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Highlights

- The National Adult Nutrition Survey food composition database was updated to current vitamin D food concentrations.
- Vitamin D intakes and patterns of intake of older adults in Ireland were estimated.
- Fortifying milk or bread would increase the proportion of older adults meeting Vitamin D recommendations to ~30% when milk is fortified and ~55% when bread is fortified.
- Fortifying milk and bread simultaneously would result in ~70% of older adults meeting recommendations.
- Fortifying foods with vitamin D is safe and would improve the vitamin D intakes of older adults.

Efficacy and safety of food fortification to improve Vitamin D intakes of older adults.

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Abstract

Objective: The aim of this study is to determine the best foods for potential Vitamin D food fortification and to model the efficacy and safety of different food fortification scenarios in adults aged 50+ years in Ireland.

Research Methods & Procedures: National Adult Nutrition Survey Vitamin D data for participants aged 50+ years was updated. Vitamin D from foods with natural and added Vitamin D was estimated and daily Vitamin D intake patterns were examined. Data modelling was used to estimate the impact of target food fortification scenarios.

Results: Almost two thirds of the mean daily Vitamin D intake of adults aged 50+ years (7±7µg) comes from foods with added Vitamin D. Milks and breads are the most frequently consumed foods across all meals and were subsequently targeted for the data modelling exercise. Results from the data modelling show that Vitamin D intakes increased between 9-17µg daily, depending on the fortification scenario. Fortifying milk or bread resulted in ~30% or ~55% of individuals meeting the RDA; however fortifying both simultaneously resulted in ~70% meeting the RDA.

Conclusion(s): Currently the majority of older Irish adults are not meeting dietary recommendations for Vitamin D. Fortification of commonly consumed foods such as milk and bread could improve daily intakes such that ~70% of the cohort would meet the minimum recommendation. Future research should examine the efficacy of different food fortification scenarios to improve Vitamin D intakes for older Irish adults.

Key words

Vitamin D, older adults, natural Vitamin D, foods with added Vitamin D, food fortification.

Abbreviations

25(OH)D = 25-hydroxy-Vitamin D

IOM= Institute of Medicine

UVB= ultraviolet B

TUL= Tolerable upper level

NANS= National Adult Nutrition Survey

IUNA= Irish Universities Nutrition Alliance

CoFID= The Composition of Foods Integrated Dataset

MDI= Mean daily intake

EFSA= European food safety authority

RDA= Recommended daily intake

BMI= body mass index

Introduction

Vitamin D is a fat soluble nutrient essential for calcium homeostasis (1). Vitamin D status is measured by the metabolite 25-hydroxy-Vitamin D (25(OH)D) and the Institute of Medicine (IOM) define 25(OH)D concentrations of <50nmol/L as insufficient and <37.5nmol/L as deficient (2). Vitamin D can be synthesised in the skin on exposure to sunlight; however, synthesis is limited at northerly latitudes due to low ultraviolet B (UVB) exposure. For this reason, a large proportion of people in northern European countries, including Ireland, have insufficient circulating 25(OH)D (3-6). Vitamin D can also be consumed in foods, and dietary sources are critical in certain populations where skin synthesis does not meet physiological needs (4-6). However, dietary Vitamin D is also a concern as there are only a few foods that contain natural Vitamin D such as oily fish, egg yolk and meat. Other foods like milk and breakfast cereals that contain little or no natural Vitamin D can be fortified to improve intakes. Evidence from research suggests that fortified foods are important dietary sources of Vitamin D and therefore contribute to improved Vitamin D-related health outcomes (7).

Data modelling studies determine the most suitable foods for fortification and the impact of these fortified foods on Vitamin D intakes (8-11). One of the best examples of an effective data modelling study is described by Hirvonen and colleagues who reported a potential increase in Vitamin D intakes (17.4μg/day) when modelling Finnish food intake data (12). This research was used as the foundation to change policy in Finland to increase the recommended Vitamin D fortification amount to 1μg Vitamin D_3/100 mL of liquid dairy and 20μg Vitamin D_3/100g of fat spreads (13). A similar study in Denmark reported an increase in Vitamin D intakes of ~20.0μg/day when fortified foods were added to the foods adults usually eat (14). However, no data modelling studies have specifically targeted older adults. Fortifying commonly consumed foods may be a suitable strategy for improving Vitamin D intakes for older adults as it requires little change to the foods that older adults usually eat and is cost effective for preventing deficiency (15). Introducing natural sources of Vitamin D, like oily fish, to non-consumers would be challenging given the known barriers to dietary change in later life (16). Therefore, this study will estimate intakes and food sources of Vitamin D for older adults in Ireland, having updated food contents to current concentrations. After reporting Vitamin D intakes, this study will estimate the potential effect of food fortification scenarios to improve Vitamin D intake for this population group.

Materials and Methods

Study Population

Participants aged 50+ years (referred to as "older adults" in this manuscript) were selected from the National Adult Nutrition Survey (NANS) database. NANS is a cross-sectional survey carried out between 2008 and 2010 in the Republic of Ireland (IUNA, https://www.iuna.net/). The University College Cork Clinical Research Ethics Committee of the Cork Teaching Hospitals and the Human Ethics Research Committee of University College Dublin provided ethical approval. All participants provided written consent in accordance with the Declaration of Helsinki. Details of the study design, participant selection, recruitment and data collection are reported elsewhere (17, 18). Participants were representative of the Irish population in terms of age, sex, location and social class. Food and drink intake was estimated using a 4-day semi-weighed food diary, which included one weekend day. Every food, beverage and supplement consumed was recorded, including brand names, recipes, cooking methods and leftovers. Nutrient intakes were estimated using WISP version 3.0 (Tinuviel Software, Anglesey, UK).

Food Composition Database

A Food Composition Database was developed as part of NANS 2008-2010 (IUNA, https://www.iuna.net/). The Vitamin D_2 (ergocalciferol) and Vitamin D_3 (cholecalciferol) content of each food (referred to as "Vitamin D" in this manuscript) was updated per 100g based on current food composition data, guided by a protocol (Figure 1). Supermarket websites were used to update packaged foods (Tesco Ireland and Supervalu Ireland). Supermarket websites contain nutritional information from food packaging. According to EU directive 90/496/EEC, food packaging nutritional information is based on manufacturer's analysis or food composition data. If packaging data was not available the Composition of Foods Integrated Dataset (CoFID) was used to update the Vitamin D content of the food. CoFID was also used where brand names were not provided or if there was insufficient detail describing the type of food consumed. For example, when fresh salmon was consumed the CoFID code for farmed salmon was used for all entries. The Vitamin D content of each eating occasion was then estimated. Foods with added Vitamin D were those with Vitamin D in the ingredient list (EU Regulation 1925/2006). When foods with added Vitamin D also contained natural Vitamin D, the natural Vitamin D content of the generic food from CoFID was subtracted from the total Vitamin D on the packaging to estimate the added content. The Vitamin D content of the individual components of recipes were updated and then summed to estimate the total Vitamin D content. All calculations for the current analysis were completed using IBM SPSS Statistics, Version 24 (Armonk, NY: IBM Corp.).

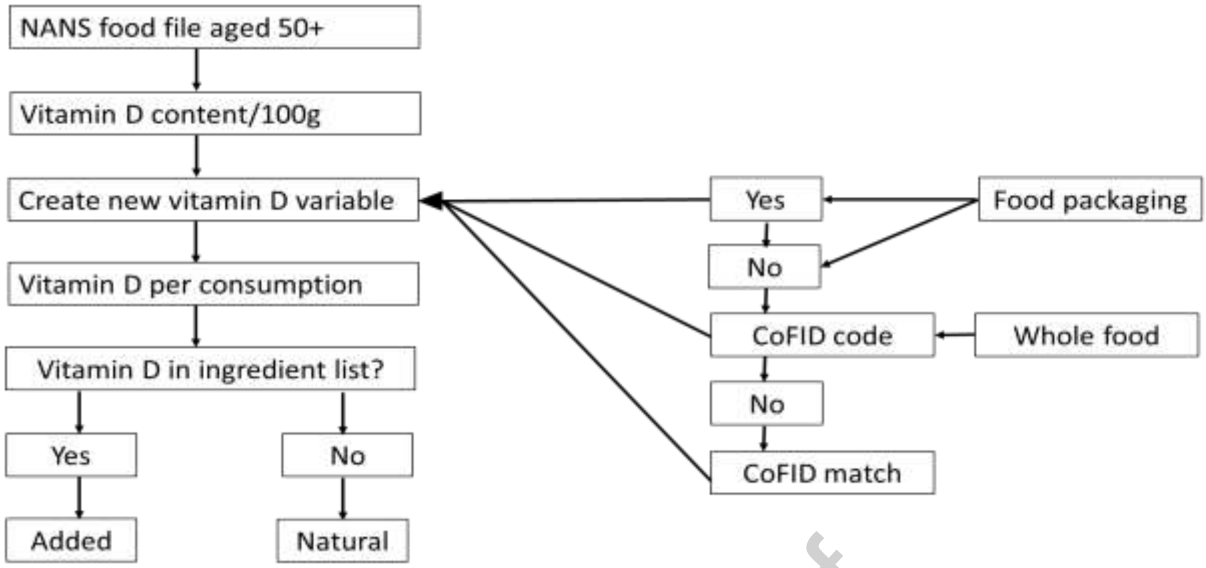

Figure 1. Flow chart describing the updating process for foods in the NANS food file.

Vitamin D Consumption Patterns

Mean daily total Vitamin D intake was estimated as well as contribution of foods with natural and added Vitamin D. Mean daily intakes (MDI) were compared to Vitamin D recommendations worldwide (Irish, UK, EFSA and IOM). The number of participants exceeding the Tolerable Upper Limit (TUL) (100µg) and MDI of total, natural and added Vitamin D from each food group was estimated. The mean daily frequency for food groups was determined by estimating frequency of consumption per person and estimating the mean frequency for the population, informing targeted food groups for modelling (i.e. those with a high frequency of consumption but low mean daily Vitamin D). MDI of Vitamin D from food groups was also estimated for weekdays and weekend days and for different types of meals.

Data Modelling

Cow's milk (referred to as "milk" in this manuscript) and breads were selected for Vitamin D_3 fortification. Selection was based on food group intake frequencies; 95% of the population consume cow's milk and 99% consume bread. Fortification of milk and bread are also likely to result in low implementation barriers as they are already fortified in Ireland at a voluntary level (15). Scenarios 1 and 2 for milk and bread ensured safety at population level, and scenarios 3-5 are based on current consumptions (Table 1). Milk was fortified with 1.5µg/100mL, with the exception of "super-milks", which were fortified at 2.5µg/100mL.

Supplementation of 10µg was selected as this is the current RDA in Ireland (19). The modelling was performed in IBM SPSS Statistics, Version 24 (Armonk, NY: IBM Corp.). Current consumptions were updated using the following equation: (food weight (g) /100) (Vitamin D content of strategy food/100g). Total Vitamin D intake, the contribution of foods with added and natural Vitamin D and the minimum and maximum intake for each scenario was estimated. Percentage meeting the RDA in Ireland (10µg) and IOM RDAs (15µg <70 years and 20µg >70 years) was estimated to determine intake adequacy.

Table 1. Outline of scenarios for data modelling.

Milk	
Scenario 1	Remove current intakes and add a single daily portion of fortified milk for each individual.
Scenario 2	Add a single daily portion of fortified milk for each individual.
Scenario 3	Substitute current intakes with milk at the proposed fortification level
Scenario 4	Substitute current intakes with milk at the proposed fortification level and add a 5µg supplement for non-consumers.
Scenario 5	Substitute current intakes with milk at the proposed fortification level and add a 10µg supplement for non-consumers.
Bread	
Scenario 1	Remove current intakes and add a single daily portion of fortified bread for each individual.
Scenario 2	Add a single daily portion of fortified bread for each individual.
Scenario 3	Substitute current intakes with bread at the proposed fortification level
Scenario 4	Substitute current intakes with bread at the proposed fortification level and add a 5µg supplement for non-consumers.
Scenario 5	Substitute current intakes with bread at the proposed fortification level and add a 10µg supplement for non-consumers.
Supplements	
Scenario 1	Add 5µg supplement for non-consumers.
Scenario 2	Add 10µg supplement for non-consumers.
Scenario 3	Add 5µg supplement for each individual.
Scenario 4	Add 10µg supplement for each individual.

Milk+Bread	Milk scenario 3 and bread scenario 3 combined.

Statistical Analysis

Statistical analysis was performed in IBM SPSS Statistics, Version 24 (Armonk, NY: IBM Corp.). Normality tests were run using Shapiro-Wilks testing ($p \leq 0.05$) and histograms inspected. Outliers were inspected via boxplots but were not removed. Variables were log-transformed to normality. Descriptive statistics for population demographics were calculated and are presented as mean and standard deviation (SD). P-values for differences in demographics between men and women were calculated using independent t-tests for continuous data and chi-square tests for categorical data. One way repeated measures Analysis of Variance (ANOVA) and post-hoc pairwise comparisons were performed to compare individual differences in MDI across days and meals. MDI were compared between male and females using general linear model (GLM) analysis of covariance, adjusting for age, gender and body mass index (BMI).

Results

Study Population

In total, 557 NANS participants aged 50+ years were included in this study; 49% were males and 51% were females (Table 2). Mean BMI was 29kg/m^2 (±5kg/m^2).

Table 2. Subject characteristics

	All (n=557)		Males (n=271)		Females (n=286)		p value
	Mean	SD	Mean	SD	Mean	SD	
Age (years)	63	9	63	9	63	9	0.23
Weight (kg)	79	17	87	15	72	15	<0.001
Height (m)	1.7	0.1	1.7	0.1	1.6	0.1	<0.001
BMI (kg/m^2)	29	5	29	5	28	6	0.006
Body Fat (%)	33	8	28	6	37	7	<0.001
Fat Mass (kg)	26	10	26	10	27	10	0.01
	n	**%**	**n**	**%**	**n**	**%**	
Smoking status							0.55
Current	66	12	30	11	36	13	
Previous	206	38	106	40	100	36	
Never	272	50	128	49	144	51	

Sun Exposure							0.09
Rarely	198	37	84	32	114	41	
Sometimes	244	45	128	49	116	42	
Often	101	19	52	20	49	18	

Continuous data presented as mean ± SD. Categorical data presented as n and %.
Chi-square statistics and t-tests were used to explore differences between males and females.
P-value <0.05 is considered statistically significant.

Vitamin D Intakes

There were no non-consumers of Vitamin D. The MDI of Vitamin D was 7µg (±7µg). Foods with natural vitamin D accounted for 3µg (±3µg) and foods with added Vitamin D accounted for 4µg (±7µg). Fifty-five percent of foods were foods with natural Vitamin D, 42% were foods with added Vitamin D and 3% contained both. There was no difference between the MDI of Vitamin D for men and women (p=0.24). Nineteen percent of participants met the Irish RDA (10µg), 10% met the EFSA AI and IOM <70 years RDA ad 6% met the IOM >70years RDA. No participants exceeded the 100µg TUL.

Vitamin D Consumption Patterns

The 5 food groups that contributed most to MDI and mean daily frequency are presented in Figure 2. “Nutritional supplements” accounted for the largest MDI of Vitamin D (34%). “Fish and fish products”, “Low fat, skimmed and fortified milks”, “Egg and egg dishes” and “Low fat spreads”, provided 16%, 8%, 7% and 6% of MDI of Vitamin D (µg). Of the top 5 foods, “Low fat, skimmed and fortified milks” were consumed most frequently, whereas “Fish and fish products” were consumed less frequently; but contributed a MDI of 1µg (±3µg) (Figure 2). Figure 3 separates foods into natural sources and foods with added Vitamin D, according to the highest contributing food group. “Fish and fish products”, “Eggs and egg dishes”, “Beef and veal”, “Sausages” and “Bacon and ham” accounted for 77% of natural Vitamin D. “Nutritional supplements”, “Low fat, skimmed and fortified milks”, “Low fat spreads”, “Ready to eat breakfast cereals” and “Other fat spreads” accounted for 93% of foods with added Vitamin D. The mean daily frequency of all food groups were assessed across meals, including breakfast, light meals, mean meals and snacks, to inform the modelling scenarios. Cow’s milk and bread food groups were most frequently consumed across all meals so were targeted for fortification modelling.

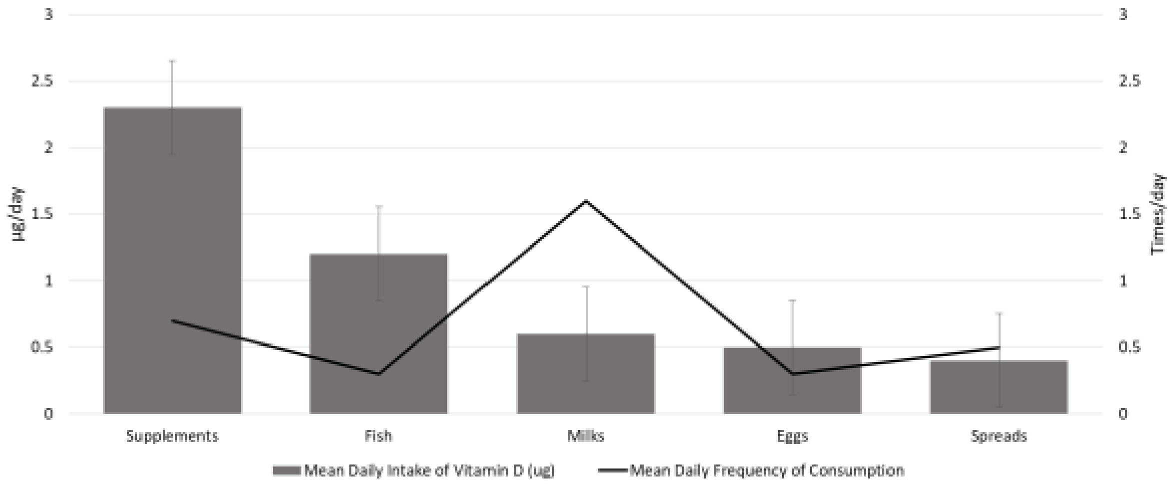

Figure 2. The top 5 largest contributing food groups to mean daily Vitamin D intakes (µg) (bars) and their mean daily frequency (line).
Standard error of the mean is presented as error bars.

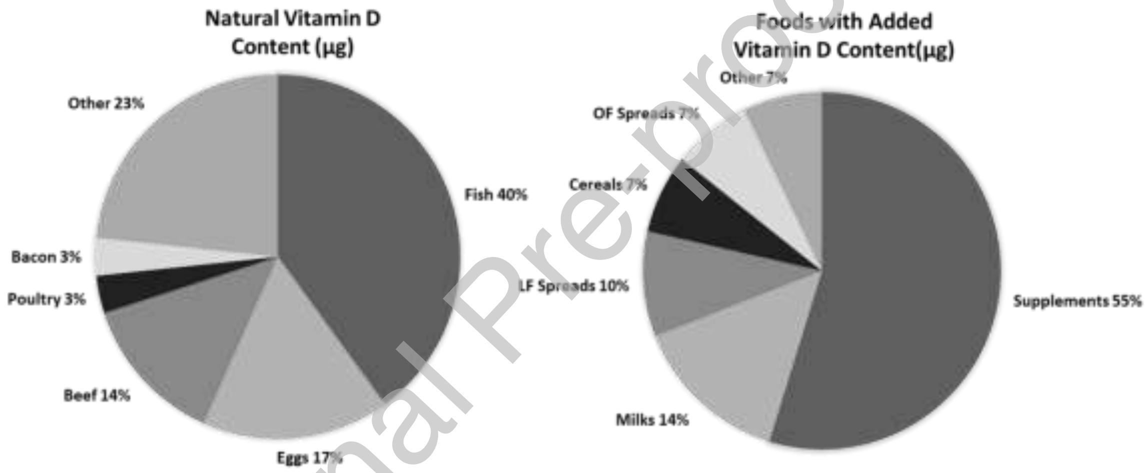

Figure 3. Food sources of natural vitamin D and foods with added Vitamin D.
Milks= Low fat, skimmed and fortified milks; LF Spreads= Low fat spreads, OF Spreads= other fat spreads, Other= All remaining food groups.

Data Modelling

The MDI of each scenario is presented in Table 3. The MDI for 9 of the 14 scenarios exceeded the RDA in Ireland of 10µg. No participants exceeded the TUL (100µg) in any scenario. The scenario with the highest population MDI was supplement scenario 4 (17 ±7.µg), and the lowest was supplement scenario 1 (7 ±7µg). The scenario with the most participants meeting the RDA in Ireland was supplement scenario 4 (100%) and the lowest was supplement scenario 2 (22%). Milk scenarios increased the MDI to 10-11µg, with 30-35% of the population meeting the RDA (10µg). Bread scenarios increased the MDI to 10-16µg, with 33-84% of the population meeting the RDA (10µg). However, if both products were fortified simultaneously assuming the current intakes of both food groups (scenario 3) the MDI would be 15µg, with 96% consuming more than 5µg of Vitamin D, 71% of the population meeting the RDA (10µg) and 21% meeting the IOM RDA (20 µg).

Table 3. Modelling of Vitamin D intakes and proportion of population meeting recommendations.

	MDI (µg)	Min (µg)	Max (µg)	*RDA in Ireland (%)	*IOM RDA (< 70y) (%)	*IOM RDA (≥70y) (%)
Milk						
Scenario 1	10	4	73	31	15	8
Scenario 2	11	4	73	35	17	9
Scenario 3	9	1	73	31	14	7
Scenario 4	9	1	73	32	15	15
Scenario 5	10	1	73	36	16	9
Bread						
Scenario 1	10	4	73	33	16	7
Scenario 2	16	4	79	84	46	23
Scenario 3	13	1	75	56	29	15
Scenario 4	13	2	75	56	28	15
Scenario 5	13	2	75	57	28	15
Supplement						
Scenario 1	7	0	69	22	10	8
Scenario 2	12	0	69	67	22	8
Scenario 3	2	5	74	44	19	10
Scenario 4	17	10	80	100	44	20
Milk+bread	15	1	78	71	41	20

MDI= Mean daily intake; Min= Minimum mean daily intake; Max= Maximum mean daily intake; RDA=Recommended Daily Allowance; IOM= Institute of Medicine.
*Percentage meeting recommendation calculated using individual method.

Discussion

This study used data from the NANS, which was nationally representative at data collection (2008-2010). Vitamin D_2 and D_3 contents of foods were updated and foods were recoded to foods with natural and added Vitamin D. Vitamin D intakes of older adults in the cohort were updated. The updated intakes showed no change in total Vitamin D MDI; however, there was a shift to a higher proportion of MDI from foods with added compared to natural Vitamin D. Bread and milk were frequently consumed and were selected for fortification with Vitamin D_3. Five fortification scenarios for milk and bread and 4 supplementation scenarios were modelled; as well as a combined milk and bread scenario. Each scenario assessed the adequacy and safety of increasing Vitamin D intakes. No individual would reach the TUL for Vitamin D (100µg), therefore all scenarios are safe. Mandatory Vitamin D supplementation or fortified bread scenarios would be the most effective at increasing intakes of Vitamin D in this cohort. The combined approach resulted in 71% of the study cohort meeting the RDA in Ireland.

The updated food composition database did not change the MDI of Vitamin D of older adults in Ireland. Despite this, the proportion of Vitamin D from foods with added Vitamin D increased, suggesting a change in the number of Vitamin D fortified foods available or an increase in the amount of Vitamin D added to foods. The updated MDI (7µg) remains below the RDA (10µg) (19). In total, 19% of this cohort were meeting the RDA; however, only 10% of adults 50-70 years and 6% of those >70 years were meeting the IOM RDAs. Globally, Vitamin D intakes are low, with studies from the UK and Australia reporting Vitamin D intakes in the range of 3.5-5.7µg/day for older adults, and less than 10% of the Australian cohort are meeting IOM recommendations (20, 21). Although MDIs are higher in the US than in Ireland (7.8-8.1µg); more than 70% are not meeting IOM recommendations (22). The high proportions of older adults not meeting recommendations is a public health concern. Furthermore, there are suggestions in the literature that current vitamin D intake recommendations were underestimated and should be revised upwards to maintain adequate serum 25(OH)D concentrations which would exacerbate the current situation (23, 24). Low Vitamin D status in older adults is associated with an increased risk of osteoporosis, higher rates of falls and bone fractures, and poor metabolic health (25, 26). Recent changes to the healthy eating guidelines in Ireland and the UK have emphasised the importance of Vitamin D and recommend supplementation when dietary intakes are low (19, 27). However, translating public health messages into behaviour changes is difficult, particularly when targeting subgroups of the population. A recent literature review reported low knowledge regarding Vitamin D health effects and dietary sources in older adult cohorts (16). Furthermore, improved knowledge of health effects and dietary sources does not always correlate with associated behaviours (16). Therefore policy changes or interventions must consider older adult preferences and ways to make it easy for older adults to adopt the behaviours required to improve Vitamin D status.

All fortification scenarios would increase the MDI, and no participants would exceed the TUL in any scenario. The entire population consuming a 10µg supplement daily (supplement scenario 4) would be most successful, with a MDI of 17µg. However, food fortification removes the need for behaviour changes associated with the introduction of a supplement or new foods (28). The most effective food based scenario would be the entire population consuming an additional 2 slices of fortified bread as well as their normal diet (bread scenario 2), which would increase the MDI to 17µg, but this would increase total energy intake. Thus, replacing bread with a fortified product and providing a 10µg supplement to non-bread-consumers (bread scenario 5) would be more appropriate, increasing MDI to 13µg. Despite the increased MDI, only 55% of the cohort would meet the RDA and only 15-28% would meet IOM recommendations with scenario 5. Other studies have examined the effect of Vitamin D fortified bread on Vitamin D status using an interventional approach. For example, two studies reported increased 25(OH)D concentrations for families and older adults consuming Vitamin D fortified bread compared to placebo bread (29, 30). Furthermore, two other studies reported no significant difference in the change in 25(OH)D when participants consumed Vitamin D fortified bread compared to a Vitamin D supplement (31, 32). However, it is important to note that in all cases, bread was fortified with Vitamin D_3 rather than D_2 as other research shows poor bioavailability of D_2 from bread fortified with Vitamin D from UVB-irradiated yeast (33).

Milk scenarios would also improve intakes, increasing the MDI to 10-11µg and the proportion meeting the RDA to ~31-35%. Another data modelling study using an Irish pre-school cohort, reported an increase of ~2-4µg in the daily intake of vitamin D when cow's milk was fortified with 1-2µg/100mL (34). The effects of milk fortification on Vitamin D status are also supported as effective interventions by other evidence and consequently countries including Canada and Finland have developed policies to support mandatory fortification of fluid milks with Vitamin D (13, 35). An intervention study examining the effects of a Vitamin D fortified milk (5µg) over a 16 week period reported an increase of 8.9nmol/L in 25(OH)D concentrations (36). Similarly, another study with a Vitamin D fortified milk (15µg) reported an increase of 7.6nmol/L in 25(OH)D concentrations after 12 months (37). In both studies, the participants were Vitamin D sufficient at baseline; thus, greater increases may be observed in Vitamin D insufficient cohorts. Similar to bread, there is data supporting milk fortification in older adults with evidence from both data modelling and human studies (38, 39).

The results of this study show that despite increased MDIs with milk or bread fortification, there would still be a large proportion of the population not meeting recommendations. Hence, this study also examined the impact of fortifying both milk and bread together (milk and bread scenario 3 combined). This scenario would result in an MDI of 16μg, with 96% consuming >5μg of Vitamin D and 71% consuming more than the 10μg RDA. Similar results were reported in an Australian cohort when milk and breakfast cereals were fortified simultaneously compared to in isolation (21). In support of these findings, Hirvonen and colleagues reported that it was safer and more efficient to fortify a range of foods together at a lower dose, rather than fortifying single foods at a higher dose (12). In contrast, a recent UK study concluded that fortifying flour alone at a higher dose (10μg/100g), was more successful at improving Vitamin D intakes than fortifying flour and milk together at lower doses (2.5μg/100g and 100mg/L respectively) (40). Another recent study in Belgium provided the same conclusions as the current study, recommending fortification of milk and bread simultaneously (41). These results reinforce the importance of modelling Vitamin D intakes at a country level, due to variations in the vitamin D content of foods and country specific eating patterns. However, before any recommendations are implemented, their safety and efficacy must be examined as part of human intervention studies, as emphasised in a summary paper from the ODIN project (42). ODIN also highlights the issues of fortifying a single food and the need to scale up interventions in real-world settings so that these results can be translated into action through policies and changes to food production and processing (42). A multipronged approach is needed that includes mandatory milk and bread fortification at the same time as maintaining current voluntary fortification practices, supplementation where required, and promotion of the increased consumption of natural food sources.

A strength of this study is that the data is from Ireland's national nutrition survey and was collected using a 4-day weighted food diary, which despite the inherent limitations, is the current "gold-standard". Food packaging and CoFID are reliable sources of food composition data. Other studies have differentiated Vitamin D intakes from supplements and food sources, but few have divided foods into foods with natural and added Vitamin D (43-46). The main limitation in this study is that the dietary data is 10 years old. Despite being updated to account for current food concentrations, it is possible that consumer trends, product availability and dietary patterns have changed. In addition, research has recognised that 25(OH)D in foods contribute to Vitamin D intakes (47, 48). However, CoFID does not include the 25(OH)D content of all foods, hence 25(OH)D contents were not updated. Also, the strategy used to update the food composition database, although essential for standardisation, is subjective and may introduce bias. To the best of our knowledge there are no other Vitamin D modelling studies of older adults in Ireland.

In summary, action needs to be taken to improve Vitamin D intakes of older adults in Ireland. Updating the composition of foods consumed in NANS did not change total Vitamin D intake, with intakes remaining below international recommendations. Separating Vitamin D into foods with natural and added Vitamin D and assessing intake patterns showed that older adults are more likely to consume Vitamin D supplements and fortified foods than natural sources of Vitamin D. Bread and milks were selected for data modelling as they were consumed by ~95% and 99% of the population, respectively. Supplementation and food fortification increased Vitamin D concentrations by up to ~250%, but all older adults were still not meeting the IOM recommendations. Policy makers can use the current data to inform future food fortification guidelines. However, milk and bread fortification needs to be modelled in the total population, using updated intake data. Those studies, alongside fortification dose-response studies, will determine the effectiveness and safety of mandatory fortification. Improving Vitamin D intakes of older adults will not only lead to improved health outcomes, but will benefit the economy directly, by reducing healthcare costs associated with Vitamin D-related disease and indirectly through improved quality of life and longer independent living time (15).

Author Contributions

All authors contributed to the paper. AMcC analysed and interpreted the data and drafted the manuscript. AOS was responsible for the conception and design of this research, contributed to the analysis and interpretation of data, paper editing and review. BAMcN and JW provided essential data for the study. All authors reviewed the manuscript and approved the final version submitted for publication.

Declarations of Competing interest

none

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We would like to acknowledge the contribution of the NANS participants and NANS study team for data collection, analysis and management of the NANS database. All authors contributed to the paper. AMcC analysed and interpreted the data and drafted the manuscript. AOS was responsible for the conception and design of this research, contributed to the analysis and interpretation of data, paper editing and review. BAMcN and JW provided essential data for the study. All authors reviewed the manuscript and approved the final version submitted for publication.

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