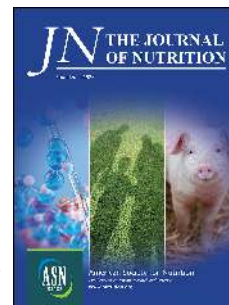


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Canada's Updated Vitamin D Fortification Strategy is Anticipated to Improve Vitamin D Intakes and Status based on Modeling of National Data

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Selected estimates of usual intakes of vitamin D, and food sources of vitamin D from the 2015 Canadian Community Health Survey – Nutrition are available on the Open Government Portal https://search.open.canada.ca/opendata/?sort=metadata_modified+desc&search_text=cchs-nutrition&page=1

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Supplementary Materials included

Abbreviations: CCHS: Canadian Community Health Survey; CHMS: Canadian Health Measures Survey; DRI: Dietary Reference Intake; EAR: Estimated Average Requirement; FPBB: fortified plant-based beverages; PBB: plant-based beverages; UL: Tolerable Upper Intake Level; 25(OH)D: 25-hydroxyvitamin D; UI: usual intakes; UVB: ultraviolet B.

1 Abstract

2 **Background:** Inadequate vitamin D status remains a public health concern in Canada. To help
3 address this, Health Canada implemented an updated (2022-2024) vitamin D fortification
4 strategy. The strategy increased the mandated amounts of vitamin D in cow's milk and
5 margarine, supported higher voluntary fortification of plant-based beverages (PBB) and
6 permitted voluntary fortification of yogurt/kefir.

7 **Objective:** The objectives of this study were to model the potential impact of recent vitamin D
8 fortification measures on vitamin D intakes and status among people living in Canada.

9 **Methods:** Usual intakes (UI) from the cross-sectional 2015 Canadian Community Health
10 Survey–Nutrition (n=19,369, ≥ 1 year) were modeled using National Cancer Institute
11 methodology and increased amounts of vitamin D in cow's milk, fortified PBB (2 $\mu\text{g}/100\text{ mL}$),
12 and margarine (26 $\mu\text{g}/100\text{ g}$), and new permission for yogurt/kefir ($\sim 5\text{ }\mu\text{g}/\text{serving}$). For each life-
13 stage, self-reported racial or Indigenous-identity group, risk was evaluated using the proportion
14 $< \text{Estimated Average Requirement (EAR: } 10\text{ }\mu\text{g}/\text{day})$ and the proportion $> \text{Tolerable Upper Intake}$
15 Level (UL) . Canadian Health Measures Survey (2012-2019, n=21,387 3-79 years) cross-
16 sectional data were modeled to evaluate the impact of the updated vitamin D fortification
17 strategy on inadequate vitamin D status ($< 40\text{ nmol/L}$ serum 25-hydroxyvitamin D).

18 **Results:** In 2015, the $\% < \text{EAR}$ was $> 85.7\%$ across life-stages. Modeling using higher amounts of
19 vitamin D in fortified foods reduced the $\% < \text{EAR}$ to: 34.3 to 66.3% among children/adolescents,
20 62.8 to 80.6% among non-pregnant/lactating adults, and 51.0% in pregnant/lactating females;
21 and was reduced according to racial group and Indigenous-identity. No group exceeded the UL.
22 The prevalence of inadequate vitamin D status with modeling declined from 15.3 to 10.6% in
23 children/adolescents, and from 19.6 to 14.6% in adults.

24 **Conclusions:** Health Canada's vitamin D fortification strategy appears to safely increase
25 population level UI and status of vitamin D. The impact will need to be confirmed using new
26 surveillance data.

27

28 **Key words:** vitamin D, food fortification, regulations, usual intake and biomarker modeling

Introduction

Vitamin D can be obtained exogenously from foods and supplemental sources or synthesized endogenously in skin exposed to ultraviolet B (UVB) radiation. The 2011 Estimated Average Requirement (EAR) for vitamin D is 10 µg/day (400 IU/day) for people living in North America (1). The EAR is based on dietary intakes that support adequate vitamin D status (≥ 40 nmol/L 25-hydroxyvitamin D, 25(OH)D) for persons ≥ 1 year of age, and under the assumption of minimal UVB exposure (1). Usual intakes (UI) of vitamin D below the EAR increase the risk of inadequate vitamin D status (< 40 nmol/L 25(OH)D) (1). In the 2015 Canadian Community Health Survey (CCHS)–Nutrition, UI of vitamin D below the EAR are observed in $\geq 85.7\%$ of the population ≥ 1 year of age (2). In the Canadian Health Measures Survey (CHMS) 2012-2019, vitamin D status is inadequate in 19.0% of the population 3-79 years (3-5). Inadequacy is most prevalent in adolescents 14-18 years (25.1%), adults 19-30 years (28.4%), racialized groups (24.6-39.3%) and supplement non-users (24.7%) (3).

Mandatory fortification of cow's milk and margarine with vitamin D (Table 1) has been in place in Canada since the 1970's as a public health measure to help support bone health (6). With the increase in the recommended intake of vitamin D in 2011, it was anticipated that people in Canada could not easily meet the EAR from food alone. The main dietary sources of vitamin D in the 2015 CCHS–Nutrition include fortified foods, with the combined category of cow's milk and fortified plant-based beverages (FPBB) as the leading dietary source, followed by margarine, and then natural sources (2, 7) overall, and among all self-reported racial groups (2).

In response to the high prevalence of UI of vitamin D from foods below the EAR in the population (2) and the prevalence of inadequate vitamin D status (3, 8), Health Canada developed an updated vitamin D fortification strategy (6). In 2022, the Food and Drug

Regulations were amended to approximately double the amount of vitamin D required in cow's milk and margarine, and that permitted in goat's milk (Table 1) (9). Changes were also implemented to support increasing the amount of vitamin D in FPBB to align with the new amount required in cow's milk (10). In 2024, the voluntary addition of vitamin D to yogurt and kefir was enabled through a marketing authorization (11). A range of permitted vitamin D amounts were established (Table 1) to accommodate manufacturing practices of yogurt and kefir. For fruit and flavored products, lower vitamin D amounts are permitted because fortified plain yogurt or kefir typically serves as the base ingredient (11). Both yogurt and kefir are useful vehicles for vitamin D fortification because they are consumed by a meaningful proportion of people living in Canada. Yogurt is consumed by 21.4% of people over 1 year of age based on a one-day dietary recall in the 2015 CCHS-Nutrition (12) with upward trends in consumption (13). Moreover, kefir is growing in popularity (14). Other vitamin D fortified foods in Canada include some breakfast cereals and biofortified eggs permitted through temporary marketing authorizations (15), as well as yeast-leavened bakery products under an interim policy (10).

The main objective of this study is to report on modeled UI of vitamin D from foods of people living in Canada under Health Canada's new vitamin D fortification strategy which increased vitamin D in milks and margarine, supported higher vitamin D in FPBB, and permitted its addition to yogurt and kefir (scenario 1). Our second objective explored UI under a broader fortification scenario that included all foods with permitted vitamin D fortification (scenario 2). The third objective modeled whether the vitamin D fortification strategy would help to reduce the prevalence of inadequate vitamin D status based on biomarker data, while ensuring safety from excess. Because kefir consumption was not captured in the dietary survey along with biomarker data, the status modeling included all components of scenario 1 except kefir.

Methods

Modeling of UI using 2015 CCHS-Nutrition (objectives 1-2)

The main objective of this study used data collected in a nationally representative sample of people ≥ 1 year of age living in Canada based on 2015 CCHS-Nutrition, a cross-sectional survey (response rate 61.6%) conducted by Statistics Canada in partnership with Health Canada as recently reported (2). Individuals ($<10\%$ of target population) who were full-time members of the Canadian Forces or who lived in the Territories, on reserves and other Indigenous settlements, in some remote areas, or in institutions were excluded from the sampling frame. All data were collected under the authority of the Statistics Act of Canada. Further details about the 2015 CCHS-Nutrition, including descriptions of the survey sample, how the survey was conducted and survey components, can be found in Health Canada's "Reference Guide to Understanding and Using the Data" (16). The present analysis was based on the subset ($n=19,673$ out of $n=20,487$) of respondents who consented to sharing data with Health Canada (**Supplementary Figure 1**). Population sociodemographic information and data pertaining to vitamin D intakes for the 2015 CCHS-Nutrition is shown in **Supplementary Table 1**.

All survey participants completed one computer-assisted, in-person interviewer-administered, 24-hour dietary intake recall including dietary supplement intake, using the validated Automated Multiple-Pass Method (17). Respondents 12 years and over self-reported intakes, age, sex, racial group or Indigenous-identity. The interview was conducted with a parent/guardian for children 1 to <6 years of age, and with both the child and parent/guardian for those 6 to 11 years of age. A second interview, including an additional 24-hour dietary recall, was conducted in a random subsample of 7,608 participants to adjust vitamin D intakes for within-person variability (2). Dietary supplement questions assessed supplement use over the previous

month, including the number of different supplements taken, frequency of use, and usual amount consumed, as well as any supplements taken on the previous day (i.e., during the 24-hour recall period). Supplement dosages of vitamin D (cholecalciferol or ergocalciferol) were audited for accuracy using the Natural Product Number. Only participants using over-the-counter supplements ($<25 \mu\text{g/day}$) were included in this analysis. Further details are available in our recent report (2).

The serving sizes, timing and eating occasion, and total amount of natural (e.g. fatty fish, egg yolk) and fortified food sources of vitamin D were captured in the dietary recalls. Vitamin D content, including cholecalciferol (vitamin D₃) or ergocalciferol (vitamin D₂), of foods and beverages were extracted from the Canadian Nutrient File Version 2015 database to calculate UI from food (18); only vitamin D₃ and vitamin D₂ are included in the food composition database and not the 25-hydroxy metabolites. UI from food and total UI (reflecting intakes from foods and supplemental sources of vitamin D) were modeled using the increased amounts in fortified foods (**Table 1**). Scenario 1 included increased amounts in milks (cow's and fortified goat's), margarine, FPBB as well as the newly permitted addition of vitamin D to yogurt and kefir. Full uptake by industry was assumed for voluntarily fortified foods including yogurt and kefir to determine maximum potential benefit and to assess risk of excess. Plant-based beverages (PBB) were modelled as fortified because the 2015 CCHS-Nutrition did not distinguish fortified from unfortified PBB, and since most PBB on the market at the time were fortified. Scenario 2 included a broader range of vitamin D-fortified foods available in the marketplace, including breakfast cereals (15), yeast leavened bakery products (10) and biofortified eggs (15); full uptake of these vitamin D food fortification permissions were assumed to enable assessment of possible excessive intakes against the age-specific Tolerable Upper Intake Level (UL) (1-3 y: $63 \mu\text{g/d}$; 4-

8 y: 75 µg/d; ≥ 9 y: 100 µg/d) as used in North America (1). Supplemental intakes of vitamin D were included in both modeling scenarios resulting in four models: UI and total UI models for the scenario 1, and then UI and total UI for scenario 2.

Food mapping was conducted by reviewing all foods and ingredients reported in the 2015 CCHS-Nutrition to identify the foods relevant to scenario 1 and 2. Ingredient-level data were obtained by disaggregating all recipes into their individual components (ingredients). For certain multi-ingredient foods (e.g., milk content in soups or puddings), proportional adjustment factors based on preparation instructions on product labels were applied to isolate the relevant ingredient contribution when further disaggregation was not possible.

Statistical analyses – dietary intakes

A three-part mixed effects model was used to estimate UI and total UI of vitamin D adapted from the method described by Verkaik-Kloosterman et al. (19) representing an extension of the National Cancer Institute method (20, 21). We estimated mean UI and distributions for each age-sex group including pregnant/lactating females before modeling: 1) from food only, and 2) from food and supplements combined as recently reported (2), and after modeling scenario 1 and then 2. Estimated distributions of intake from food used an amount model with day of recall (weekend vs. weekday), sequence of recall and province as covariates as described elsewhere (22). Vitamin D intakes (UI from food only, and total UI from food and supplemental sources) were also calculated before/after modeling scenario 1 according to disaggregated self-reported Indigenous-identity or racial group, with the groups set using the proposed standards for race-based and Indigenous-identity data in Canada (23). For these analyses, the Dietary Reference Intake (DRI) age-sex groups were collapsed resulting in the following groups of males and

females combined: 1-8 years; 9-14 years; 14-18 years; 19-50 years; and ≥ 51 years. Pregnant/lactating females were excluded from the analysis of racial group given the small sample size ($n=300$, 31.0 ± 0.5 years of age).

Modeling of UI was conducted using 2 scenarios for increases in vitamin D fortification of foods (**Table 1**). For the main objective, scenario 1 modeled UI with increases to milks plus FPBB, margarine and new amounts in yogurt/kefir whether as a whole food or in a mixed dish or recipe. We did not separate out milk from FPBB, as FPBB are commonly consumed as milk alternatives and were modelled using the same vitamin D fortification level. Vitamin D intakes from all other foods were held constant using participant data from 2015 (e.g. natural amounts from fish or eggs; fortified cold cereals or yeast-leavened bakery products). Data were expressed as UI from food only, and total UI to reflect food and supplement use. For the second objective, scenario 2, UI was modeled with the foods listed above, as well as additional food categories included in the broader fortification scenario, including, yeast-leavened bakery products (10), and breakfast cereals (15), as well as biofortified eggs (15).

Before and after applying the modeling scenarios 1 and 2, the distribution of UI (5-95th percentiles) and mean (SE) were estimated for each DRI age-sex group including pregnant/lactating females among supplement users and non-users combined and expressed as UI from food alone, then as total UI to reflect supplement use. The prevalence of UI below the EAR ($\% < \text{EAR}$, SE) were estimated using the EAR cut-point method (24). For each age-sex group the proportion exceeding the UL was calculated ($\% > \text{UL}$, SE) to assess risk of excess.

For all age-sex groups including pregnant/lactating females, the top food sources of vitamin D were estimated using an adapted food category list established by the Bureau of Nutritional Sciences, Food and Nutrition Directorate, Health Canada (25). All estimates

correspond to daily intakes calculated from the first 24-hour recall only. The second recall was not used as it was collected only from a subsample of respondents, limiting the food-level analyses to the first recall was required to preserve the representativeness of the estimates. Estimates for food categories were generated by combining foods consumed as a whole item (i.e. milk or FPBB for drinking) and as ingredients in recipes (i.e. milk or FPBB or eggs used in baking). Top food sources and the mean amount ($\mu\text{g/day}$) were analyzed according to age-sex groups as well as self-reported racial group or Indigenous-identity before and after the modeling scenarios.

All data are weighted to represent the population of Canada. Sample weights are created so that their sum matches population estimates at the provincial level for all DRI age-sex groups. Variance was estimated using a set of 500 bootstrap weights using the balanced repeated replication option in Statistical Analysis System Enterprise Guide (SAS EG) 7.1 (SAS Institute Inc., Cary, NC). SE values were used to calculate the 95% CI based on normal approximation ($\text{estimates} \pm 1.96 * \text{SE}$). Differences before/after modeling were assumed if 95%CI did not overlap.

Modeling of Biomarker-based Vitamin D Status using CHMS cycles 3-6 (2012-2019) ***(objective 3)***

Serum 25-hydroxyvitamin D (25(OH)D) is an ideal biomarker of vitamin D status as it reflects intake from all sources (1). It is estimated that for each μg increase in vitamin D intake per day that serum 25(OH)D increases by 1.2 (95%CI: 0.72-1.68) nmol/L (26). Guidance on modeling of serum 25(OH)D recommends including age, sex, body mass index (BMI), supplement use and possible exposure to UVB or season of blood draw in the model (26). We modeled data from CHMS cycles 3-6 (2012-2019) to reflect vitamin D status of people living in

Canada after the introduction of the EAR in 2011 (1). The CHMS is a cross-sectional survey conducted in 2-year cycles by Statistics Canada and is designed to be representative of the household population (3-79 years of age) of Canada living in the 10 provinces. The CHMS protocols were reviewed and approved by the Health Canada Ethics Review Board (REB 2005-025H). Participants 14 years of age and over signed a consent form before their participation, those 6 to 13 years of age signed an assent form in addition to their parent signing the consent form, and for those 3-5 years parental consent was required. The CHMS includes self-reported data including age, sex, racial group or Indigenous-identity, highest household education, and supplement use plus direct health measures including weight and height for derivation of BMI along with serum 25(OH)D as previously reported, children 3-5 years of age were not required to be fasted (3). For children below 12 years of age, the survey was conducted with the presence and assistance of a parent, guardian or older member of the household. The present analysis was based on the full sample (n=23,162 master and share file) of respondents who consented to the survey (**Supplementary Figure 2**). Population sociodemographic information and data related to vitamin D intakes for CHMS cycles 3-6 combined is shown in **Supplementary Table 1**.

Participants completed a food frequency questionnaire (FFQ) that included frequency of consuming foods containing vitamin D over the past year. This provided for frequency of milks, FPBB, margarine, and yogurt. Milks and FPBB were combined into a single food category to align with the main objective (scenario 1). At the time of the CHMS cycles 3-6 kefir was not surveyed. Based on the frequency of intakes of milks, FPBB, margarine or yogurt, participants were categorized as consumers of these products or as having zero reported consumption, the latter of whom would not be expected to benefit as much from the higher amounts of vitamin D in fortified foods. For milks, the CHMS survey question asked “how often do you drink milk or

flavored milk beverages or use them on cereal?” (i.e. not in coffee/tea, soup etc.), a similar question was asked for FPBB. Since only frequency was surveyed, for the present study the median serving sizes were imputed based on quantitative intake data from the 2015 CCHS-Nutrition, with median of the UI distribution selected to represent a typical serving size. For children and adolescents (M+F 3-5, M+F 6-8, M 9-13, F 9-13, M 14-18 and F 14-18 years) the median serving sizes were used to impute volumes of milk and FPBB. For adults (M 19-50, F 19-50, M ≥ 51 and F ≥ 51 years), data for participants with small intakes (below the 25th percentile, <30 ml) of milk and FPBB were removed prior to estimation of the median serving size. Median serving sizes for margarine and yogurt from 2015 CCHS-Nutrition were applied to all of the age-sex groups modeled.

The CHMS reported annual frequencies of consumption of milks and FPBB, yogurt, and margarine were first converted to average daily frequencies of consumption. Vitamin D intake from each fortified food category was then estimated by multiplying the daily frequency of consumption by the median portion size and the vitamin D fortification level under both the 2015 and increased fortification scenario 1 used in the main objective. Vitamin D intakes from milks and FPBB, yogurt, and margarine were summed for each CHMS participant to estimate total dietary vitamin D intake from these three fortified food categories.

Statistical analyses – serum 25(OH)D

The present analysis was based on the subset (n=21,387 out of n=21,770) of respondents who had serum 25(OH)D data along with all of the covariates of interest (Supplementary Figure 2), exclusions were on the basis of missing BMI (n=209), or owing to being an outlier as described below (n=174). The relationship between serum 25(OH)D concentrations and vitamin

D intake from fortified foods was assessed using linear regression analysis. For models that included consumers of the fortified foods, an additional adjustment was made for vitamin D supplement use (yes/no). The regression model included the vitamin D intake from fortified foods, age (continuous), sex (male, female), along with self-reported racial group or Indigenous-identity (23), household education (high school or less; postsecondary graduate; or not stated), BMI (continuous) and UVB exposure period (April-October; November-March) (27) as shown in the predictive linear regression model below:

$$\log[25(\text{OH})D_i] = \alpha + \beta \text{VitD}_{\text{total},i} + \gamma^T X_i + \varepsilon_i$$

where: $\text{VitD}_{\text{total},i}$ represents total vitamin D intake from milk/FPBB, margarine, and yogurt for individual i ; X_i is a vector of sociodemographic characteristics; β and γ are model parameters; α is the intercept; and ε_i is the error term.

To better satisfy the normality assumption of the linear regression models, serum 25(OH)D concentrations were log-transformed prior to analysis. Observations with studentized residuals greater than 3 in absolute value ($|\text{studentized residual}| > 3$) were considered outliers and excluded from the final models; specifically 75 children/adolescents and 99 adults were excluded (Supplementary Figure 2). Model assumptions were assessed using standard diagnostic procedures and were found to be adequately satisfied. No evidence of multicollinearity among the covariates was detected.

Linear regression models were fitted for children and adolescents (3–18 years) combined, and separately for adults (≥ 19 years). Within each of these age groups, separate models were developed for all consumers of the fortified foods as surveyed, for those who in addition consumed vitamin D supplements, and for those who did not consume the vitamin D fortified foods as surveyed. To assess the impact of the proposed fortification levels on the general

household population, the model-predicted biomarker values for consumers of the fortified foods (including supplement users and non-users) were combined with the observed biomarker values for participants who did not consume any of the vitamin D fortified foods as surveyed (i.e. no milk on cereal or to drink was reported).

The coefficient of determination (R^2) for the linear regression models ranged from 18% to 32%. Because the models explained only a modest proportion of the variability in serum 25(OH)D concentrations, the predicted biomarker values exhibited reduced variability and were shrunk toward the mean. To restore a more realistic distribution of predicted biomarker values, 100 pseudo-observations were generated for each survey participant by sampling from a normal distribution with a mean equal to the participant-specific model-predicted biomarker value and a standard deviation equal to the residual standard deviation from the fitted regression model. This approach preserved the expected mean while reintroducing the unexplained variability in biomarker concentrations. A similar approach is used in the National Cancer Institute method for estimating usual intake distributions, in which pseudo-observations are generated by incorporating residual variation to recover the population distribution (20).

The simulated biomarker values were back-transformed to the original scale and used to estimate the distributions of serum 25(OH)D concentrations. These distributions were then used to estimate the proportions of the population below or above the following predefined DRI thresholds: <30 nmol/L which is the threshold at which signs of deficiency increases; <40 nmol/L which is considered inadequate for populations; and >125 nmol/L as the threshold above which risk of adverse effects increases (1). Data were then reported using similar age-sex groups as were used for the main objective for children and adolescents (M+F 3-5, M+F 6-8, M 9-13, F 9-13, M 14-18 and F 14-18 y) and adults (M 19-50, F 19-50, M $\geq$ 51 and F $\geq$ 51 y). All analyses

incorporated the survey sampling weights to produce population-representative estimates. Standard errors were estimated using the bootstrap method with 500 replicate weights. Confidence intervals were calculated using the *t*-distribution with 44 degrees of freedom, consistent with the CHMS bootstrap variance estimation approach.

To assess the impact of the proposed vitamin D fortification levels, the relative (%) change in the population proportions below or above the predefined serum 25(OH)D thresholds (<30, <40 or >125 nmol/L) (1) were calculated. Change (%) was calculated using regression modeled vitamin D status as follows, confidence intervals for the difference were not generated:

$$\% \text{ Change} = \frac{\text{Anticipated Status \% (Scenario 1)} - \text{Predicted Status \%}}{\text{Predicted Status \%}} \times 100$$

Statistical Analysis System Enterprise Guide (SAS EG) 7.1 was used for these analyses. Data with a CV% between 16.6 to 33.3% are demarked with an E “interpret with caution”, whereas data with a CV% of >33.3% or for sample sizes <10 are demarked with an F, and are suppressed in view of the extreme variability of the data and/or to maintain confidentiality.

Results

Objective 1: UI using 2015 CCHS-Nutrition and under Scenario 1

For the main objective focused on scenario 1 (increased vitamin D in milks, FPBB, margarine and permitted addition of vitamin D to yogurt/kefir), the %<EAR of vitamin D was reduced in all age-sex groups whether UI from food only or total UI from food and supplements combined (**Figure 1 A-B**). The %<EAR based on food consumption alone ranged from 34.3% (children 1-3 years) to 80.6% (females ≥ 71 years), and with consideration of supplemental vitamin D intakes, the %<EAR ranged from 19.5% (pregnant/lactating females) to 60.9% (males 31-50 years) (Figure 1 A-B). The %>UL from food alone remained zero, whereas the %>UL based on total UI from food and supplements combined remained <3% in all age-sex groups (**Supplementary Tables 2-5**). The statistics for %<EAR, %>UL, mean UI and the distribution of UI ($\mu\text{g/day}$) from the 5th to 95th percentiles are available in the supplementary materials (Supplementary Tables 2-5).

Under scenario 1 for increased vitamin D fortification of milks, FPBB, margarine and permitted fortification of yogurt/kefir the %<EAR was significantly reduced in all self-reported racial or Indigenous-identity groups (**Table 2; Supplementary Table 6**). Total UI data from modeling of these fortified foods combined with supplemental intakes of vitamin D showed further reductions in %<EAR in all groups that were significantly different from that observed in 2015 (**Supplementary Table 7**). Statistics for %<EAR, %>UL and mean UI are available in the supplementary materials (**Supplementary Tables 6-7**).

With scenario 1, shifts in the top food sources of vitamin D and/or their contribution to intakes were observed (**Table 3**). The top food source was milk and FPBB as a combined group among all age-sex groups both before and after modeling. Although their contribution to vitamin

D intakes approximately doubled with modeling, mean UI from milk and FPBB remained below the EAR across all age-sex groups, ranging from 2.7 to 8.0 $\mu\text{g/day}$. The second leading food source shifted from mainly margarine to either margarine or yogurt/kefir with yogurt/kefir being a common source among young children and females whereas margarine was more commonly consumed as a second source among males. Contributions of the second food source to vitamin D intakes ranged from 1.0 to 3.0 $\mu\text{g/day}$. The third source of vitamin D before modeling was mainly fish in most age-sex groups, and this shifted to yogurt/kefir or margarine with modeling; contributions of the third ranked source to intakes ranged from 0.7 to 1.3 $\mu\text{g/day}$. Regular eggs formed the fourth source of vitamin D before modeling and was replaced by a combination of yogurt/kefir and fish such that regular eggs were no longer among the top four leading food sources of vitamin D; yogurt/kefir and fish, as the fourth ranked source, contributed 0.3 to 1.0 $\mu\text{g/day}$. In our analysis of the leading food sources of vitamin D among self-reported racial group or Indigenous-identity (1 year of age and over combined), the top source was milk and FPBB among all groups with modeling ranging from mean intakes of 2.7 to 4.9 $\mu\text{g/day}$, followed by various combinations of margarine (mean intake range: 0.8 to 1.5 $\mu\text{g/day}$), yogurt/kefir (mean intake range: 0.8 to 1.7 $\mu\text{g/day}$) or fish (mean intake range: 0.3 to 1.5 $\mu\text{g/day}$) (**Table 4**).

Objective 2: UI using 2015 CCHS-Nutrition and under Scenario 2

For the secondary objective and scenario 2, additional vitamin D fortified foods (breakfast cereals, yeast-leavened bakery products and biofortified eggs), were included with the foods included in the main objective. Under this broader fortification scenario 2, %<EAR based on food intakes alone appears to be reduced since the 95%CI did not overlap with those observed in 2015 (Figure 1 A) with %<EAR values ranging from 23.5 % (males 14-18 years) to 59.2 %

(females 31-50 years) (**Supplementary Tables 8 vs. 2**). When considering intakes from these foods plus supplement use, reductions in the %<EAR were observed in all groups (Figure 1B), and %>UL remained <3% among all age sex groups (**Supplementary Table 9**) compared to intakes from food and supplements in 2015 (Supplementary Table 2). The top food sources of vitamin D under scenario 2 showed that milk and FPBB remained the top food source among all age-sex groups (**Supplementary Table 10 vs. 9**) with yogurt, breads or margarine forming the second ranked source depending on age-sex group, and breads, yogurt, margarine or eggs forming the third and fourth source depending on age-sex group. The top ranked food sources of vitamin D according to self-reported identity also showed milk and FPBB as the top source, followed by different patterns regarding the second through fourth top sources of vitamin D which included fish or fortified foods such as margarine, breads, yogurt or eggs (**Supplementary Table 11**).

Objective 3: Biomarker-based Vitamin D Status using CHMS (2012-2019) under Scenario 1

Modeling based on scenario 1 and anticipated changes to serum 25(OH)D showed that the prevalence of children and adolescents 3-18 years with inadequate vitamin D status (<40 nmol/L) would be anticipated to be reduced to 10.6% (95%CI: 8.7, 12.5%), and in adults 19-79 years it would be anticipated to be reduced to 14.6% (95%CI: 12.8, 16.4%) (**Table 5**). The anticipated prevalence of inadequate vitamin D status for the disaggregated age-sex groups of children and adolescents was estimated to range from 4.5 to 18.2%, and in adults from 6.8 to 20.3% (Table 5).

The anticipated risk of vitamin D deficiency based on serum 25(OH)D <30 nmol/L and modeled under scenario 1 was estimated to be reduced among children and adolescents (3-18

years) to 2.5% (95%CI: 1.7, 3.2%) (Table 5); values for disaggregated age-sex groups ranged from 0.7 to 4.9%. Similarly, in adults (19-79 years) the anticipated prevalence of vitamin D deficiency under scenario 1 was estimated to be reduced to 4.6% (95%CI: 3.8, 5.5%); values for disaggregated age-sex groups ranged from 1.7 to 7.2%.

Risk of adverse effects based on serum 25(OH)D >125 nmol/L in children and adolescents may increase under fortification scenario 1, with 3.8% potentially exceeding 125 nmol/L. Risk of adverse effects based on modeling of serum 25(OH)D >125 nmol/L showed smaller relative increases in all adult age-sex groups compared to children (Table 5), potentially reaching 7.1% overall. The 5-95 percentile distribution of observed, and regression modeled predicted and anticipated serum 25(OH)D are shown in **Supplementary Figure 3** for children, and **Supplementary Figure 4** for adults.

Discussion

This study reports on the anticipated increase in UI of vitamin D by people living in Canada (6) based on statistical modeling of increased amounts of vitamin D in fortified foods (9-11). The main objective tested Health Canada's vitamin D fortification strategy: higher vitamin D levels in milks, margarine and FPBB and the new permission to fortify yogurt/kefir (9-11). We modeled vitamin D intakes and status across the life-stages utilizing two national surveys for a fulsome analysis of the anticipated outcome. In 2015, UI of vitamin D from food is below the EAR in 85.7% to 99.7% of the population depending on life-stage. The prevalence of UI <EAR of vitamin D is anticipated to be reduced in all life-stage and all racialized groups while maintaining minimal risk of excessive UI. Children 1-8 years, males 9-18 years and pregnant/lactating females may benefit the most from the updated vitamin D fortification strategy with an estimated %<EAR of vitamin D from food ranging from 34.3 to 53.4%. The top food sources of vitamin D remained milks and FPBB combined, followed by various combinations of margarine, yogurt/kefir and fish which reflects the food choices among population sub-groups in 2015 (2). With modeling of serum 25(OH)D, the prevalence of inadequate vitamin D status (<40 nmol/L) is anticipated to decline from 15.3 to 10.6% in children/adolescents, and in adults from 19.6 to 14.6% (3).

Similar to Canada, in the USA using NHANES 2011-2014 data on people ≥ 1 year of age the mean UI of vitamin D from food is 4.9 $\mu\text{g/day}$ and the population prevalence of risk of inadequate vitamin D status (defined therein as 30-49 nmol/L 25(OH)D) is 18.3% (28). Since 2016, the USA has permitted higher vitamin D fortification amounts in milk and PBB and has enabled vitamin D fortification of plant-based yogurt alternatives (29). Surveillance spanning 2007-2023 suggests that the risk of inadequate vitamin D status has declined to 15.6%, although

this may reflect increases in supplement use (30), rather than increases in vitamin D from foods. In that report, caution is warranted as, among supplement users, risk of excess reached 11% if using 1 supplement and 30% if using 2 supplements (30). Recently the USA increased permitted vitamin D levels in dairy-based yogurt and other cultured dairy products (31); however the impact of these actions on UI of vitamin D is to our knowledge not published. The experience in the USA supports the premise that expanding vitamin D fortification can contribute to reductions in inadequate vitamin D status. The recent changes in Canada are expected to result in further reductions in the proportion of the general population with vitamin D intakes <EAR while maintaining risk >UL at <3%. Whether the increased vitamin D fortification is implicated in risk of excess among vitamin D supplement users is not known. Dietary guidance in Canada, however, recommends a supplement containing 10 µg/day (400 IU/day) of vitamin D for individuals who do not regularly consume foods containing vitamin D and for adults 51 years of age and older. This amount minimizes the risk of inadequacy from a population health perspective (32), and is well below the UL.

Similar to Canada and the USA, Finland has implemented fortification measures to increase vitamin D in their food supply. In 2003 they enacted systematic voluntary fortification of fat spreads plus fluid milk products and alternatives (33). In 2010, in response to increases to recommended intakes, they enabled further increases to fortification (33). In 2011, inadequate vitamin D status (<40 nmol/L 25(OH)D) shows declines from 34.2% to 5.0% in adults who do not use supplements (34). The success has been ascribed to doubling of vitamin D intakes resulting in an UI of 14 µg/day and 26% <10 µg/day in males and 12 µg/day and 42% <10 µg/day in females. The top food sources of vitamin D are similar to our study including fortified milk products, fortified fat spreads and fish (35). Simultaneous increases in the proportion of the

adult population using supplements almost eradicated inadequate vitamin D status (3.2%) (34). Similar standardized serum 25(OH)D and UI data in children are, to the best of our knowledge, not available. In adults ≥ 19 years in our modeling scenario 1 for food and supplemental intakes, the anticipated %<EAR is 53.6% in males and 48.6% in females. The anticipated increases in intakes are more prominent in young children and pregnant/lactating females and overall <3% were at risk of excess UI. Whether the revisions to vitamin D fortification of foods in Canada under scenario 1 translate to meaningful improvements to vitamin D intakes in the overall population and how this compares to other countries requires new surveillance data.

In the secondary objective, scenario 2, we included vitamin D-fortified yeast-leavened bakery products, and breakfast cereals, as well as biofortified eggs, which have become available in Canada through different regulatory or policy mechanisms (10, 15). The %<EAR is further reduced and, milk and FPBB remain the top source of vitamin D followed by margarine, yogurt or fish depending on age-sex group; and breads emerge as a “top four” source overall and among all racialized groups. Regular eggs are commonly consumed in Canada (12), and represent the fourth top food contributor to vitamin D intakes in 2015 (2). The average vitamin D content of regular eggs in Canada is 1.4 $\mu\text{g}/100\text{ g}$ raw egg (36). Health Canada now supports up to 4.7 $\mu\text{g}/100\text{ g}$ raw egg through biofortification under temporary marketing authorizations (15). The contribution of biofortified eggs to modeled intakes of vitamin D suggest that eggs could remain among the top sources in many age-sex and racial groups. In contrast, fortified cereals did not emerge among the top food sources which could be because cereals are usually consumed in smaller quantities (e.g. 1 cup of cereal is 30 g, rather than the 100 g basis). Food-based solutions to improving vitamin D intakes in other countries (37, 38) have also explored vitamin D fortification of breads and eggs based on modeling of vitamin D intakes in the general population

(39-42) and among Aboriginal people (43). In a meta-analysis of vitamin D fortified bread, most of the evidence in support of bread as a vehicle for fortification was from the addition of vitamin D₃ (44), which is a permitted form for vitamin D fortification in Canada. In trials of fortified breads and eggs, wintertime declines in vitamin D status are attenuated among high risk groups in Denmark (45). Similarly, consuming 7 vitamin D biofortified eggs per week (1.04 µg vitamin D₃, plus 0.5 µg 25(OH)D₃/egg) in adults in Ireland prevents wintertime declines in vitamin D status (46). Whether the increases in the amount of vitamin D in fortified foods in Canada collectively alleviate wintertime declines in vitamin D status is not known.

To date, quantitative dietary intakes of vitamin D (2) and biomarker assessment of vitamin D status (3) are not assessed in the same surveillance studies in Canada. Surveillance data spanning 2012 to 2019 shows that 19.0% of people living in Canada experience inadequate vitamin D status with higher rates seen in adolescents and younger adults (3). As recommended (26), our models include multiple sociodemographic factors and vitamin D intakes, plus time of blood draw to reflect possible vitamin D synthesis due to exposure to UVB (27). More granular data on UVB exposure is not available across survey cycles. The predicted prevalence of inadequate vitamin D status in children/adolescents and adults is similar to the observed prevalence estimates. Based on increased vitamin D intakes from milks, FPBB, margarine, and yogurt, and corresponding modeled increases in serum 25(OH)D, the proportion of the population with inadequate vitamin D status (<40 nmol/L) could be reduced in children and adolescents combined from 15.3 to 10.6%, and in adults from 19.6 to 14.6%. Risk of adverse effects based on serum 25(OH)D >125 nmol/L may reach 3.8% in children/adolescents and 7.1% in adults. In a sensitivity analysis of supplement users, risk of excess based on serum 25(OH)D >125 nmol/L could rise in theory by 1.8 to 4.5% in adults, depending on age-sex group.

However, it is known that the response of serum 25(OH)D to supplemental vitamin D intakes at or above the UL is not linear in adults due to factors such as genotype (47) and metabolism of vitamin D to 24,25-dihydroxyvitamin D (48). Thus, a modeling scenario under the assumptions of a linear regression in supplement users has limitations.

This study has other limitations to consider including that we assume full uptake by industry for increased amounts of vitamin D added to PBB and yogurt/kefir which are only voluntary permissions. Over 90% of PBB have been fortified with vitamin D in the Canadian marketplace (49); industry uptake for increased amounts of vitamin D remains to be reported. Older modeling scenarios in Canada (2004) suggest that 33% uptake by industry based on market share scenarios for yogurt is reasonable for voluntary fortification (50). Other important assumptions in our modeling include that food intakes, food composition, supplement use, and population demographics in the 2015 CCHS-Nutrition and CHMS 2012-2019 data have remained stable. The 2015 CCHS-Nutrition data are >10 years old and thus do not reflect potential shifts in intake patterns that could modulate the impact of the increases in vitamin D fortification of foods. Nonetheless, vitamin-D fortified foods available in Canada that are alternatives to dairy-based products, such as PBB (10) can fit various dietary preferences and patterns; which is a strength of the present study. We also could not address cost to the consumer and whether uptake may be lower among lower income consumers, potentially limiting benefits in populations at higher risk of inadequate status. While we considered the possible risks of excessive UI of vitamin D from food and supplements, we did not address risk ascribed to supplemented foods, such as vitamin waters, which may contain vitamin D (51), as data on this is not available. Of note though, the framework governing supplemented foods focuses on safety of these products (52), whereas the objective of the fortification framework is to address intakes

below the EAR while mitigating risks of excess consumption. The CCHS-Nutrition reports vitamin D intakes from food, whereas the amount of 25(OH)D has not been considered and can vary according to season or agricultural practices and contribute to vitamin D activity in food (53). This could be relevant to intakes by people who consume animal-based foods (37, 46). In addition, we excluded respondents using higher amounts of vitamin D ($>25 \mu\text{g/day}$), however, the risk of excess intakes from fortified foods would be of lesser risk. Since CHMS uses food frequency, imputed median serving sizes from CCHS-Nutrition were used to model the response of serum 25(OH)D to changes in vitamin D fortification. Modeling of serum 25(OH)D relied on consumption of foods selected on the basis of being fortified at the time of the survey and thus foods, such as kefir, were not surveyed, nor were small amounts of milks or FPBB consumed as ingredients.

In conclusion, modeling using updated fortification policy appears to safely increase UI of vitamin D in the general population across all life-stages, especially among younger children, adolescent males and pregnant/lactating females, and all racialized groups. The prevalence of inadequate biomarker-based vitamin D status is anticipated to fall to 10.6% in children and adolescents, and to 14.6% in adults. As new vitamin D containing foods emerge on the market, uptake by the population may be driven by food preferences, culture and socioeconomic factors, some of which (e.g. household income (54, 55)) could influence the success of Health Canada's policies on vitamin D fortification of foods as a public health strategy to help improve vitamin D status and reduce health inequities. New surveillance will help evaluate the success of the vitamin D fortification strategy in minimizing the prevalence of inadequate vitamin D status, mitigating inequalities in vitamin D status of Canada's increasingly diverse population (56), and the risk of excessive intakes in association with supplemented foods or vitamin supplements.

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Figure Legends

Figure 1. Vitamin D intakes based on 2015 CCHS-Nutrition according to scenario 1 (increased vitamin D fortification of milks, fortified plant-based beverages, margarine and yogurt/kefir) and scenario 2 (scenario 1 plus hot and cold breakfast cereals, yeast leavened bakery products and biofortified eggs) for each age-sex group. Data are the proportion with usual intake (UI) <EAR from A) food only or B) food plus supplements. * $P < 0.05$, 95%CI do not overlap with modeled scenarios; E: coefficient of variation (CV%) of 16.6-33.3, interpret with caution.

Table 1. Vitamin D amounts required or permitted under Canadian regulations, policies and authorizations

Modeling Scenarios	Vitamin D Fortified Foods Potentially Consumed	
	2015 ¹	2026 ²
Main Objective/Scenario 1		
Milk (including cow's and fortified goat's milk)	0.88 µg/100 mL ³	2 µg/100 mL ⁴
Fortified plant-based beverage (FPBB)	0.85 µg/100 mL ³	2 µg/100 mL ⁴
Margarine	13 µg/100 g ³	26 µg/100 g ⁴
Yogurt (dairy based)	0 ⁵	5 µg/100 g ⁶
Drinkable yogurt (dairy based)	0 ⁵	5.2 µg/100 mL ⁶
Yogurt, fresh cheese-type (dairy based)	0 ⁵	5 µg/100 g ⁶
Kefir (dairy based)	0 ⁵	2.7 µg/100 mL ⁶
Second Objective/Scenario 2 (Foods above plus):		
Eggs	0 ⁷	4.7 µg/100 g raw egg ⁸
Breakfast cereals	3.7 µg/100 g ⁹	5 µg/100 g ¹⁰
Yeast-leavened bakery products	2.25 µg/100 g ⁹	2.25 µg/100 g ¹⁰

¹ Vitamin D amounts shown for the 2015 scenario reflect vitamin D amounts permitted or required under regulations, policies, or authorizations in effect in 2015. These values were not used in dietary intake modeling; modeling was based on food composition values extracted from the Canadian Nutrient File Version 2015 (18). Food-specific differences between the values shown and those used in modeling are noted in subsequent footnotes.

² Vitamin D amounts used in the January 1, 2026 dietary intake modeling scenario. For foods where vitamin D addition was permitted but not mandatory, modeling assumed full uptake at the specified level. Values reflect vitamin D amounts permitted or required under regulations, policies, or authorizations in effect on January 1, 2026.

³ Foods fortified with vitamin D under the *Food and Drugs Regulations* as they read in 2015 for milks and margarine (57), or the Interim Policy on the Use of Expired Interim Marketing Authorizations Related to Food Fortification, Appendix A1 for FPBB (10).

⁴ Foods fortified with vitamin D under the *Food and Drugs Regulations* as amended on July 20, 2022 for milks and margarine (9) or the Interim Policy on the Use of Expired Interim Marketing Authorizations Related to Food Fortification, Appendix B amended in 2022 for FPBB (10).

⁵ The value shown in this table is zero because direct vitamin D fortification of yogurt and kefir was not permitted in 2015. However, some yogurt and kefir products on the market at that time contained a small amount of vitamin D through the use of fortified milk in manufacturing. Amounts used in estimating usual intakes in 2015 were based on market-share-weighted composite values in the Canadian Nutrient File and therefore reflected marketplace uptake (18).

⁶ Vitamin D total amount in fortified products as per 2024 marketing authorization. The marketing authorization permits a range of vitamin D amounts for fruit or flavored yogurt, drinkable yogurt and kefir (yogurt: 3.8-5 µg/100 g; drinkable yogurt: 3.9 to 5.2 µg/100 mL; kefir: 2.3 to 2.7 µg/100 mL) (11); for the present analyses, the maximum permitted amount was used.

⁷ The value shown in this table is zero because vitamin D biofortification of eggs was not permitted in 2015. However, vitamin D content of eggs in the Canadian Nutrient File was based on naturally occurring amounts (e.g., 0.8 µg/53 g raw egg or 1.4 µg/100 g raw egg) (18). Consequently, dietary intake modeling accounted for naturally occurring vitamin D in eggs.

⁸ Biofortified eggs with permissible amounts up to 2.5 µg/53 g raw egg or 4.7 µg/100 g raw egg (15). The value shown reflects total vitamin D content, including naturally occurring and added vitamin D. For the present analyses, the maximum permissible amount was used.

⁹ The values shown in this table reflect vitamin D amounts permitted under temporary marketing authorizations for breakfast cereals (15) and the Interim Policy on the Use of Expired Interim Marketing Authorizations Related to Food Fortification, Appendix A10 for yeast-leavened bakery products (10). Some breakfast cereals on the market in 2015 contained added vitamin D (ranging from 1.9 to 3.7 µg/100 g, while few yeast-leavened bakery products contained added vitamin D. Consequently, the amounts used in estimating usual intakes in 2015 were based on market-share-weighted composite values in the Canadian Nutrient File (18) and reflected actual marketplace uptake, resulting in values that differed from those shown in this table for 2015.

¹⁰ Permissible amounts of vitamin D in fortified breakfast cereals under temporary marketing authorizations (15) and yeast-leavened bakery products under an interim policy (10).

Table 2. The proportion of people in Canada with usual intake (UI) of vitamin D from food below the EAR in 2015 and after applying scenario 1 for increased amounts of vitamin D in milks, fortified plant-based beverages, margarine and yogurt/kefir, and according to self-reported racial or Indigenous-identity group¹.

Self-reported group	UI	Children 1-8 years		M+F 9-13 years		M+F 14-18 years		M+F 19-50 years		M+F ≥51 years	
		n	%<EAR (95%CI)	n	%<EAR (95%CI)	n	%<EAR (95%CI)	n	%<EAR (95%CI)	n	%<EAR (95%CI)
Black	2015	56	93.1 (87.5, 98.7)	37	97.2 (94.7, 99.6)	44	88.5 (79.2, 97.8)	143	98.5 (96.0, 100.9)	101	98.0 (95.8, 100.3)
	Scenario 1		45.5 (31.1, 59.8) ²		73.3 (62.7, 84.0) ²		61.2 (45.3, 77.0) ²		83.1 (73.1, 93.2) ²		83.5 (74.9, 92.1) ²
East Asian	2015	77	93.1 (88.9, 97.3)	72	93.8 (87.8, 99.9)	82	86.2 (76.2, 96.1)	272	96.8 (94.5, 99.1)	225	96.8 (94.0, 99.6)
	Scenario 1		46.8 (34.0, 59.6) ²		53.7 (41.2, 66.3) ²		57.5 (41.4, 73.5) ²		79.2 (71.5, 86.8) ²		81.4 (74.7, 88.2) ²
Indigenous	2015	147	96.3 (93.5, 99.2)	121	94.8 (90.3, 99.3)	120	96.3 (92.8, 99.8)	294	97.7 (95.6, 99.8)	213	96.0 (90.6, 101.4)
	Scenario 1		54.2 (42.9, 65.5) ²		59.5 (47.6, 71.4) ²		76.2 (65.1, 87.4) ²		80.8 (72.6, 88.9) ²		72.5 (59.0, 86.0) ²
Latino	2015	22	94.6 (87.3, 101.8)	18	94.0 (88.8, 99.2)	31	91.6 (85.6, 97.5)	79	95.6 (91.1, 100.1)	49	99.6 (97.4, 101.9)
	Scenario 1		43.0 (21.3, 64.7) ^{E2}		59.2 (44.0, 74.4) ²		62.1 (48.1, 76.2) ²		73.4 (61.1, 85.7) ²		90.2 (78.9, 101.5) ²
Middle Eastern	2015	61	91.9 (85.5, 98.3)	35	97.8 (94.9, 100.7)	32	98.4 (94.3, 102.5)	123	99.2 (98.3, 100.1)	58	98.9 (95.3, 102.6)
	Scenario 1		34.8 (230, 46.6) ^{E2}		72.3 (57.5, 87.1) ²		84.1 (67.5, 100.7) ²		85.0 (76.9, 93.1) ²		89.4 (75.2, 103.6) ²
South Asian	2015	85	91.4 (86.5, 96.2)	73	97.2 (94.5, 99.9)	84	89.9 (83.8, 96.0)	258	97.7 (95.7, 99.7)	159	99.2 (98.1, 100.4)
	Scenario 1		35.3 (25.5, 45.0) ²		65.2 (53.3, 77.1) ²		52.0 (40.4, 63.6) ²		66.4 (57.2, 75.7) ²		82.5 (73.3, 91.6) ²
South East Asian	2015	66	93.0 (87.3, 98.8)	52	98.3 (95.9, 100.6)	70	94.4 (89.3, 99.6)	198	98.4 (96.3, 100.5)	118	95.1 (90.7, 99.6)
	Scenario 1		48.9 (35.5, 62.3) ²		71.1 (58.2, 84.0) ²		74.8 (61.7, 87.8) ²		87.2 (79.7, 94.7) ²		80.0 (70.0, 90.0) ²
All others	2015	188	94.9 (92.1, 97.7)	109	97.6 (94.7, 100.4)	93	94.6 (90.8, 98.3)	157	98.3 (96.8, 99.8)	143	96.9 (94.0, 99.8)
	Scenario 1		47.3 (37.6, 57.0) ²		70.6 (57.0, 84.2) ²		67.4 (56.9, 78.0) ²		83.6 (76.1, 91.1) ²		79.2 (69.1, 89.3) ²
White	2015	1,785	94.4 (92.6, 96.2)	1,444	93.9 (91.7, 96.2)	1,329	88.9 (85.4, 92.3)	4,393	96.3 (94.9, 97.7)	5,951	95.3 (93.6, 96.9)
	Scenario 1		44.1 (39.8, 48.5) ²		53.3 (48.6, 58.0) ²		52.8 (48.0, 57.6) ²		71.6 (68.3, 74.8) ²		70.1 (67.5, 72.8) ²
Overall	2015	2,487	94.1 (92.3, 95.8)	1,961	94.9 (93.0, 96.9)	1,885	89.9 (86.8, 92.9)	5,917	96.8 (95.6, 98.1)	7,017	95.6 (94.1, 97.2)
	Scenario 1		44.2 (40.6, 47.9) ²		58.0 (53.9, 66.2) ²		56.9 (52.8, 61.0) ²		74.2 (71.4, 77.0) ²		72.0 (69.6, 74.5) ²

¹ Usual intakes are based on food only, sexes are combined. Racial group and Indigenous-identity are self-reported and categorized based on standards for data collection and reporting in Canada (23). Values with superscript E indicate a coefficient of variation (CV%) of 16.6-33.3, interpret with caution. Abbreviations: EAR: Estimated Average Requirement (10 µg/day); F: female; M: male; UI: usual intake.

² P<0.05 within group before/after values are different as indicated by 95%CI that do not overlap.

Table 3. Contribution of top four food sources of vitamin D (µg/day) among age-sex groups in 2015 and after applying scenario 1 for increased amounts of vitamin D in milks, fortified plant-based beverages, margarine and yogurt/kefir¹.

Sex, Age, y	2015								Scenario 1								
	Top source		Second source		Third source		Fourth source		Top source		Second source		Third source		Fourth source		
	n	n	Mean (95%CI)	n	Mean (95%CI)	n	Mean (95%CI)	n	Mean (95%CI)	n	Mean (95%CI)	n	Mean (95%CI)	n	Mean (95%CI)	n	Mean (95%CI)
Both 1-3	1,288	1,226	Milk+FPBB 4.1 (3.8, 4.4)	685	Margarine 0.6 (0.5, 0.7)	147	Fish 0.4 (0.2, 0.5) ^E	594	Yogurt 0.4 (0.3, 0.4)	1,226	Milk+FPBB 8.0 (7.3, 8.7)	594	Yogurt 3.0 (2.5, 3.4)	685	Margarine 0.9 (0.8, 1.1)	147	Fish 0.4± (0.2, 0.5) ^E
Both 4-8	1,199	1,115	Milk+FPBB 3.0(2.8, 3.2)	645	Margarine 0.7 (0.6, 0.7)	110	Fish 0.4 (0.2, 0.6) ^E	438	Yogurt 0.2 (0.2, 0.3)	1,115	Milk+FPBB 5.8 (5.4, 6.2)	438	Yogurt 2.1 (1.8, 2.4)	645	Margarine 1.0 (0.9, 1.1)	110	Fish 0.4 (0.2, 0.6) ^E
M 9-13	1,023	919	Milk+FPBB 3.1 (2.9, 3.4)	519	Margarine 0.8 (0.7, 0.9)	83	Fish 0.3 (0.2, 0.5) ^E	586	Eggs 0.3 (0.2, 0.3)	919	Milk+FPBB 6.0 (5.5, 6.5)	250	Yogurt 1.5 (1.3, 1.8)	519	Margarine 1.2 (1.0, 1.4)	83	Fish 0.3 (0.2, 0.5) ^E
M 14-18	900	775	Milk+FPBB 3.4(3.0, 3.8)	442	Margarine 1.0 (0.8, 1.3)	73	Fish 0.5 (0.2, 0.9) ^E	516	Eggs 0.4 (0.4, 0.5)	775	Milk+FPBB 6.5 (5.7, 7.3)	442	Margarine 1.6 (1.1, 2.0)	108	Yogurt 0.7 (0.5, 0.9)	73	Fish 0.5 (0.2, 0.9) ^E
M 19-30	855	669	Milk+FPBB 2.3(1.9, 2.7)	427	Margarine 0.9 (0.7, 1.0)	96	Fish 0.6 (0.3, 1.0) ^E	474	Eggs 0.5 (0.4, 0.6)	669	Milk+FPBB 4.6 (3.7, 5.5)	427	Margarine 1.3 (1.0, 1.6)	119	Yogurt 1.0 (0.7, 1.4) ^E	96	Fish 0.6 (0.3, 1.0) ^E
M 31-50	2,022	1,691	Milk+FPBB 1.7 (1.5, 1.8)	1,058	Margarine 1.0 (0.8, 1.1)	262	Fish 0.7 (0.4, 1.0) ^E	1,148	Eggs 0.5 (0.4, 0.6)	1,691	Milk+FPBB 3.1 (2.8, 3.5)	1,058	Margarine 1.5 (1.2, 1.7)	296	Yogurt 1.1 (0.8, 1.3)	262	Fish 0.7 (0.4, 1.0) ^E
M 51-70	2138	1,,790	Milk+FPBB 1.7 (1.5, 1.9)	1,232	Margarine 1.4 (1.2, 1.6)	346	Fish 1.3 (0.9, 1.7)	1,252	Eggs 0.5 (0.4, 0.5)	1,790	Milk+FPBB 3.3 (2.9, 3.6)	1,232	Margarine 2.1 (1.8, 2.4)	346	Fish 1.3 (0.9, 1.7)	342	Yogurt 1.0 (0.8, 1.3)
M ≥71	1,164	1,042	Milk+FPBB 1.8 (1.6, 2.0)	733	Margarine 1.2 (1.1, 1.4)	202	Fish 0.8 (0.5, 1.1)	748	Eggs 0.4 (0.4, 0.5)	1,042	Milk+FPBB 3.4 (3.0, 3.7)	733	Margarine 1.9 (1.7, 2.1)	164	Yogurt 1.0 (0.7, 1.3)	202	Fish 0.8 (0.5, 1.1)
M ≥19	6,159	5,192	Milk+FPBB 1.8 (1.7, 1.9)	3,450	Margarine 1.1 (1.0, 1.2)	906	Fish 0.9 (0.7, 1.1)	3,622	Eggs 0.5 (0.4, 0.5)	5,192	Milk+FPBB 3.5 (3.2, 3.7)	3,450	Margarine 1.7 (1.6, 1.8)	921	Yogurt 1.0 (0.9, 1.2)	906	Fish 0.9 (0.7, 1.1)
F 9-13	938	818	Milk+FPBB 2.8 (2.5, 3.1)	518	Margarine 0.9 (0.7, 1.0)	76	Fish 0.3 (0.1, 0.4) ^E	560	Eggs 0.3 (0.2, 0.3)	818	Milk+FPBB 5.4 (4.9, 6.0)	518	Margarine 1.3 (1.1, 1.5)	207	Yogurt 1.2 (1.0, 1.5)	76	Fish 0.3 (0.1, 0.4) ^E
F 14-18	985	801	Milk+FPBB 2.5 (2.2, 2.8)	87	Fish 0.8 (0.3, 1.3) ^E	502	Margarine 0.7 (0.6, 0.8)	550	Eggs 0.2 (0.2, 0.3)	801	Milk+FPBB 4.8 (4.2, 5.3)	158	Yogurt 1.0 (0.7, 1.3)	502	Margarine 1.0 (0.9, 1.2)	87	Fish 0.8 (0.3, 1.3) ^E

F 19-30	871	715	Milk+FPBB 1.8 (1.5, 2.2)	101	Fish F	446	Margarine 0.7 (0.6, 0.9)	496	Eggs 0.3 (0.3, 0.4)	715	Milk+FPBB 3.5 (2.8, 4.2)	184	Yogurt 1.3 (0.7, 1.9) ^E	446	Margarine 1.1 (0.9, 1.3)	101	Fish F
F 31-50	2,189	1,873	Milk+FPBB 1.5 (1.3, 1.6)	1,124	Margarine 0.8 (0.7, 0.9)	296	Fish 0.7 (0.5, 0.9)	1,209	Eggs 0.3 (0.3, 0.4)	1,873	Milk+FPBB 2.8 (2.5, 3.1)	501	Yogurt 1.4 (1.1, 1.7)	1,124	Margarine 1.2 (1.0, 1.4)	296	Fish 0.7 (0.5, 0.9)
F 51-70	2,287	1,927	Milk+FPBB 1.4 (1.3, 1.5)	359	Fish 0.8 (0.6, 1.0)	1,252	Margarine 0.8 (0.7, 0.9)	1,274	Eggs 0.3 (0.2, 0.3)	1,927	Milk+FPBB 2.7 (2.5, 3.0)	597	Yogurt 1.6 (1.4, 1.8)	1,252	Margarine 1.2 (1.1, 1.4)	359	Fish 0.8 (0.6, 1.0)
F ≥71	1,428	1,277	Milk+FPBB 1.5 (1.4, 1.7)	853	Margarine 0.8 (0.8, 0.9)	229	Fish 0.7 (0.5, 0.9)	864	Eggs 0.3 (0.3, 0.3)	1,277	Milk+FPBB 3.0 (2.6, 3.3)	853	Margarine 1.3 (1.2, 1.4)	325	Yogurt 1.3 (1.0, 1.5)	229	Fish 0.7 (0.5, 0.9)
F ≥19	6,775	5,792	Milk+FPBB 1.5 (1.4, 1.6)	3,675	Margarine 0.8 (0.7, 0.9)	985	Fish 0.8 (0.6, 0.9)	3,843	Eggs 0.3 (0.3, 0.3)	5,792	Milk+FPBB 2.9 (2.7, 3.1)	1,607	Yogurt 1.5 (1.3, 1.6)	3,675	Margarine 1.2 (1.1, 1.3)	985	Fish 0.8 (0.6, 0.9)
F Pregnant or Lactating	300	276	Milk+FPBB 2.7 (2.3, 3.2)	153	Margarine 0.7 (0.5, 0.9)	42	Fish F	173	Eggs 0.4 (0.3, 0.5)	276	Milk+FPBB 5.3 (4.4, 6.2)	82	Yogurt 1.7 (1.1, 2.4) ^E	153	Margarine 1.1 (0.8, 1.3)	42	Fish F

¹ Data are mean (95%CI) (µg/day). Top food sources are for supplement non-users and users combined. Total sample size does not equal overall survey given only top 4 sources of vitamin D from food. Values with superscript E indicate a coefficient of variation (CV%) of 16.6-33.3, interpret with caution; and F >33.3% or n<10 data are not reliable estimates and are suppressed. Abbreviations: F: female; FPBB: fortified plant-based beverages; M: male.

Table 4. Top four food sources of vitamin D (µg/day) of people living in Canada 1 year of age and over by self-reported racial group or Indigenous-identity in 2015 and after applying scenario 1 for increased amounts of vitamin D in milks, fortified plant-based beverages, margarine and yogurt/kefir¹.

Self-reported Group	2015								Scenario 1									
	Top source			Second source		Third source		Fourth source		Top source			Second source		Third source		Fourth source	
	n	n	Mean (95%CI)	n	Mean (95%CI)	n	Mean (95%CI)	n	Mean (95%CI)	n	Mean (95%CI)	n	Mean (95%CI)	n	Mean (95%CI)	n	Mean (95%CI)	
Black	381	291	Milk+FPBB 1.7 (1.3, 2.0)	74	Fish F	196	Margarine 0.7 (0.5, 1.0) ^E	187	Eggs 0.3 (0.2, 0.5) ^E	291	Milk+FPBB 3.2 (2.5, 3.9)	74	Fish F	196	Margarine 1.1 (0.7, 1.5) ^E	59	Yogurt 0.8 (0.4, 1.2) ^E	
East Asian	732	562	Milk+FPBB 1.4 (1.2, 1.6)	178	Fish 1.3 (0.6, 2.1)	444	Margarine 1.0 (0.7, 1.2)	464	Eggs 0.4 (0.3, 0.4)	562	Milk+FPBB 2.7 (2.3, 3.2)	444	Margarine 1.5 (1.1, 1.9)	178	Fish 1.3 (0.6, 2.1) ^E	141	Yogurt 0.8 (0.6, 1.1) ^E	
Indigenous	895	761	Milk+FPBB 2.1 (1.7, 2.5)	471	Margarine 1.0 (0.8, 1.1)	60	Fish F	509	Eggs 0.3 (0.2, 0.4)	761	Milk+FPBB 4.1 (3.3, 4.9)	471	Margarine 1.5 (1.2, 1.7)	152	Yogurt 0.9 (0.7, 1.2)	60	Fish F	
Latino	199	169	Milk+FPBB 2.0 (1.6, 2.4)	30	Fish F	97	Margarine 0.5 (0.4, 0.7)	109	Eggs 0.5 (0.3, 0.6)	169	Milk+FPBB 3.9 (3.0, 4.8)	49	Yogurt 1.1 (0.5, 1.8) ^E	30	Fish F	97	Margarine 0.8 (0.6, 1.1)	
Middle Eastern	309	251	Milk+FPBB 1.6 (1.3, 1.9)	155	Margarine 0.6 (0.5, 0.8)	50	Fish 0.6 (0.2, 1.0) ^E	169	Eggs 0.4 (0.2, 0.5) ^E	251	Milk+FPBB 3.0 (2.4, 3.6)	83	Yogurt 1.7 (0.9, 2.4) ^E	155	Margarine 1.0 (0.7, 1.2)	50	Fish 0.6 (0.2, 1.0) ^E	
South Asian	659	571	Milk+FPBB 2.5 (2.1, 2.9)	371	Margarine 0.7 (0.6, 0.9)	78	Fish 0.3 (0.2, 0.4) ^E	333	Eggs 0.3 (0.2, 0.3)	571	Milk+FPBB 4.9 (4.1, 5.7)	176	Yogurt 1.6 (0.9, 2.3) ^E	371	Margarine 1.1 (0.9, 1.3)	78	Fish 0.3 (0.2, 0.4) ^E	
South East Asian	506	127	Fish 1.5 (0.9, 2.1) ^E	390	Milk+FPBB 1.4 (1.2, 1.7)	267	Margarine 0.8 (0.5, 1.1) ^E	300	Eggs F	390	Milk+FPBB 2.7 (2.2, 3.1)	127	Fish 1.5 (0.9, 2.1) ^E	267	Margarine 1.2 (0.7, 1.7) ^E	300	Eggs F	
All Others	684	592	Milk+FPBB 1.8 (1.5, 2.0)	97	Fish 1.2 (0.5, 1.8) ^E	362	Margarine 0.7 (0.6, 0.8)	387	Eggs 0.3 (0.2, 0.4)	592	Milk+FPBB 3.4 (2.9, 3.9)	160	Yogurt 1.3 (0.9, 1.7)	97	Fish 1.2 (0.5, 1.8) ^E	362	Margarine 1.1 (0.9, 1.3)	
White	14,902	13,051	Milk+FPBB 2.0 (2.0, 2.1)	8,073	Margarine 1.0 (0.9, 1.0)	1,773	Fish 0.6 (0.5, 0.7)	8,669	Eggs 0.4 (0.3, 0.4)	13,051	Milk+FPBB 3.9 (3.7, 4.0)	8,073	Margarine 1.5 (1.4, 1.5)	3,404	Yogurt 1.4 (1.3, 1.5)	1,773	Fish 0.6 (0.5, 0.7)	

¹ Data are mean (95%CI) (µg/day), pregnant/lactating participants excluded. Top food sources are for supplement non-users and users combined. Racial group and Indigenous-identity are self-reported and categorized based on standards for data collection and reporting in Canada (23). Total sample size does not equal overall survey given only top 4 sources of vitamin D from food. Values with superscript E indicate a coefficient of variation (CV%) of 16.6-33.3, interpret with caution; and F >33.3% or n<10 data are not reliable estimates and are suppressed. Abbreviations: FPBB: fortified plant-based beverages.

Table 5. Vitamin D status of people 3-79 years living in Canada using Canadian Health Measures Survey Data cycles 3-6, 2012-2019 and relative change expected based on modeling of vitamin D intakes using updated fortification amounts under scenario 1

Population Prevalence Based on Serum 25(OH)D Concentration													
		<30 nmol/L				<40 nmol/L				>125 nmol/L			
Age-sex Group (years)	n	Observed Status % (95%CI) ¹	Predicted Status by Regression	Anticipated Status by Regression	% Change Anticipated vs. Predicted ²	Observed Status % (95%CI)	Predicted Status by Regression	Anticipated Status by Regression	% Change Anticipated vs. Predicted ²	Observed Status % (95%CI)	Predicted Status by Regression	Anticipated Status by Regression	% Change Anticipated vs. Predicted ²
Children													
MF 3-5	1,889	F	1.3 (0.9, 1.8) ^E	0.7 (0.4, 0.9) ^E	↓46.2 ^E	5.5 (3.6, 7.4) ^E	8.0 (6.1, 9.8)	4.5 (3.3, 5.7)	↓43.8	0.9 (0.4, 1.4) ^E	3.0 (2.4, 3.6)	7.3 (6.0, 8.6)	↑143.3
MF 6-8	1,603	F	2.2 (1.5, 2.8)	1.0 (0.7, 1.4) ^E	↓54.5 ^E	8.8 (5.0, 12.5) ^E	10.7 (8.5, 13.0)	6.5 (4.9, 8.2)	↓39.3	F	2.3 (1.8, 2.7)	5.4 (4.4, 6.4)	↑134.8
M 9-13	1,555	4.3 (2.3, 6.4) ^E	3.1 (2.2, 4.0)	1.9 (1.2, 2.5) ^E	↓38.7 ^E	12.0 (8.1, 16.0)	14.0 (11.5, 16.5)	9.2 (7.1, 11.3)	↓34.3	F	1.3 (1.0, 1.5)	3.5 (2.9, 4.1)	↑169.2
F 9-13	1,518	3.8 (1.9, 5.6) ^E	3.1 (2.3, 3.8)	2.0 (1.4, 2.6)	↓35.5	14.1 (9.7, 18.6)	14.2 (11.8, 16.5)	9.6 (7.8, 11.5)	↓32.4	F	1.3 (1.0, 1.6)	3.3 (2.7, 3.9)	↑153.8
M 14-18	1,178	10.5 (6.8, 14.2) ^E	5.9 (4.2, 7.7)	4.3 (2.7, 5.8) ^E	↓27.1 ^E	24.2 (18.0, 30.4)	21.6 (18.2, 25.0)	15.4 (12.4, 18.3)	↓28.7	F	0.7 (0.5, 0.9)	2.2 (1.5, 2.8)	↑214.3
F 14-18	1,141	11.4 (6.8, 16.1) ^E	6.7 (4.9, 8.5)	4.9 (3.4, 6.3)	↓26.9	23.5 (17.5, 29.5)	23.5 (19.7, 27.3)	18.2 (14.8, 21.5)	↓22.6	F	0.5 (0.3, 0.6)	1.1 (0.8, 1.4)	↑120.0
MF 3-18	8,884	5.7 (4.0, 7.3)	3.7 (2.8, 4.7)	2.5 (1.7, 3.2)	↓32.4	14.7 (11.5, 18.0)	15.3 (12.9, 17.7)	10.6 (8.7, 12.5)	↓30.7	E	1.5 (1.2, 1.8)	3.8 (3.2, 4.4)	↑153.3
Adults													
M 19-50	3,684	11.4 (7.5, 15.0)	10.7 (8.6, 12.1)	7.2 (5.8, 8.7)	↓30.1	25.8 (20.6, 31.0)	27.5 (24.6, 30.5)	20.3 (17.7, 23.0)	↓26.2	0.8 (0.2, 1.3) ^F	1.7 (1.4, 1.9)	3.8 (3.2, 4.4)	↑123.5
F 19-50	3,590	9.5 (6.5, 12.4)	7.0 (5.8, 8.1)	4.8 (3.9, 5.7)	↓31.4	22.4 (17.6, 27.3)	20.9 (18.4, 23.4)	15.7 (13.6, 17.9)	↓24.9	2.3 (0.9, 3.6) ^E	2.9 (2.4, 3.5)	5.4 (4.6, 6.2)	↑86.2 ^E
M 51-79	2,603	6.7 (4.5, 8.8)	5.0 (4.1, 6.0)	3.7 (2.9, 4.6)	↓26.0	15.8 (12.1, 19.4)	16.4 (14.2, 18.6)	12.6 (10.7, 14.5)	↓23.2	1.9 (1.0, 2.8) ^E	4.0 (3.4, 4.7)	7.0 (5.9, 8.1)	↑75.0 ^E
F 51-79	2,626	3.5 (2.1, 48) ^E	2.6 (1.8, 3.3)	1.7 (1.1, 2.3) ^E	↓34.6 ^E	9.3 (7.2, 11.4)	9.6 (8.1, 11.1)	6.8 (5.5, 8.2)	↓29.2	7.4 (5.1, 9.7)	8.8 (7.8, 9.7)	14.0 (12.6, 15.4)	↑59.1
MF 19-79	12,503	8.2 (6.2, 10.2)	6.6 (5.6, 7.7)	4.6 (3.8, 5.5)	↓30.3	19.3 (15.8, 22.7)	19.6 (17.4, 21.7)	14.6 (12.8, 16.4)	↓25.5	2.8 (2.0, 3.7)	4.0 (3.6, 4.5)	7.1 (6.3, 7.8)	↑77.5

¹ Data are proportion (%), 95%CI, for each serum 25-hydroxyvitamin D (25(OH)D) concentration thresholds.

² Data are relative changes in the general population calculated from the difference between the regression prediction modeled using data before (2015 amounts of vitamin D) and after applying the revised fortification amounts in milks, fortified plant-based beverages, margarine and yogurt and according to frequency of daily consumption; some children (n=46) and adults (n=371) reported no consumption of fortified foods and thus were included using observed data only. The %change (anticipated vs. predicted) is expressed as a percent of regression predicted values. Each regression model included vitamin D intake from each of the fortified foods, as well as age (continuous), sex (Male: M, or female: F), body mass index (continuous), disaggregated self-reported racial group or Indigenous-identity, highest household education (high school or less, postsecondary or not reported) and time of blood draw (April-October; November-March); supplement use was included in the modeling. Analytical sample excluded participants without body mass index, pregnant females, or if outliers in the regression analyses (residual >3). Values with superscript E indicate a coefficient of variation (CV%) of 16.6-33.3, interpret with caution; and F >33.3% or n<10 data are not reliable estimates and are suppressed.

Unclassified / Non classifié

