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Vitamin D deficiency in Chilean women aged 18–49 y and adults aged ≥65 y: Prevalence and associated factors in a nationally representative survey

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ABSTRACT

Background: Vitamin D status is influenced by age, adiposity, sunlight exposure, season, and latitude. Chile's pronounced north–south geographic gradient provides a distinctive setting for examining these determinants in population groups at increased risk of deficiency.
Objectives: To estimate the prevalence of vitamin D deficiency among women aged 18–49 y and adults aged 65 y or older in Chile, examine associated factors, and determine whether seasonal patterns differed geographically.
Methods: This cross-sectional study used data from the nationally representative Chilean National Health Survey 2016–2017. Serum 25-hydroxyvitamin D concentrations below 20 ng/mL were classified as deficient. Analyses incorporated survey weights, strata, and primary sampling units. Associations were examined separately in each population using survey-weighted Poisson regression and are reported as adjusted prevalence ratios with 95% confidence intervals (CIs). Interactions between season and geographic macroregion were evaluated using design-adjusted Wald tests.
Results: The analysis included 1270 women and 993 older adults; complete-case regression models included 1182 and 976 participants, respectively. In these complete-case samples, weighted deficiency prevalence was 50.5% (95% CI 45.1–55.9) among women and 61.8% (55.7–67.6) among older adults. Among women, spring blood collection was associated with higher prevalence than summer collection (adjusted prevalence ratio 2.29, 95% CI 1.66–3.15). Compared with the northern macroregion, prevalence was higher in the central (1.67, 1.30–2.14), southern (2.41, 1.90–3.06), and austral (4.08, 3.02–5.50) macroregions. The season-by-macroregion interaction was significant ($P < 0.001$). Among older adults, deficiency was associated with female sex (1.35, 1.10–1.67), spring blood collection (1.48, 1.11–1.96), and residence in the southern (1.35, 1.11–1.64) or austral (1.74, 1.38–2.20) macroregions. No season-by-macroregion interaction was evident ($P = 0.563$). Sensitivity analyses supported the main findings.
Conclusions: Vitamin D deficiency was common in both populations and showed marked seasonal and geographic patterning, particularly among adult women. These findings may inform geographically and seasonally targeted surveillance and prevention strategies.
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Introduction

Skin synthesis following ultraviolet B radiation exposure constitutes the primary source of vitamin D for most individuals. Vitamin D has an established role in calcium and phosphorus homeostasis

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and in maintaining skeletal health [1]. Serum 25-hydroxyvitamin D [25(OH)D], its principal circulating metabolite, is considered the most appropriate biomarker of vitamin D status [2].

For population-based analyses, a serum 25(OH)D concentration below 20 ng/mL (50 nmol/L) is commonly used as an operational threshold for vitamin D deficiency [3], although the interpretation of this threshold can vary according to the population and clinical context.

Vitamin D status reflects the combined influence of individual, behavioral, and environmental factors. Cutaneous synthesis decreases with age, while greater adiposity is associated with lower circulating 25(OH)D concentrations. Sun-exposure behaviors, skin pigmentation, season, and latitude can also influence vitamin D status by modifying the availability of ultraviolet B radiation [4–6].

Chile provides a particularly relevant setting in which to examine these determinants. The country extends for more than 4000 km from north to south, encompassing climatic environments ranging from the Atacama Desert to the subpolar regions of Patagonia. This pronounced latitudinal gradient is accompanied by substantial geographic and seasonal variation in solar radiation, which could produce marked differences in vitamin D status across the country. These environmental differences may be especially relevant for older adults, whose capacity for cutaneous vitamin D synthesis is reduced [4].

Previous studies in Chile have reported a high prevalence of vitamin D deficiency in selected populations, including postmenopausal women and other geographically or clinically defined groups [7,8]. Analyses of the Chilean National Health Survey 2016–2017 have also examined social and geographic determinants of vitamin D deficiency among older adults [9]. However, regional variation across Chile and the extent to which seasonal patterns differ geographically among adult women and older adults remain insufficiently characterized.

Against this background, we used data from the Chilean National Health Survey 2016–2017 to estimate the prevalence of vitamin D deficiency among women aged 18–49 y and adults aged 65 y or older, examine its associations with sociodemographic, geographic, and seasonal factors, and assess whether seasonal patterns in vitamin D status differed across geographic areas.

Methods

Study design and data source

This cross-sectional study used data from the Chilean National Health Survey 2016–2017 (ENS), a nationally representative, population-based survey of people living in private households in Chile [10]. The ENS used a stratified, multistage probability sampling design and included household interviews, standardized anthropometric measurements, and the collection of biological samples.

Serum 25-hydroxyvitamin D [25(OH)D] was measured by the ENS in two prespecified population groups: women aged 15–49 y and adults aged 65 y or older. For the present study, analyses were conducted separately for adult women aged 18–49 y and adults aged 65 y or older of both sexes. Consequently, the estimates apply to these two population groups and not to the entire adult population of Chile.

Participants were eligible if they had a valid serum 25(OH)D measurement and information on region of residence and season of blood collection. Primary analyses excluded participants with high alcohol consumption or a history of chronic liver or kidney disease because these conditions may affect circulating 25(OH)D concentrations. Participant selection is detailed in Figure 1.

Measurement of vitamin D

Serum total 25(OH)D, defined as the sum of 25(OH)D_2 and 25(OH)D_3, was measured in blood samples collected by trained personnel according to standardized ENS protocols. Concentrations were expressed in ng/mL. Serum 25(OH)D was analyzed continuously and dichotomized to define vitamin D deficiency. Deficiency was defined as a serum 25(OH)D concentration below 20 ng/mL.

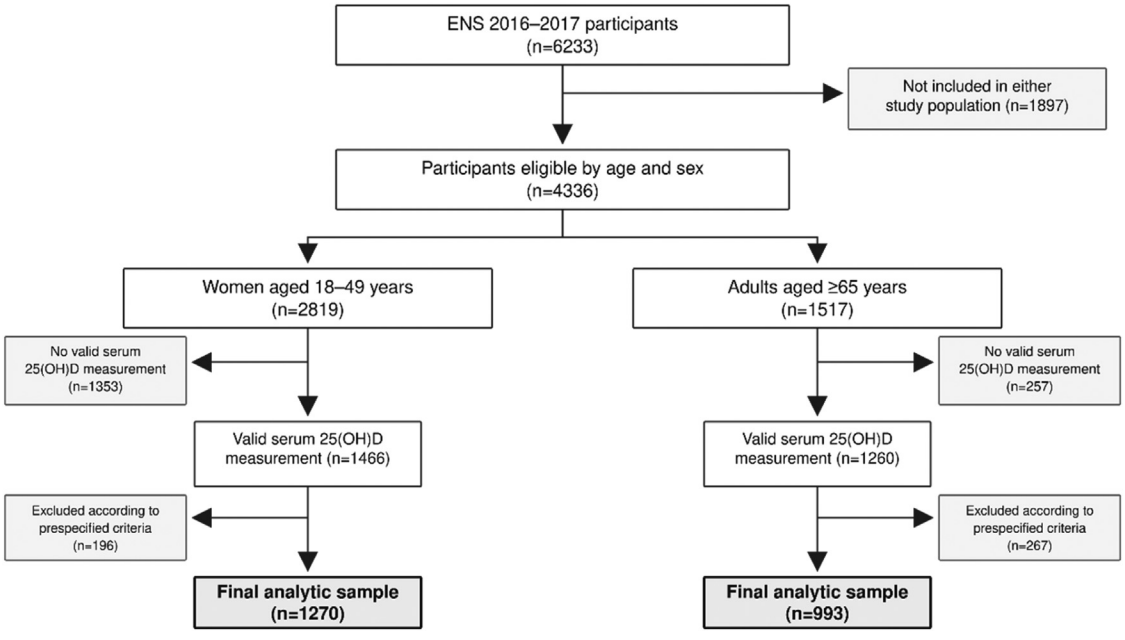


Fig. 1. Flow diagram of participant selection for the analytic samples. Participants from the Chilean National Health Survey 2016–2017 were selected separately for the two study populations: adult women aged 18–49 y and adults aged 65 y or older. Final analytic samples included 1270 adult women and 993 older adults.

Covariates

Age was analyzed continuously in the regression models and expressed in 5-y increments. For descriptive purposes, age was categorized as 18–34 and 35–49 y among adult women and as 65–74 and 75 y or older among older adults. Sex was included only in analyses of adults aged 65 y or older because the younger analytic group consisted exclusively of women.

Body-mass index (BMI) was calculated as weight in kilograms divided by height in meters squared, using standardized anthropometric measurements. BMI was included continuously in the regression models and expressed in increments of 5 kg/m^2.

Area of residence was classified as urban or rural. Self-reported sun exposure was assessed using a questionnaire item referring to sunlight exposure during the week preceding the interview and was categorized as low or high. This variable was regarded as an indicator of recent self-reported behavior rather than a quantitative measure of cumulative ultraviolet B exposure.

Geographic location was defined using the participant's region of residence. The 15 administrative regions were retained for descriptive regional analysis. For multivariable analyses, regions were grouped into four macroregions: north (Arica y Parinacota, Tarapacá, Antofagasta, Atacama, and Coquimbo), central (Valparaíso, Metropolitana, O'Higgins, and Maule), south (Biobío, La Araucanía, Los Ríos, and Los Lagos), and austral (Aysén and Magallanes y Antártica Chilena).

Season was determined from the date of blood collection and classified according to the Southern Hemisphere calendar. Because virtually all eligible measurements were obtained during spring or summer, analyses compared these two seasons. Four observations obtained during autumn were excluded.

Statistical analysis

All analyses incorporated the ENS sampling weights, strata, and primary sampling units. The two study populations were analyzed as separate survey domains using subpopulation estimation procedures, thereby retaining the complete survey design when calculating standard errors.

Participant characteristics were summarized separately for the two study populations, adult women aged 18–49 y and adults aged 65 y or older. Categorical variables are presented as unweighted frequencies and survey-weighted percentages, and continuous variables as survey-weighted means with 95% confidence intervals (CIs). The prevalence of vitamin D deficiency was estimated using survey-weighted proportions with 95% CIs, overall and across sociodemographic, anthropometric, geographic, and seasonal subgroups.

Factors associated with vitamin D deficiency were examined separately in each study population using survey-weighted generalized linear models with a Poisson distribution and log link. Results are reported as adjusted prevalence ratios (aPRs) with 95% CIs. The model for women aged 18–49 y included age, BMI, season of blood collection, geographic macroregion, area of residence, and self-reported sun exposure. The model for adults aged 65 y or older additionally included sex. Age and BMI were entered continuously and rescaled so that their aPRs represented increments of 5 y and 5 kg/m^2, respectively. Global P values for categorical variables were obtained using design-adjusted Wald tests.

Effect modification of the association between season and vitamin D deficiency by geographic macroregion was assessed by adding a season-by-macroregion interaction term to each multivariable model. The interaction was evaluated using a design-adjusted Wald test. When evidence of interaction was identified, adjusted prevalences and contrasts between spring and summer were estimated within each macroregion.

In secondary analyses, survey-weighted mean serum 25(OH)D concentrations were estimated for each administrative region and season using linear regression models containing region, season, and their interaction. Differences in mean concentrations were calculated as spring minus summer, such that negative values indicated lower concentrations during spring. Global region-by-season interactions were evaluated with design-adjusted Wald tests. Region-specific comparisons were considered exploratory and were not adjusted for multiple testing; estimates based on fewer than 20 unweighted observations were identified and interpreted cautiously.

Age-related patterns in serum 25(OH)D concentrations were examined using survey-weighted linear regression, with age retained as a continuous variable and interactions between age and season. Adjusted mean concentrations with 95% CIs were estimated at selected 5-y age values. Models for adults aged 65 y or older were additionally adjusted for sex. Multivariable models used complete observations for all included covariates. The number of observations contributing to each model was reported.

All analyses were conducted using Stata MP, version 17 (StataCorp, College Station, TX, USA) [11]. Tests were two-sided, and P values below 0.05 were considered statistically significant.

Results

Study population

The final analysis included 1270 women aged 18–49 y and 993 adults aged 65 y or older. Participant selection is presented in Figure 1. Most participants in both groups lived in urban areas and had their blood sample collected during spring. Mean BMI was 28.9 kg/m^2 (95% CI 28.4–29.5) among adult women and 28.1 kg/m^2 (27.7–28.6) among older adults. Further characteristics are presented in Table 1.

Adult women

Vitamin D deficiency was present in 50.8% of adult women in the full analytic sample. Among the 1182 women with complete data for all variables included in the multivariable model, the weighted prevalence was 50.5% (95% CI 45.1–55.9).

Prevalence in the complete-case sample was 61.1% (95% CI 54.7–67.2) among women assessed in spring and 28.2% (21.1–36.7) among those assessed in summer. After adjustment, blood collection during spring was associated with a higher prevalence of deficiency (aPR 2.29, 95% CI 1.66–3.15; $P < 0.001$).

Macroregion was also associated with vitamin D deficiency. Prevalence ranged from 31.4% (95% CI 24.9–38.8) in the northern macroregion to 88.2% (77.5–94.2) in the austral macroregion. With the north as the reference, the aPR was 1.67 (95% CI 1.30–2.14) in the central macroregion, 2.41 (1.90–3.06) in the south, and 4.08 (3.02–5.50) in the austral macroregion. The global association was significant ($P < 0.001$). There was also evidence that the association between season and deficiency differed across macroregions (P for interaction <0.001). Age and BMI were not associated with deficiency. The estimates for urban residence (aPR 1.43, 95% CI 0.94–2.19; $P = 0.095$) and low self-reported sun exposure (1.16, 0.98–1.39; $P = 0.090$) did not reach statistical significance (Table 2).

When the 15 administrative regions were examined separately, prevalence ranged from 19.4% (95% CI 12.3–29.2) in Arica and Parinacota to 88.8% (75.5–95.3) in Aysén. The global comparison provided evidence of regional variation ($P = 0.010$) (Supplementary Table S1).

Table 1
Characteristics of adult women and older adults included in the analysis, Chilean National Health Survey 2016–2017

Characteristic	Adult women 18–49 y (n = 1270)	Older adults ≥65 y (n = 993)
Age, y		
18–34	629 (52.2)	-
35–49	641 (47.8)	-
65–74	-	571 (55.8)
≥75	-	422 (44.2)
Sex		
Men	-	327 (38.7)
Women	1270 (100.0)	666 (61.3)
BMI, kg/m^2	28.9 (28.4–29.5)	28.1 (27.7–28.6)
Season of blood collection		
Summer	469 (32.2)	355 (29.3)
Spring	801 (67.8)	638 (70.7)
Area of residence		
Urban	1059 (87.7)	796 (85.1)
Rural	211 (12.3)	197 (14.9)
Self-reported sun exposure in the previous week		
Low	682 (54.5)	680 (63.4)
High	501 (45.5)	313 (36.6)
Geographic macroregion		
North	374 (12.5)	238 (11.7)
Central	455 (61.4)	383 (60.3)
South	332 (24.7)	264 (26.6)
Austral	109 (1.4)	108 (1.5)
Vitamin D status		
No deficiency	638 (49.2)	394 (37.9)
Deficiency	632 (50.8)	599 (62.1)

BMI, body-mass index; CI, confidence interval
Data are unweighted n (survey-weighted %) or survey-weighted mean (95% CI). Estimates account for the sampling weights, stratification, and clustering of the Chilean National Health Survey 2016–2017. Vitamin D deficiency was defined as a serum 25-hydroxyvitamin D concentration below 20 ng/mL (approximately 50 nmol/L)

Table 2
Prevalence and factors associated with vitamin D deficiency among adult women, Chilean National Health Survey 2016–2017

Characteristic	Weighted prevalence, % (95% CI)	aPR (95% CI)	P value*
Overall prevalence	50.5 (45.1–55.9)	-	-
Age, per 5-y increase	-	1.02 (0.97–1.07)	0.535
BMI, per 5 kg/m^2 increase	-	1.01 (0.93–1.09)	0.854
Season of blood collection			<0.001
Summer	28.2 (21.1–36.7)	Ref.	
Spring	61.1 (54.7–67.2)	2.29 (1.66–3.15)	
Geographic macroregion			<0.001
North	31.4 (24.9–38.8)	Ref.	
Central	50.4 (42.5–58.2)	1.67 (1.30–2.14)	
South	59.0 (51.4–66.2)	2.41 (1.90–3.06)	
Austral	88.2 (77.5–94.2)	4.08 (3.02–5.50)	
Area of residence			0.095
Rural	26.2 (17.3–37.7)	Ref.	
Urban	53.9 (47.8–59.8)	1.43 (0.94–2.19)	
Self-reported sun exposure in the previous week			0.09
High	46.2 (39.0–53.5)	Ref.	
Low	54.1 (47.0–61.1)	1.16 (0.98–1.39)	

CI, confidence interval
Analyses were restricted to 1182 adult women with complete data for all variables included in the model. Prevalence estimates are survey-weighted and unadjusted. Adjusted prevalence ratios were estimated using a survey-weighted Poisson regression model with a log link
*Global P values were obtained from design-adjusted Wald tests. Vitamin D deficiency was defined as a serum 25-hydroxyvitamin D concentration below 20 ng/mL.

Mean serum 25-hydroxyvitamin D concentrations varied according to region and season (P for interaction <0.001). Concentrations were generally lower in spring, particularly in central and southern Chile. The mean spring–summer difference was −10.1 ng/mL (95% CI −14.2 to −6.0) in Los Ríos and −10.3 ng/mL (−14.2 to −6.3) in Los Lagos. Some estimates were based on small numbers of observations and should be interpreted cautiously (Supplementary Table S2). Across the age range examined, estimated concentrations remained lower in spring than in summer. Summer concentrations were generally above the deficiency threshold, whereas spring concentrations remained below it across most ages (Fig. 2A).

The main findings were similar when participants meeting the clinical or behavioral exclusion criteria were retained. Analyzing serum 25-hydroxyvitamin D as a continuous outcome also showed lower concentrations during spring and in the central, southern, and austral macroregions. Age, BMI, area of residence, and self-reported sun exposure remained unassociated with vitamin D status (Supplementary Table S3).

Older adults

Vitamin D deficiency was present in 62.1% of older adults in the full analytic sample. Among the 976 participants with complete data for all variables included in the multivariable model, the weighted prevalence was 61.8% (95% CI 55.7–67.6).

In the complete-case sample, prevalence was 69.7% (95% CI 63.0–75.6) among women and 49.5% (39.2–59.9) among men. After adjustment, women had a higher prevalence of deficiency (aPR 1.35, 95% CI 1.10–1.67; P = 0.005).

Prevalence was 68.5% (95% CI 62.4–74.0) among older adults assessed in spring and 45.6% (35.5–56.0) among those assessed in summer. Blood collection during spring remained associated with a higher prevalence after adjustment (aPR 1.48, 95% CI 1.11–1.96; P = 0.007).

Macroregion was associated with vitamin D deficiency (P < 0.001). Compared with the northern macroregion, adjusted prevalence was higher in the south (aPR 1.35, 95% CI 1.11–1.64) and the austral macroregion (1.74, 1.38–2.20). The estimate for the central macroregion was 1.18 (0.96–1.44). Unlike the findings among adult women, there was no evidence that the association between season and deficiency differed across macroregions (P for interaction = 0.563). Age, BMI, area of residence, and recent self-reported sun exposure were not associated with deficiency (Table 3).

Across the 15 administrative regions, prevalence ranged from 29.2% (95% CI 14.4–50.3) in Atacama to 80.4% (64.1–90.4) in Magallanes and Chilean Antarctica. The global comparison did not provide evidence of regional variation (P = 0.475) (Supplementary Table S1). Mean serum 25-hydroxyvitamin D concentrations varied according to region and season (P for interaction = 0.001). The mean spring–summer difference was −8.5 ng/mL (95% CI −11.6 to −5.4) in Biobío and −11.8 ng/mL (−19.0 to −4.6) in Los Lagos. Some seasonal estimates were based on small numbers of participants and had wide CIs (Supplementary Table S2). Estimated concentrations tended to decrease with age, particularly during spring. The difference between seasons became more pronounced at older ages, although CIs widened at the upper end of the age range (Fig. 2B).

Sensitivity analyses produced similar findings when participants meeting the clinical or behavioral exclusion criteria were retained. Female sex, spring blood collection, and residence in the southern or austral macroregions remained associated with vitamin D deficiency. Analyses using continuous 25-hydroxyvitamin D concentrations supported these findings. Urban residence was not associated with binary deficiency but was associated with a lower mean concentration in the continuous analysis (β −3.09 ng/mL, 95% CI −5.24 to −0.93) (Supplementary Table S3).

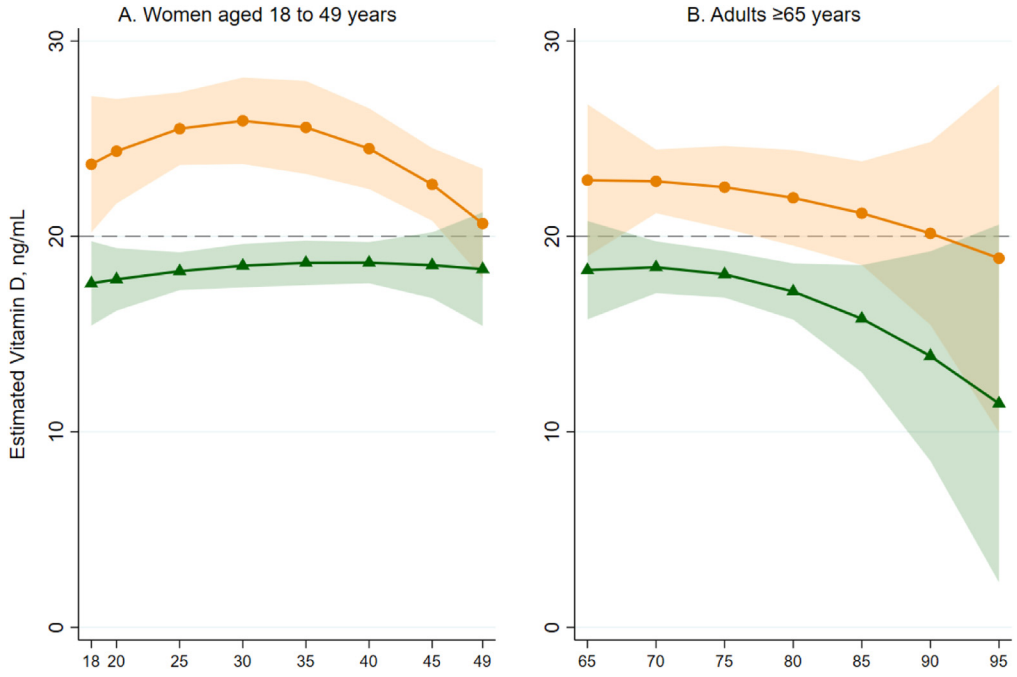


Fig. 2. Estimated serum 25-hydroxyvitamin D concentrations by age and season among adult women and older adults. Lines show survey-weighted mean serum 25-hydroxyvitamin D concentrations by age during summer (orange circles) and spring (green triangles); shaded areas represent 95% CI. The dashed horizontal line indicates the threshold for vitamin D deficiency at 20 ng/mL (approximately 50 nmol/L). Panel (A) shows women aged 18–49 y. Panel (B) shows adults aged 65 y or older, with estimates adjusted for sex. CI, confidence interval.

Table 3
Prevalence and factors associated with vitamin D deficiency among older adults, Chilean National Health Survey 2016–2017

Characteristic	Weighted prevalence, % (95% CI)	aPR (95% CI)	*P* value*
Overall prevalence	61.8 (55.7–67.6)	-	-
Sex			0.005
Men	49.5 (39.2–59.9)	Ref.	
Women	69.7 (63.0–75.6)	1.35 (1.10–1.67)	
Age, per 5-y increase	-	1.02 (0.95–1.09)	0.584
BMI, per 5 kg/m^2 increase	-	1.04 (0.95–1.13)	0.418
Season of blood collection			0.007
Summer	45.6 (35.5–56.0)	Ref.	
Spring	68.5 (62.4–74.0)	1.48 (1.11–1.96)	
Geographic macroregion			<0.001
North	53.2 (43.9–62.2)	Ref.	
Central	63.2 (53.6–71.8)	1.18 (0.96–1.44)	
South	61.5 (53.5–69.0)	1.35 (1.11–1.64)	
Austral	79.6 (67.0–88.2)	1.74 (1.38–2.20)	
Area of residence			0.239
Rural	42.9 (32.8–53.7)	Ref.	
Urban	65.1 (58.0–71.6)	1.20 (0.88–1.64)	
Self-reported sun exposure in the previous week			0.501
High	57.1 (47.5–66.2)	Ref.	
Low	64.6 (57.8–70.8)	1.06 (0.90–1.24)	

Analyses were restricted to 976 older adults with complete data for all variables included in the model. Prevalence estimates are survey-weighted and unadjusted. Adjusted prevalence ratios were estimated using a survey-weighted Poisson regression model with a log link

*Global *P* values were obtained from design-adjusted Wald tests. Vitamin D deficiency was defined as a serum 25-hydroxyvitamin D concentration below 20 ng/mL.

Discussion

Vitamin D deficiency was common in both populations examined in this study, affecting approximately half of women aged 18–49 y and nearly two-thirds of adults aged ≥65 y. The magnitude of deficiency was accompanied by marked geographic and seasonal variation, but these patterns were not identical between the two populations.

Among adult women, geographic location and season were the dominant factors, and the significant season-by-macroregion interaction showed that the seasonal difference was not uniform across the country. Among older adults, deficiency was associated with female sex, spring blood collection, and residence in the southern and austral macroregions, but the seasonal association did not vary significantly by macroregion. Rather than indicating a single national pattern, these findings point to important differences in how vitamin D status is distributed across population groups and geographic settings.

The geographic pattern was particularly striking among adult women. Deficiency ranged from 31.4% in the northern macroregion to 88.2% in the austral macroregion, with an adjusted prevalence more than four times higher in the austral than in the north. Similar geographic variation has been reported in other South American populations [12,13]. In a systematic review and meta-analysis of 96 studies including 227 758 participants, Mendes et al. [14] reported an overall prevalence of vitamin D deficiency of 34.8% and found significant differences according to latitude, season, country, age, and sex. Previous analysis of ENS 2016–2017 data among older Chilean adults likewise found greater latitude to be associated with a higher probability of deficiency [9]. Our findings extend this observation by showing how pronounced the geographic pattern can be among adult women and by demonstrating that it is accompanied by geographic differences in seasonal variation. Although greater latitude may contribute to this pattern through reduced ultraviolet B availability [15], latitude alone is unlikely to explain the observed geographic differences, as geographic location also reflects a broader set of environmental and behavioral determinants of vitamin D status.

The seasonal pattern further illustrates the importance of geographic context. Among adult women, deficiency was 61.1% in

spring compared with 28.2% in summer, but the magnitude of this difference varied across macroregions, resulting in a significant season-by-macroregion interaction. Thus, season should not be considered simply a uniform adjustment factor when describing vitamin D status across Chile. Earlier Chilean work has also shown substantial seasonal variation in vitamin D status, with a reduction in deficiency from 48.9% in winter to 4.9% in summer among women aged 20–39 y living in Santiago [16]. Our results suggest that seasonal differences persist at the national level and that their magnitude varies according to geographic location. The corresponding analyses of continuous 25(OH)D concentrations showed similar geographic and seasonal differences, supporting the consistency of these patterns beyond the 20 ng/mL threshold.

The pattern among older adults was different. Spring was associated with a higher prevalence of deficiency, but the season-by-macroregion interaction was not significant. Geographic differences were also less pronounced than among adult women: prevalence was higher in the southern and austral macroregions, whereas the estimate for the central macroregion was not statistically different from the north. This distinction is important because it argues against interpreting the Chilean north–south gradient as a uniform phenomenon across age groups. Previous analyses of older Chilean adults have also identified geographic location as a correlate of vitamin D status [17]. Although age was not independently associated with deficiency, the continuous analysis showed a tendency toward lower 25(OH)D concentrations with increasing age, particularly during spring. Taken together, these findings suggest that geographic and seasonal heterogeneity may be more pronounced among younger adult women than among older adults.

Among older adults, women had a higher prevalence of deficiency than men, and female sex remained independently associated with the outcome after adjustment. This finding is compatible with previous Chilean evidence [17,18], although sex differences have not been entirely consistent across studies [7]. The high prevalence among women aged 18–49 y also deserves attention from a life-course perspective. Recent evidence from Greece reported a strong correlation between maternal and neonatal 25(OH)D concentrations, supporting the relevance of maternal vitamin D status for neonatal vitamin D status [19]. Our study did not evaluate pregnancy or neonatal outcomes, however, and the finding should therefore be interpreted primarily as evidence that women of reproductive age represent an important population for vitamin D surveillance.

Neither age nor BMI was independently associated with vitamin D deficiency in either study population. The absence of an association with age should be interpreted in the context of the restricted age ranges examined separately, which may limit the ability to detect associations across the broader adult life course. Similarly, although greater adiposity has been consistently associated with lower circulating 25(OH)D concentrations in previous studies [5], BMI was not independently associated with deficiency in our models. This finding differs from the recent analysis by Álamos et al. [17] of Chilean adults aged ≥65 y, in which obesity was independently associated with vitamin D deficiency. Differences in the operationalization of adiposity, analytic samples, covariate adjustment, and statistical modelling may partly account for these apparently divergent findings.

Recent self-reported sun exposure was also not independently associated with deficiency. This finding contrasts with previous Chilean analyses in which lifestyle behaviors related to outdoor exposure and shorter sun exposure were associated with vitamin D status in women and older adults, respectively [17,20]. This result should not be interpreted as evidence that sunlight is unimportant for vitamin D status. The ENS measure referred only to sunlight exposure during the preceding week and therefore provides, at most, an indicator of recent behavior rather than cumulative UVB exposure.

Duration and timing of outdoor activity, occupation, clothing, sunscreen use, skin pigmentation, and local UV conditions were not captured, leaving substantial scope for exposure misclassification and residual confounding.

The high prevalence of vitamin D deficiency observed in both populations has important public health implications, particularly in the context of the mandatory vitamin D fortification policy recently implemented in Chile. Since June 2026, vitamin D3 fortification of fluid milk, powdered milk, and wheat flour has been required [21]. Because the 25(OH)D measurements analyzed here were collected in 2016–2017, our findings provide a prefortification baseline for the two populations studied. The marked geographic and seasonal variation observed in this baseline will be important when assessing whether fortification reduces vitamin D deficiency consistently across population groups, geographic regions, and seasons.

This study has several strengths. It used data from a large, population-based national health survey with a stratified multistage probability sampling design and incorporated survey weights, strata, and primary sampling units in the analyses. Vitamin D status was examined separately in two prespecified population groups, and the consistency of the main findings across binary and continuous 25(OH)D outcomes and sensitivity analyses support their robustness.

Several limitations should be acknowledged. The cross-sectional design precludes causal inference, and because vitamin D was measured only in women aged 18–49 y and adults aged ≥65 y, our findings should not be generalized to the entire Chilean adult population. Blood samples were collected almost exclusively during spring and summer, limiting characterization of the full annual seasonal cycle. Sun exposure was self-reported for the preceding week and did not capture cumulative UVB exposure or other relevant determinants such as outdoor activity, occupation, clothing, sunscreen use, skin pigmentation, or local UV conditions. Dietary intake of vitamin D from foods or supplements was also unavailable. Finally, some region-by-season estimates were based on relatively small subgroups and should be interpreted cautiously.

In conclusion, vitamin D deficiency was highly prevalent among women aged 18–49 y and adults aged ≥65 y in Chile, with distinct geographic and seasonal patterns between the two populations. Among women, geographic variation was particularly pronounced and differed by season, whereas among older adults, deficiency was associated with female sex, spring season, and residence in the southern and austral macroregions. These findings underscore the importance of considering population group, geographic location, and season when monitoring vitamin D status in Chile. As the measurements were obtained before the implementation of mandatory vitamin D fortification, they provide a valuable prefortification baseline for evaluating the population impact of this policy.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

CRediT authorship contribution statement

Frank Carrera-Gil: Writing – review & editing, Writing – original draft. **Samuel Durán Agüero:** Writing – original draft, Supervision, Conceptualization. **Macarena Valladares:** Writing – review & editing, Conceptualization. **Julio Parra-Flores:** Writing – original draft, Conceptualization. **Kevin Correa:** Writing – original draft, Conceptualization. **Macarena Ortiz:** Writing – review & editing, Conceptualization. **Rodrigo Daga:** Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization.

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Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.nut.2026.113441.

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