vitamin D3 form [24], since it's less hydrophobic and more soluble than vitamin D3, allowing easier absorption in the small intestine [25]. When added to milk, 25(OH)D3 was more effective at raising serum 25(OH)D levels than vitamin D3, with a 1.5-fold higher incremental area under the curve [26]. Volunteers consuming vitamin D3 and 25(OH)D3 enriched eggs had higher circulating 25(OH)D levels than those consuming control eggs [27] although the study did not allow for comparison of the two forms. Fortification of animal feed with 25(OH)D3 can also increase circulating 25(OH)D levels in the animal and the derived milk or eggs [28]. When taken as a supplement by healthy individuals, 25(OH)D3 increased total serum 25(OH)D concentrations by 3.2-fold as compared to vitamin D3 [29] (Table 1). The EFSA recently evaluated the bioavailability of 25(OH)D3 (calcifediol), establishing a conversion factor of 2.5 reflecting the higher relative bioavailability compared to vitamin D3 [30].

Table 1
Main vitamin D forms, food categories, dietary sources, and bioavailability relative to vitamin D3.

Vitamin D form	Food categories	Other dietary sources	Relative bioavailability vs. vitamin D3
Vitamin D3 (cholecalciferol)	Fish, meat, eggs, dairy	Fortified feed Fortified food Supplements	
Vitamin D2 (ergocalciferol)	UV-radiated fungi and yeast	Fortified food Supplements	In food and in supplements: lower bioavailability, heterogeneous data [22]
25(OH)-Vitamin D3 (calcifediol)	Fish, meat, eggs, dairy	Fortified feed: some species Fortified food: not registered Supplements [19]	In feed: higher bioavailability vs D3 [31] Food: ~2.5 higher bioavailability vs D3 [26] Supplements: ~3.2 higher bioavailability vs D3 [29] EFSA: 2.5 higher bioavailability vs D3 [30]

2.2. Food sources and vitamin D forms contributing to the average European diet's vitamin D intake

The second aim of this narrative review is to estimate the mean vitamin D intake from the average European diet, the relative contribution of the different food categories, and the relative contribution of three main forms of vitamin D (vitamin D2, D3 and 25(OH)D3). To that end, the chronic food consumption was analysed using the EFSA Comprehensive European Food Consumption Database Foodex2 [32]. Data were obtained at exposure hierarchy level (L4), i.e. food category sub-items, such as type of cheese. An average European diet was composed based on food consumption data of 25 countries. Food items consumed by $\geq$ 20 % consumers and food items consumed at $\geq$ 2 g were included to obtain a "representative" diet composed of 289 food items. The weighted average intakes of food items were calculated by multiplying the amount consumed with the percentage of consumers. The vitamin D composition of food items was estimated using the total vitamin D, vitamin D3, D2 and 25(OH)D3 composition of the closest matching food item in the Dutch Food Composition Database (NEVO) of 2023 [13]. Fat-based spreads were assumed to be all fortified with vitamin D, probably resulting in an overestimate of the total vitamin D consumption from the diet.

The mean total intake of vitamin D from an average European diet was estimated to be 3.2 μg/d when using no conversion factor for 25

Table 2
Dietary intake of vitamin D among Europeans (aged 18 + y) as total vitamin D, 25(OH)D3, vitamin D3 and D2, either or not corrected using a bioequivalence factor of 2.5–25(OH)D3.

	Conversion factor D3 → 25(OH)D3	Total vitamin D μg/d	Vitamin D3 μg/d	Vitamin D2 μg/d	25(OH) D3 μg/d
Vitamin D, μg	1	3.2	2.7	0.1	0.4
Vitamin D Equivalents, μg VDE	2.5	3.8	2.7	0.1	1.1
Relative vitamin D intake			**71 %**	**2 %**	**27 %**

(OH)D3 (Table 2). When using a conversion factor of 2.5 (as set by EFSA to correct for the higher bioequivalence of 25(OH)D3 compared to vitamin D3 [33]), the mean total intake was approximately 3.8 μg/d Vitamin D Equivalents (VDE). The estimated intake proportions of vitamin D3, vitamin D2 and 25(OH)D3, were 71 %, 2 %, and 27 %, respectively (Table 2).

Fig. 1 shows the daily contribution of total vitamin D and 25(OH)D3 (corrected for higher bioequivalence of 25(OH)D3) from the different food categories. Fortified fats and spreads contributed most to total vitamin D intakes, followed by egg, seafood, meat, and poultry, and fortified (alternative) milk products. Animal source foods such as meat and poultry (0.20 μg VDE/d), eggs, cold meat cuts and cheese constituted the main sources of 25(OH)D3 in the European diet.

2.3. *Evaluation of inadequate vitamin D intakes in fortified food and non-fortified food consumers in Europe*

The literature was reviewed for literature reporting on the percentage of the population not meeting the Estimated Average Requirement (EAR) or AI for vitamin D in European countries. The literature was systematically searched by using the following search string in PubMed: (vitamin D) AND (inadequate* OR adequate*) AND (EAR OR Adequate Intake) AND survey. We selected publications with data for Europe. The percentage of the population with intakes below the defined intake references is summarized in Table 3. The vitamin D reference value used as cut-off for inadequacy across the different surveys ranged from 2.5 to 15 μg/d. Preferably EAR values rather than AI values are used as a cut-point for assessing nutrient intakes of groups. If data on the prevalence of inadequate calcium intakes were reported, these were also reported in Table 3.

The majority (94–100 %) of the European population aged $\geq$ 13 years in Denmark, Czech Republic, Italy, France, Ireland, the Netherlands, Greece, and Portugal fails to meet the reference intake for vitamin D of 10 or 15 μg/d (Table 3). Other data from Denmark, Slovenia and Spain reported on proportions of the population below reference intakes for vitamin D of 2.5, 5 or 7.5 μg/d making it difficult to compare different studies.

The literature was also reviewed for studies reporting on the percentage of the population not meeting the reference intakes for vitamin D in European countries when consuming a base diet without and with fortified foods. To that end, the PubMed database was searched using the following search method: (vitamin D) AND (inadequate* OR adequate*) AND (EAR OR Adequate Intake) AND survey AND fortifi*.

The results are summarized in Table 4. Of the population in the UK [43] and the Netherlands [44] 99–100 % of vitamin D fortified food consumers, and 98–100 % of fortified food non-consumers failed to meet 10 μg/d of vitamin D. In both countries, vitamin D fortification barely reduced the prevalence of vitamin D intakes below 10 μg/d. The tolerable Upper intake Level (UL) was not exceeded by consumers of vitamin D-fortified foods in the UK [43], the Netherlands [44] and Belgium [45]. An example of vitamin D intake distribution among the total Dutch population is shown in Fig. 2.

2.4. *Availability of prepacked vitamin D-fortified food products in Europe*

The Mintel product database [46] was searched for vitamin D-fortified prepacked foods and beverages newly launched in all retail channels of the EFTA (EU, Norway, Iceland and Switzerland) and UK over the past 3 years. Infant nutrition, medicated confectionary, ready-to-use meals, and meal replacements were excluded from the search. A total number of 245,922 food and beverage products were launched of which 2'856 (1.2 %) were fortified with vitamin D (Table 5). The most frequently fortified products included margarines and plant-based alternative foods and drinks; 44 % of margarine & other blends, 28 % and 25 % of plant-based milk and yoghurts, respectively, and 27 % and 12 % of drinking yogurt and milk, respectively. Of meat alternatives, 0.1 % were fortified with vitamin D.

The mean (median) fortification level of vitamin D of the European retail products was 3.0 (1.3) μg/100 g or mL, and 1.9 (1.8) μg per serving, respectively (Table 5). All products contained less than 10 μg vitamin D per serving except for three juice shots that contained 20 μg per serving. About 1.5 % of prepacked food products contained more than 5 μg of vitamin D per serving. The majority of the products was fortified at a level of approximately 0.75 μg vitamin D per 100 g/mL, which represents the minimum of 15 % of the Recommended Daily Allowance of 5 μg set by the EU needed for a "source of vitamin D" claim front of pack [47].

3. Discussion

This narrative review examines the forms and bioavailability of vitamin D. In addition, the mean vitamin D intakes and main contributing forms and dietary sources in the European diet are evaluated. The proportion of fortified and non-fortified food users in European countries meeting vitamin D reference intakes is reviewed. Moreover, the availability and fortification levels of prepackaged vitamin D-fortified products in the European market are evaluated.

Vitamin D3 is more bioavailable than vitamin D2 but a conversion factor has not been established due to heterogeneity in the data. The bioavailability of 25(OH)D3 is higher than vitamin D3 which led to an EFSA-recognized conversion factor of 2.5. The addition of the more bioavailable 25(OH)D3 to animal feed currently provides an indirect pathway to enhance human vitamin D intake via animal products. Adding 25(OH)D3 to foods at controlled levels may also represent a strategy to enhance vitamin D intakes.

Due to limitations in analytical methods, the measurement of 25(OH)D3 in food and food databases has not been possible until now. Going forward, it is essential to expand food composition databases to include

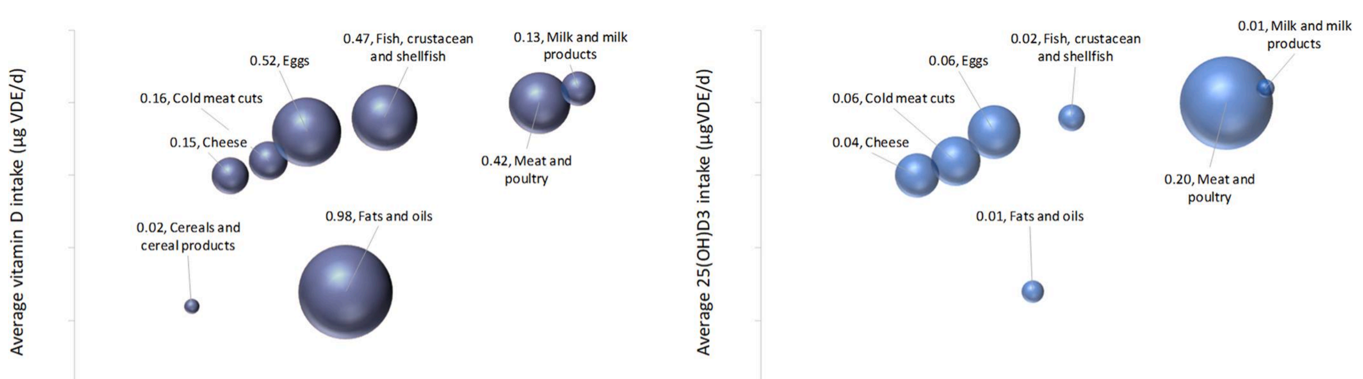

Fig. 1. Estimated mean total vitamin D and 25(OH)D3 intake (μg VDE/d) per food category in Europe.

Table 3
Percentage of the population with intakes below reference intakes for vitamin D and calcium.

Country	Survey-year	Age	Number n=	Vitamin D[a]% < 15 µg/d	Calcium[b]% < 860 (F)/750 (M) mg/d
Denmark [34]	The Danish National Survey on Diet and Physical Activity (DANSA) 2005–2008	18–75 y	2025	97 %	30 %
Czech Republic [34]	Czech National Food Consumption Survey 2003–2004 (SISP04)	18–90 y	1869	99 %	69 %
Italy [34]	Italian National Food Consumption Survey INRAN-SCAI 2005–2006	18–98 y	2831	99 %	57 %
France [34]	Individual and National Study on Food Consumption INCA−2 2006–2007	18–79 y	2624	99 %	38 %
Ireland [35]	National Teens' Food Survey II 2019–2020	13–18 y	428	94 %	67 %
				Vitamin D[c]% < 10 µg/d	**Calcium % < 860 (F)/750 (M) mg/d**
Czech Republic [36]	Study of Individual Food Consumption, SISP04 2002–2004	≥ 4 y	2590	95–100 %	
The Netherlands [37]	Dutch National Food Consumption Survey 2012–2016.	18–79		99.4 % (M)(NU)[d] 100 % (F)(NU) 98.6 % (M)(U) 99.2 % (F)(U)	
		18–24			41 % (M)(NU) 64.4 % (F)(NU) 27.1 % (M)(U) 48.7 % (F)(U)
		25–69 25–49			17.9 % (M)(NU) 32.4 % (F)(NU) 11 % (M)(U) 22 % (F)(U)
Greece [38]	Hellenic National Nutrition and Health Survey (HNNHS) 2013–2015	≥ 19 y	907	100 %	
Portugal [39]	The Portuguese National Food, Nutrition and Physical Activity Survey 2015–2016	18–75 y	3272	94 %	
				Vitamin D % < 7.5 µg/d	
Denmark [40]	The Danish National Survey of Dietary Habits and Physical Activity (DANSDA) 2011–13	18–50 y F	855	88 % (F)	
				Vitamin D % < 4 µg/d	**Calcium % < 800 mg/d**
Spain [41]	Anthropometry, Intake and Energy Balance (ANIBES study)	9–75 y	2009	94 %	76 %
				Vitamin D % < 2.5 µg/d	
Slovenia [42]	Slovenian national food consumption survey (SI.Menu study) 2017–2018	10–17 y	468	55 %	
		18–64 y	364	46 %	
		65–74 y	416	61 %	

[a] AI for vitamin D (EFSA),
[b] EAR for calcium: 860 mg for adults aged 18–24 y. EAR: 750 mg for females (F) 25–50 y and males (M) 25–70 y old.
[c] EAR for vitamin D
[d] Non-users (NU) and users (U) of fortified foods.

the 25(OH)D3 form and harmonize regulatory approaches to incorporate this form as well.

The unique availability of vitamin D3, D2 and 25(OH)D3 amounts in different foods in the Dutch food composition tables together with the food consumption data from the EFSA database allowed to estimate European dietary intakes for all three vitamin D forms. The accuracy was limited by assumptions made to match European foods with the foods in the Dutch composition tables and the assumption that all fat-based spreads are fortified with vitamin D, which may not accurately reflect food compositions in other European countries. Moreover, excluding foods consumed by less than 20 % of the population may have further reduced accuracy. The estimated European diet included enriched and fortified foods providing approximately 3.2 µg/d and 3.8 µg/d of total vitamin D when, respectively, not accounting and accounting for the ~2.5-fold higher bioequivalence of 25(OH)D3 [33]. This is significantly lower than the 10 µg/d commonly used as a reference intake by various countries [2]. The 25(OH)D3 and vitamin D3 forms contributed approximately one-third and two-third, respectively, to the total intake of Vitamin D Equivalents (VDE), while vitamin D2 contributed negligibly. A recent dietary analysis of the Danish diet similarly showed that mean daily intakes of vitamin D3 and 25(OH)D3, were 0.52 and 2.29 µg/d, respectively, while vitamin D2 intake was negligible [10]. When applying a conversion factor of 2.5–25(OH)D3 in this study [33], the mean intake of 25(OH)D3 and vitamin D3 were 1.3 (36 %) and 2.3 µg/d (64 %), respectively.

This analysis found that fortified fats and spreads contributed most to daily total intakes of total vitamin D equivalents, followed by animal foods such as eggs, fish, meat and fortified (alternative) milk products. Recent food analyses have accordingly shown that animal source foods contain significant amounts of the vitamin D25(OH)D3 form [9–12]. Animal source foods were the main contributors to the daily intake of the 25(OH)D3 form. This suggests that eliminating animal products from the diet can further compromise vitamin D intakes, especially in the absence of vitamin D-fortified food products.

This narrative review of vitamin D intake distributions suggests that 94–100 % of the Europeans aged 13 y fail to meet an intake of 10 µg/d. The EFSA Panel, based on evaluation of dietary intake data, also concluded that intakes of around 16 µg/day from food alone (i.e. somewhat higher than the AI) were only achieved in high consumers (95th percentile) [6]. Two national surveys from the UK [43] and the

Table 4
Percentage of the population consuming a base diet with or without fortified foods with intakes below the national reference intake for vitamin D and above the UL.

Country	Age	Number of participants	% < 10 μg/d vitamin D		% > 50 (<10 y) or 100 (≥10 y) μg/d vitamin D	
			Non-users of fortified foods	Users of fortified foods	Non-users of fortified foods	Users of fortified foods
Netherlands [44]	< 2 y	51	100 %	90.3 %	0.0 %	0.0 %
	2–5 y	188	99.9 %	98.8 %	0.0 %	0.0 %
	6–9 y	215	100 %	100 %	0.0 %	0.0 %
	M 10–13 y	119	99.7 %	99.7 %	0.0 %	0.0 %
	F 10–13 y	104	100 %	100 %	0.0 %	0.0 %
	M 14–17 y	100	99.5 %	98.9 %	0.0 %	0.0 %
	F14–17 y	90	99.5 %	99.5 %	0.0 %	0.0 %
	M 18–69 y	1549	98.9 %	97.8 %	0.0 %	0.0 %
	F 18–69 y	1551	99.1 %	98.6 %	0.0 %	0.0 %
	M 70 + y	166	100 %	100 %	0.0 %	0.0 %
	F 70 + y	179	100 %	100 %	0.0 %	0.0 %
UK [43]	≤ 18 y	1258	99.6 %	99 %	0.0 %	0.0 %
	≥ 19 y	1288	99 %	99 %	0.0 %	0.0 %
Belgium [45]	3–6 y	3200			0.0 % (M/F)	0.0 % (M/F)
	7–10 y				0.0 %	0.0 %
	11–14 y				0.0 %	0.0 %
	15–17 y				0.0 %	0.0 %
	18–39 y				0.0 %	0.0 %
	40–64 y				0.0 %	0.0 %

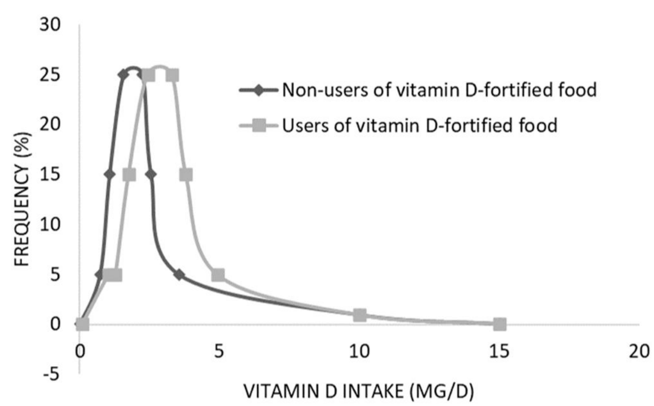

Fig. 2. Distribution of vitamin D intake in Dutch users and non-users of fortified foods.

Netherlands [44] reporting on adult non-consumers and consumers of vitamin D-fortified foods, showed that voluntary vitamin D fortification barely reduced the percentage of the population with intakes below 10 μg/d. In conjunction with relatively low calcium intakes [6], this may be a concern. Despite a 43 % increase in vitamin D intake from fortified foods in the Netherlands, only 1 % of fortified food consumers met the EAR of 10 μg/d, indicating that this target is difficult to achieve through diet alone [37]. Even in the US where vitamin D fortification is widespread, 100 % remain below the EAR of 10 μg/d when relying only on the diet, and 93 % when also consuming fortified foods [48]. To remove the complexity of the factor of sun exposure, most recommendations including those by EFSA [2] assume limited sun exposure, which for those with more sun exposure, could lead to an overestimate of vitamin D needs.

The risk of vitamin D exceeding the UL due to fortification seems low as demonstrated by this narrative review. Also broader safety data from 20 observational studies and 61,082 observations across the European populations show that the prevalence of high 25(OH)D (>125 nmol/L) from all dietary sources was found to be < 0.3 % and there was no indication of adverse effects [49]. Also the EFSA panel considered the

Table 5
Median and mean vitamin D fortification level of the European retail products.

Category	Count of fortified	% Of category fortified	Mean vitamin D μg/100 g	Median vitamin D μg/100 g	Mean vitamin D μg/serving	Median vitamin D μg/serving
Bakery	64	0.2 %	2.3	1.5	1.1	0.8
Breakfast Cereals	475	9.2 %	4.8	4.0	1.5	1.3
Carbonated Soft Drinks	16	0.4 %	1.1	1.0	3.8	3.6
Chocolate Confectionery	3	0.0 %	2.3	2.3	0.8	0.8
Dairy	1667	6.6 %	2.2	0.9	1.9	1.8
Desserts & Ice Cream	84	0.9 %	1.4	0.9	1.3	0.9
Fruit & Vegetables	1	0.0 %	1.0	1.0	0.5	0.5
Hot Beverages	20	0.2 %	4.8	3.3	1.0	0.8
Juice Drinks	138	2.3 %	1.9	0.8	2.4	1.8
Nutritional Drinks & Other Beverages	70	3.6 %	6.9	6.3	0.7	0.6
Processed Fish, Meat & Egg Products	9	0.0 %	2.8	2.4	2.4	2.3
RTDs	20	1.2 %	0.9	0.8	2.1	1.9
Sauces & Seasonings	35	0.1 %	14.0	6.8	2.0	1.0
Savoury Spreads	1	0.0 %	9.5	9.5	1.4	1.4
Snacks	122	0.6 %	4.8	2.8	1.9	1.1
Soup	27	1.2 %	3.4	4.0	2.2	1.8
Sports & Energy Drinks	56	4.0 %	2.4	1.0	3.6	2.8
Sugar & Gum Confectionery	1	0.0 %	2.0	2.0	1.6	1.6
Sweet Spreads	5	0.1 %	12.9	7.5	3.4	2.3
Water	42	2.8 %	0.8	0.5	2.3	1.6
Grand Total	2'856	**1.2 %**	3.0	1.3	1.9	1.8

risk of exceeding the UL for vitamin D unlikely, except for regular users of food supplements containing high amounts [30].

Several reports have analysed the fortification levels in food. For instance in the UK, the levels of vitamin D fortification per 100 g, analyzed from supermarket data, were highest in margarines and fat spreads followed by breakfast cereals and dried and evaporated milk and plant-based drinks [50]. As far as we know, the contribution of vitamin D-fortified prepackaged food per serving has not been assessed. This is relevant because concentrations do not account for differences in the quantities of food products consumed, not allowing for comparisons between smaller and larger amounts. The current evaluation of the prepacked food and beverage products launched in EFTA and UK over the past 3 years shows that 1.2 % of the products is fortified with vitamin D at a median level of 1.3 μg/100 g and 1.8 μg/serving. Most of the products are fortified at 0.75 μg vitamin D per 100 g/mL, the least amount set by the EU needed for a "source of vitamin D" front of pack claim, i.e. 15 % of the EU Recommended Daily Allowance of 5 μg for package labelling [47]. The main packaged food contributors to vitamin D intake included fortified fats and spreads, fortified plant-based milk and yoghurts and fortified drinking yogurts. The current availability and fortification levels of voluntary fortified foods suggest a low risk of chronically exceeding the UL.

Our review suggests that 25(OH)D3 in animal source foods provides a substantial contribution to total vitamin D intakes in Europe, especially when correcting for its higher bioequivalence. Although the current narrative review has several limitations, the findings suggest that most Europeans have low vitamin D consumption despite fortification. Even though vitamin D-fortified foods significantly contribute to increasing mean vitamin D intakes, they do not increase the proportion of individuals with intakes above 10 μg/d. This is due to the large gap between actual and adequate intake amounts as well as the low proportion of food products in the market fortified with vitamin D. The UL for vitamin D is unlikely to be exceeded by vitamin D-fortified foods as supported by other reviews. Encouraging fortification could help bridge the gap between current and recommended vitamin D intakes if implemented more widely and monitored properly. Future assessments of the quantitative health risks of excessive vitamin D intakes balanced against inadequate intakes may help forming evidence-based guidelines and policies ensuring optimal health outcomes for the population.

CRediT authorship contribution statement

Maaike Bruins: Conceptualization, Methodology, Software, Data curation, Writing – Original draft preparation, Visualization, Investigation, Writing – Reviewing and Editing.

Declaration of Competing Interest

Maaike J Bruins is employed by Taste Texture and Health a manufacturer of nutritional solutions including vitamins to the food industry.

Data availability

Data will be made available on request.

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