Health Promotion Perspectives
Shahriyari et al, Health Promotion Perspectives 2026;16(2): x-x
doi:10.34172/hpp.45347
https://hpp.tbzmed.ac.ir
TUOMS PRESS

Original Article

Changes in Micronutrient Intake and Associated Determinants in Iran: A Longitudinal Cohort Analysis Using PERSIAN Cohort Data

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ARTICLE INFO

Article History:
Received: October 18, 2025
Revised: June 7, 2026
Accepted: June 15, 2026
ePublished: xx, 2024

Keywords:
Calcium, Dietary, Eating, Iron, Dietary, Longitudinal studies, Multilevel analysis, Zinc

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Abstract

Introduction: Using data from the Prospective Epidemiological Research Studies in Iran (PERSIAN) Cohort, we assessed longitudinal changes in calcium, iron, and zinc intake between baseline (2015) and reassessment (2021) phases and examined their determinants.

Methods: We analyzed longitudinal data from 32,220 participants aged 35–70 years in the PERSIAN Cohort at baseline (2015) and reassessment (2021). Dietary intake was assessed using a validated 113-item Food Frequency Questionnaire (FFQ), with caution warranted for micronutrient-level estimates. A four-level multilevel model was applied, with repeated measurements (level 1) nested within individuals, households (level 2), residence types (level 3), and interview centers/provinces (level 4). Intraclass correlation coefficients (ICCs) were calculated to estimate the proportion of total variance in mineral intake attributable to each hierarchical level.

Results: Unadjusted paired analyses showed mean daily intakes of calcium, iron, and zinc decreased by 142.5 mg, 1.7 mg, and 1.1 mg, respectively, between baseline and reassessment. In the fully adjusted four-level multilevel model, intake decreased by 151.37 mg/day for calcium, 1.85 mg/day for iron, and 1.25 mg/day for zinc during reassessment. Women consumed 184.25 mg/day less calcium than men, and participants in the highest socioeconomic status group had higher intakes of all three minerals compared with the lowest group. ICCs indicated that 23.9% of calcium variance, 31.7% of iron variance, and 11.7% of zinc variance were attributable to interview centers, with additional 19.9%, 18.4%, and 27.9% attributable to households, respectively.

Conclusions: The decline coincided with challenges and policy changes in Iran, which may have contributed to dietary shifts, although these factors were not measured. These findings highlight the need for interventions to improve mineral intake.

Introduction

A nutrition transition describes the dietary and nutritional changes driven by economic, social, and demographic shifts.[1] Typically, these transitions involve a prominent shift from basic, minimally processed foods to diets predominantly rich in meat, vegetable oils, and highly processed items.[2] Despite these transitions, micronutrient deficiencies remain a pressing global health issue in the twenty-first century, affecting approximately two billion people globally.[3] Micronutrients, often referred to by the World Health Organization as 'magic wands', encompass essential vitamins and minerals that are vital for optimal health and human development.[4, 5]

Micronutrient deficiency contributes significantly to the pathogenesis of chronic diseases, accelerates biological aging, and exacerbates vulnerability to disability in older adults.[6] Numerous studies have established robust associations between mineral deficiencies and adverse health consequences, including decreased immunity,[7] anemia,[8] neurodegenerative diseases,[9] metabolic disorders,[10] cancer,[11] cardiovascular diseases,[12] and increased morbidity and mortality. Therefore, minerals are required as essential nutrients for humans to carry out the functions necessary for life and health.[13]

In the context of micronutrient deficiencies, adequate daily consumption of essential minerals such as calcium, iron, and zinc are of paramount importance. Insufficient consumption of these minerals can lead to serious health complications.[14] For instance, inadequate calcium consumption is linked to osteoporosis, hypertension, and certain malignancies.[14] Iron is vital for various metabolic processes, and its deficiency is particularly concerning for adult women, who experience a disproportionately higher risk for anemia and related complications.[15] Similarly, zinc deficiency has significant clinical implications, as it impairs immune competence, delays wound healing, and induces anorexia, thereby compounding existing health challenges.[15] Therefore, addressing these specific mineral deficiencies is crucial for maintaining overall health and well-being, especially amidst the ongoing nutrition transition.

Monitoring the nutritional status of the population is essential for the development of any intervention. Many countries monitor trends in micronutrient intake through population-based national surveys. [16-19] Numerous studies have been carried out in Iran, such as the Tehran Lipid and Glucose Cohort Study (TLGS),[20] the Golestan Cohort Study,[21] and the Isfahan Heart Study,[22] however, these are fundamentally single-center investigations that provide limited insights into secular dietary shifts within their target populations. Furthermore, while the National Food and Nutrition Surveillance (FNS) program has aimed to monitor the nutritional status of the Iranian population, it primarily relies on cross-sectional data collection, which limits its ability to identify longitudinal trends and changes in nutritional status.[23] Despite these efforts, a critical research gap persists in previous studies. Previous longitudinal studies have lacked nationwide geographic and ethnic generalizability.[24, 25] More importantly, no study to date has evaluated longitudinal variations across multiple essential minerals—specifically calcium, iron, and zinc—simultaneously within a nationally representative cohort during recent periods of rapid macroeconomic transition and food subsidy adjustments.[26] Furthermore, traditional statistical approaches in earlier studies have rarely accounted for the hierarchical, nested structure of dietary behavior data (where individuals are nested within households, urban/rural residential zones, and distinct geographical interview centers). Failing to address this hierarchical framework can conceal crucial contextual variations and lead to underestimated standard errors in epidemiological inferences.[27]

In contrast, the Prospective Epidemiological Research Studies in IrAN (PERSIAN), launched in 2014, encompasses participants from all ethnicities and cultures across Iran.[28] The re-assessment phase of this cohort study was conducted in 2021, and baseline information for the same individuals was re-examined. It is important to highlight that the period between the baseline and re-assessment phases coincided with substantial economic difficulties experienced by the Iranian population. For instance, the inflation rate in various consumer items (such as meat at 116%, bread and grains at 58%, oils and fats at 240%, milk, cheese, and eggs at 83.5%, and vegetables and legumes at 68.5%) has risen sharply.[26, 29] Other economic factors such as unemployment, the growth of marginalization, poverty, and the lack of suitable job opportunities have also increased.[30] Consequently, society has faced numerous challenges over the years that could have profoundly affected nutritional status and health.

Therefore, this research aimed to examine changes in mineral intake (calcium, iron, and zinc) among participants of the PERSIAN Cohort, utilizing paired longitudinal data from the baseline (2015) and re-assessment (2021) phases. Additionally, we aimed to quantify the fixed and random effects of multi-level determinants driving these longitudinal alterations.

Methods

Study design and population

The data for this study come from the enrolment and re-assessment phases of the PERSIAN cohort, a multicenter, prospective cohort study investigating the roles of metabolic, dietary, lifestyle, and environmental factors in the development of chronic diseases.[31] The cohort includes a sample size of 160,000 individuals aged 35 to 70 years from 18 geographically distinct areas of Iran. The participant centers were chosen to cover the true cultural, genetic, lifestyle, and environmental variations, representing the whole country. The locations of the PERSIAN cohort sites are shown in Figure 1, with more details provided elsewhere.[31]

The PERSIAN Cohort study was conducted in accordance with the guidelines set forth in the Declaration of Helsinki, and all procedures involving participants were approved by the Ethics Committee of the Ministry of Health and Medical Education (MOHME) and the Digestive Diseases Research Institute (DDRI), Tehran University of Medical Sciences, Iran.[31] The present study, which used data from the PERSIAN Cohort, was approved by the Ethics Committee of Kermanshah University of Medical Sciences (No: KUMS.REC.1403.095). After completing the pilot phase, the baseline phase of the PERSIAN Cohort began in March 2015. For the re-assessment phase, conducted six years later in 2021, a predefined subsample representing approximately 30% of the initial participants was selected using a multistage random sampling procedure. In cohorts comprising both urban and rural populations, participants were first stratified according to urban/rural residence, followed by systematic random sampling of households within each stratum.

Consequently, 36,813 individuals underwent repeated evaluations of their medical, demographic, behavioral, and nutritional characteristics. In alignment with the study objectives, participants with atypical energy intakes (defined as less than 500 or greater than 3,500 kcal/day for women, and less than 800 or more than 4,200 kcal/day for men) were excluded.[32, 33] Ultimately, 32,220 participants with repeated nutritional assessments were retained for analysis (Figure 2).

Explanatory Variables

Individual-Level Characteristics (Measurements and Definitions)

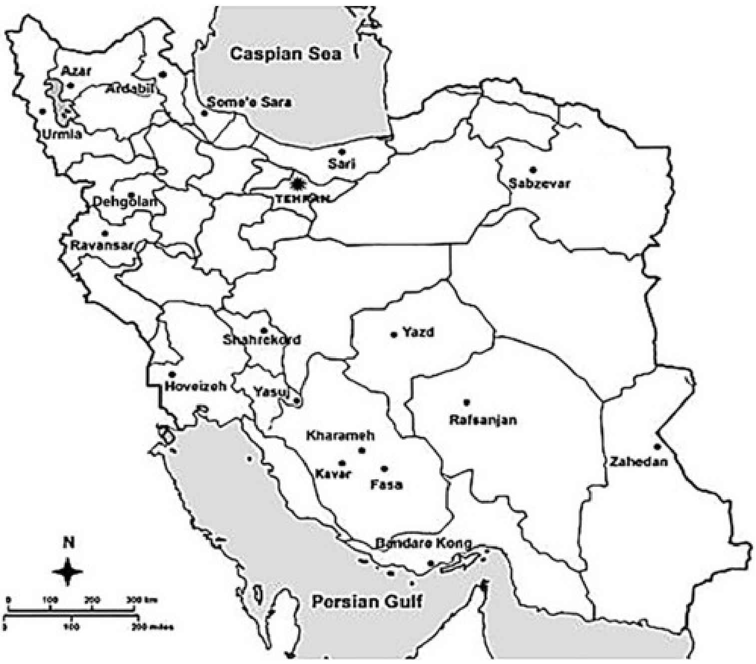

Figure 1. Locations of research centers in the PERSIAN Cohort Study, Iran, 2014–2021. The sites were chosen so that all of the major ethnic groups in Iran, as well as variable climates and geographical regions, are included. PERSIAN, Prospective Epidemiological Research Studies in Iran[31]

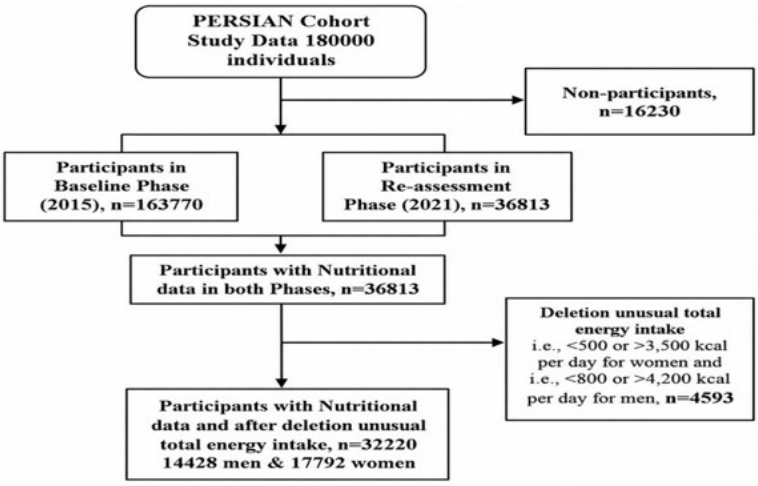

Figure 2. Flowchart of the study participants

Demographic data and additional information were collected through face-to-face interviews using a digital questionnaire. Socioeconomic status (SES) was assessed using the Wealth Score Index (WSI), a composite measure based on household assets, housing characteristics, and access to welfare facilities within the PERSIAN cohort. The index was derived using principal component analysis (PCA), and participants were categorized into five socioeconomic groups ranging from the poorest to the richest according to standardized PERSIAN cohort protocols.[31, 34, 35] Physical activity was assessed via 22 questions measuring the total hours of various activities over a 24-hour period, expressed as the Metabolic Equivalent of Task (MET).[31] Body Mass Index (BMI) was calculated as weight in kilograms divided by the square of height in meters (BMI = weight [kg] / height [m]^2). Based on BMI values, participants were classified as follows: underweight (BMI < 18.5), normal weight (BMI 18.5–24.9), overweight (BMI 25.0–29.9), and obese (BMI ≥ 30) [36]. Oral health was assessed using the Decayed, Missing, and Filled (DMF) index, representing the total number of teeth that were decayed (D), missing due to decay (M), or filled (F). Sleep duration was measured by asking participants to report the average number of hours they typically sleep per day.[36] Smoking status was self-reported and classified into current smokers (smoking at least one cigarette per day and with a lifetime consumption of over 100 cigarettes), former smokers (those who smoked more than 100 cigarettes in the past but not during the last year), and never smokers (never smoked or smoked fewer than 100 cigarettes).[37] Metabolic Syndrome (MetS) was defined according to the Joint Interim Statement (JIS) criteria adapted for Iranian adults, requiring the presence of at least three of the following: fasting blood glucose ≥ 100 mg/dl or use of glucose-lowering medication; triglycerides ≥ 150 mg/dl or use of triglyceride-lowering medication; low HDL cholesterol (≤ 40 mg/dl for men, ≤ 50 mg/dl for women) or use of HDL-raising drugs; elevated systolic (≥ 130 mmHg) or diastolic (≥ 85 mmHg) blood pressure or antihypertensive medication; and increased waist circumference (≥ 94 cm for men, ≥ 80 cm for women).[38] According to the PERSIAN cohort protocol, cardiovascular disease (CVD) cases included individuals with a history of hospitalization or treatment for cardiac conditions such as stroke, myocardial infarction, or coronary artery disease, or those taking relevant medications. Type 2 diabetes (T2D) diagnosis was based on fasting blood sugar ≥ 126 mg/dl or use of hypoglycemic drugs, and hypertension (HTN) was defined by systolic blood pressure ≥ 140 mmHg, diastolic blood pressure ≥ 90 mmHg, or use of antihypertensive drugs.[39] The variable "time" was categorized into two groups: the first group corresponded to the baseline phase of the study (2015-2017), and the second group corresponded to the reassessment phase (2021-2023).

Food Intake

A validated Food Frequency Questionnaire (FFQ) was utilized to assess participant's dietary intake both at baseline and during the re-assessment phase to evaluate changes in dietary intake. The FFQ included 113 food items assessing the frequency of intake along with their corresponding standard portion sizes (e.g., glass, cup, slice, teaspoon, tablespoon, spatula, cube). Participants reported the average frequency and portion size of these foods consumed over the past year. To reduce recall bias, trained interviewers administered the FFQ and provided participants adequate time to recall details for each food item.[39, 40] Subsequently, the FFQ data were analyzed using the United States Department of Agriculture (USDA) Food Composition Databases to estimate energy, macronutrient and micronutrient consumption.[39-41] A nutrient database was prepared using standard, non-branded foods from the USDA Food Composition Tables (USDA-FCT), containing energy and nutrients per one gram of each FFQ item.[41] This database was checked by four nutritionists to ensure that foods chosen from the USDA-FCT are the best equivalents for the FFQ items with regard to major ingredients and macronutrients.19 For foods not included in the USDA-FCT, such as native Iranian foods or local food items, the weighted average of major ingredients was used or several foods were combined to equate that food item.[41] Local items added at each cohort center (5-10 items) were equated to standard FFQ items based on their major ingredients or recipes after data collection.[39] Intake amounts for each food were converted to grams per day (g/day) to quantify daily consumption.

Household Level

In this study, a total of 10,743 households were investigated, most of which consist of 2 to 4 members. The purpose of defining this level is to evaluate the extent to which differences between households affect changes in the intake of calcium, iron, and zinc during this specified time period.

Residence type level

It refers to the type and characteristics of individuals' living locations, which in this research were classified into two categories: urban and rural.

Interview Center Level

The data for this study were collected from 18 distinct provinces across Iran, each characterized by unique attributes.

Statistical analysis

Quantitative variables were described as mean ± standard deviation (SD) and the qualitative variables as frequency (%). Changes in the variables between the two phases were analyzed using the paired t-test. In the initial phase of our analysis, we focused on enhancing data quality and mitigating the impact of erroneous data on the model. We systematically screened the FFQ data for unit errors (e.g., incorrect reporting units for food portions), magnitude errors (e.g., implausibly high or low food or nutrient intake values), and format errors (e.g., coding or data-entry inconsistencies). Identified errors were subsequently reviewed and corrected to ensure data integrity prior to statistical analyses. The proportion of missing data was low (< 2% for all variables); therefore, complete-case analysis was used and no multiple imputation was performed.

To assess the effect of outliers in micronutrient values (calcium, iron and zinc) paired t-test was conducted both with and without outliers. In fact, the inclusion of outliers did not affect the significance of the tests, standard deviation, or means. Therefore, we decided to retain the outliers in the study. Also, changes in mean micronutrient (calcium, iron and zinc) consumption were calculated separately for men and women, reported as mean ± standard deviation. In this study, the percentage of adequate intake for calcium, iron, and zinc was calculated using the Estimated Average Requirement (EAR) criterion. The EAR is defined as the nutrient intake level estimated to satisfy the requirements of 50% of healthy individuals in a particular population group.[42, 43] For this analysis, the EAR values applied were: 900 mg/day for calcium in women and 800 mg/day for men; 8 mg/day for iron in women and 6 mg/day for men; and 6.8 mg/day for zinc in women and 9.4 mg/day for men.[42, 44, 45]

Dietary data were analyzed using Stata (Stata Corp, 2014. Stata Statistical Software: Release 17, Stata Corp LP, College Station, USA). Since, in this study, the data had a hierarchical structure, multivariate multilevel analysis was used to depict the hierarchical structure of the data.[46] In this study, four levels of analysis were defined: individual level, household level, residential area level, and interview center or provincial level. To account for variability in the effect of time across interview centers, a random slope for the time variable was incorporated at the interview center level in the multilevel model. This approach allows the effect of time on micronutrient intake to vary between centers, capturing possible differences in temporal trends.

$$Ytihrc = \beta_0 + \beta_1 \, Timet + \beta' Xi + ui + uh + ur + uc + vc \, Timet + \varepsilon tihrc$$

where t denotes the assessment time; i, h, r, and c denote the participant, household, residential area, and interview center, respectively; u_i, u_h, u_r, and uc are random intercepts at the corresponding levels; vc is the interview-center-specific random slope for time; and ε denotes the residual error.

Initially, univariate analyses were conducted between the dependent variables and each independent variable, which included age, gender, education status, marital status, Socioeconomic status (SES), smoking, physical activity, BMI, DMF, sleep duration, metabolic syndrome, hypertension, diabetes, cardiovascular disease and time. The individual variables that were associated with micronutrient intake (calcium, iron and zinc) with a p-value ≤ 0.25 in the univariate analysis were subsequently included in the multivariable linear regression. Specifically, physical activity and sleep duration for calcium intake, and smoking status and hypertension for zinc intake, did not meet this screening threshold (p > 0.25) and were excluded from the respective multivariable models (Supplementary Data File, Table S1).

For the analysis of this study, various multivariate models were executed, and ultimately, the appropriate model was selected based on the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC).[47] Total energy intake was controlled using the residual method [48]. Briefly, for each nutrient (calcium, iron, and zinc), intake was regressed on total energy intake separately at baseline and reassessment phases. The residuals from these models were used as the energy-adjusted nutrient variables in the final multilevel analyses. Because the residuals have a mean close to zero, energy-adjusted nutrient values were subsequently rescaled by adding the population mean nutrient intake to facilitate interpretation in the original units (mg/day). Therefore, the reported coefficients reflect associations independent of total energy intake, and total energy intake was not entered as a separate covariate in the final models.

Coefficients and 95% confidence intervals (95% CI) were calculated in the fixed-effects part of the model, using a Restricted Maximum Likelihood estimation method. A two-tailed Wald test at a significance level of α = 0.05 was used to determine the statistical significance of the determinants. Variations between levels were assessed by computing Intra-class Correlation Coefficient (ICC). The

ICC usually has a value between 0 and 1 and is used to assess correlations within a class of data, such as those arising from repeated measurements. The ICC represents the proportion of variance explained by the grouping structure in the population.[49] Additionally, Variance Inflation Factor (VIF) analysis was used to assess correlations between individual-level variables.

Results

The study sample included a total of 32,220 participants, comprising 14,428 males and 17,792 females. The average age at the baseline phase of the study was 47.5 years with a standard deviation of 7.90. Most of the sample (71.84%) resided in urban areas. Regarding educational attainment, 70.02% of individuals had an education level below a diploma, and 18.83% were illiterate. The baseline BMI distribution showed that 26.76% of participants were within the normal weight range, whereas 71.55% were classified as overweight or obese. Non-smokers accounted for 79.45% of the participants.

The average reported sleep duration was 7.11 hours per day (SD = 1.49). In terms of marital status, the vast majority were married (93.31%), with only small proportions being single (1.57%) or divorced (0.89%). Metabolic syndrome was present in 38.53% of the participants, 26.63% had a prior history of CVD, 26.47% had hypertension, and 16.80% reported a diagnosis of diabetes (Table 1).

Changes in the intake of calcium, iron and zinc

A significant change was found in micronutrient (calcium, iron and zinc) intake across the entire population and between genders from 2015 to 2021. The average daily intake of all three minerals-calcium, iron, and zinc-has generally decreased. Specifically, calcium intake has decreased by 142.5 mg/day, iron by 1.7 mg/day, and zinc by 1.1 mg/day. Additionally, men experienced a greater daily reduction compared to women, with decreases of 166.4 mg/day in calcium, 2.1 mg/day in iron, and 1.4 mg/day in zinc (Table 2). The percentage of intake above the EAR threshold decreased for all studied minerals (calcium, iron, and zinc). Specifically, the greatest decreases were observed for calcium and zinc; calcium intake above the EAR threshold declined by approximately 15.9%, and zinc intake by about 16% in the total population. In contrast, more than 90% of participants had iron intakes above the EAR threshold. (Table 3).Iron adequacy estimates should be interpreted with caution because the distribution of iron requirements is skewed, particularly among premenopausal women.

Comparison of calcium, iron, and zinc intake across four levels: center, residence, household, and individual

Figures 3, 4, and 5 show the distribution of calcium, iron, and zinc intake across the four hierarchical levels used in our multilevel analysis. In each figure, panels A–D represent interview center (A), residence type (B), household (C), and individual (D) levels, respectively. These plots highlight between-cluster variability at each level and visually support the four-level model structure. In line with the intraclass correlation coefficients in Table 4, interview centers and households accounted for substantial proportions of variance in micronutrient intake, justifying the multilevel approach.

Calcium intake

Fixed Effect Results

The results of the multilevel linear regression analysis showed that calcium intake significantly decreased over the reassessment phase. Specifically, calcium intake decreased by 151.37 mg/day in the reassessment phase compared with the baseline phase ($P < 0.001$). In addition, for each one-year increase in age, calcium intake decreased by 0.98 mg/day ($P < 0.001$). Women consumed significantly lower amounts of calcium than men, with an average intake that was lower by 184.25 mg/day over the study period ($P < 0.001$). A positive gradient was observed between socioeconomic status (SES) and calcium intake. Compared with the lowest SES group, calcium intake was higher in the low, middle, high, and highest SES groups by 8.42 ($P = 0.048$), 10.29 ($P = 0.027$), 21.80 ($P < 0.001$), and 24.60 mg/day ($P < 0.001$), respectively. Compared with individuals with normal BMI, underweight participants consumed 71.08 mg/day less calcium ($P < 0.001$), whereas overweight and obese individuals consumed 32.75 and 56.48 mg/day more calcium, respectively (both $P < 0.001$).

Participants with hypertension and cardiovascular disease consumed significantly lower amounts of calcium compared with those without these conditions, with reductions of 11.25 ($P = 0.006$) and 14.19 mg/day ($P < 0.001$), respectively. In contrast, individuals with diabetes and metabolic syndrome had significantly higher calcium intakes, consuming on average 38.88 and 7.90 mg/day more calcium, respectively, compared with participants without these conditions (both $P < 0.001$) (Table 4).

Iron

Fixed effect results

The results of the multilevel linear regression analysis showed that iron intake significantly decreased over the reassessment phase. Specifically, iron intake decreased by 1.85 mg/day in the reassessment phase compared with the baseline phase ($P < 0.001$). In addition, for each one-year increase in age, iron intake decreased by 0.04 mg/day ($P < 0.001$). Women consumed significantly lower amounts of iron than men, with an average intake that was lower by 3.20 mg/day over the study period ($P < 0.001$). A positive gradient was observed between SES and iron intake. Compared with the lowest SES group, iron intake was higher by 0.17 ($P = 0.013$), 0.23 ($P = 0.002$), and 0.33 mg/day ($P < 0.001$) in the middle, high, and highest SES groups, respectively. Former smokers consumed higher amounts of iron compared with never smokers, with an average increase of 0.22 mg/day ($P = 0.006$). Physical activity was positively associated with iron intake, with each additional unit increase in physical activity associated with a 0.03 mg/day increase in iron intake ($P = 0.001$).

Table 1. Demographic characteristics of the study participants in the PERSIAN cohort study at baseline phases

	Baseline, n (%)		
	Total n = 32,220	Male n = 14,428	Female n = 17,792
Age	47.5(7.9)	47.6 (7.95)	47.49 (8.01)
Residence Type			
Urban	23148 (71.84)	10354 (71.76)	12794 (71.91)
Rural	9072 (28.16)	4074 (28.24)	4998 (28.09)
Education			
Illiterate	6068 (18.83)	1731(12.00)	4337 (24.38)
Up to Diploma	22561 (70.02)	10341 (71.67)	12220 (68.68)
Up to Bachelor's	3073 (9.54)	1962 (13.60)	1111 (6.24)
Master's Degree and above	518 (1.61)	394 (2.73)	124 (0.70)
Body Mass Index			
Underweight	543 (1.69)	407 (2.82)	136 (0.76)
Normal	8621 (26.76)	5165 (35.80)	3456 (19.42)
Overweight	13,337 (41.39)	6310 (43.73)	7027 (39.50)
Obesity	9719 (30.16)	2546 (17.65)	7173 (40.32)
Socioeconomic Status			
The poorest	5928 (18.43)	1964 (13.64)	3964 (22.31)
Poor	6924 (21.53)	2973 (20.65)	3951 (22.24)
Middle	7020 (21.83)	3251 (22.58)	3769 (21.21)
Rich	7203 (22.39)	3324 (23.09)	3879 (21.83)
The Richest	5089 (15.82)	2885 (20.04)	2204 (12.41)
Smoking Status			
Non-smoker	25579 (79.45)	8179 (56.74)	17397 (97.87)
Current smoker	2576 (8.05)	2376 (16.48)	200 (1.13)
Former smoker	4039 (12.55)	3860 (26.78)	179 (1.01)
Sleep Duration	7.11 (1.49)	6.96 (1.43)	7.23 (1.53)
Marital Status			
Single	506 (1.57)	113 (0.78)	393 (2.21)
Married	30366 (93.31)	14244 (98.72)	15822 (88.93)
Widowed	1347 (4.18)	33 (0.23)	1314 (7.39)
Divorced	286 (0.89)	37 (0.26)	249 (1.40)
Other	15 (0.05)	1 (0.01)	14 (0.8)
MET- Final	40.15 (7.46)	41.54 (9.60)	39.02 (4.80)
DMF	17.13 (9.63)	17.86 (10.07)	16.54 (9.21)
Metabolic syndrome			
Yes	12334 (38.53)	5064 (35.36)	7270 (41.11)
No	19674 (61.47)	9259 (64.64)	10415 (58.89)
Hypertension			
Yes	8528 (26.47)	3519 (24.39)	5009 (28.15)
No	23692 (73.53)	10909 (75.61)	12783 (71.85)
Diabetes			
Yes	5412 (16.80)	2152 (14.92)	3260 (18.32)
No	26808 (83.20)	1276 (85.08)	14532 (81.68)
CVD			
Yes	8581 (26.63)	3145 (21.80)	5436 (30.55)
No	23639 (73.37)	11283 (78.20)	12356 (69.45)

Compared with individuals with normal BMI, underweight participants consumed 0.33 mg/day less iron ($P < 0.001$), whereas overweight and obese individuals consumed 0.52 and 0.87 mg/day more iron, respectively ($P < 0.001$). Individuals with diabetes and metabolic syndrome had significantly higher iron intakes, consuming on average 0.59 and 0.17 mg/day more iron, respectively, compared with participants without these conditions ($P < 0.001$). In contrast, participants with cardiovascular disease consumed significantly lower amounts of iron compared with those without cardiovascular disease ($P < 0.001$) (Table 4).

Zinc

Fixed effect results

The results of the multilevel linear regression analysis showed that zinc intake significantly decreased over the reassessment phase. Specifically, zinc intake decreased by 1.25 mg/day in the reassessment phase compared with the baseline phase ($P < 0.001$). In addition, for each one-year increase in age, zinc intake decreased by 0.002 mg/day ($P = 0.006$). Women consumed significantly lower amounts of zinc than men, with an average intake that was lower by 1.89 mg/day over the study period ($P < 0.001$).

Compared with the lowest SES group, zinc intake was higher by 0.17, 0.29, 0.38, and 0.56 mg/day in the low, middle, high, and highest SES groups, respectively ($P < 0.001$). Compared with individuals with normal BMI, underweight participants consumed 0.10 mg/day less zinc ($P = 0.013$), whereas overweight and obese individuals consumed 0.06 and 0.10 mg/day more zinc, respectively ($P < 0.001$). Participants with cardiovascular disease consumed significantly lower amounts of zinc compared with those without cardiovascular disease, with a reduction of 0.24 mg/day ($P = 0.001$). In contrast, individuals with metabolic syndrome consumed significantly higher amounts of zinc compared with those without metabolic syndrome, with an average increase of 0.03 mg/day ($P = 0.028$) (Table 4).

Random effect results for calcium, iron and zinc

In our four-level multilevel model, the random effects represent the amount of variance in the dependent variables (calcium, iron, and zinc intake) attributable to each hierarchical level.

Interview center: The variance between interview centers for calcium (39,296.76, 23.9% of total), iron (13.10, 31.7% of total), and zinc (1.01, 11.7% of total) indicates that geographic or organizational differences between centers contribute to variations in nutrient intake.

Time (random slope within interview centers): The variance associated with time was 7,867.42 (4.8% of total variance) for calcium, 2.42 (5.9%) for iron, and 0.44 (5.1%) for zinc. This indicates that the trajectory of nutrient intake over time differs across interview centers, reflecting distinct patterns of change in calcium, iron, and zinc intake during the study period.

Residence type: The variance between residence types was 10,320.90 (6.3% of total variance) for calcium, 0.78

Table 2. Changes in the intake of micro nutrients by gender

Micronutrient	Total, n = 32220			Male, n = 14428			Female, n = 17792		
	Baseline (2015)	Follow-up (2021)	Difference (2021-2015)	Baseline (2015)	Follow-up (2021)	Difference (2021-2015)	Baseline (2015)	Follow-up (2021)	Difference (2021-2015)
	Mean ± SD†								
Calcium (mg/d)††	1032.8 ± 388.6	890.2 ± 367.1	-142.5 ± 398.8	1144.2 ± 408.6	977.7 ± 390.8	-166.4 ± 429.3	942.5 ± 346.2	819.3 ± 330.1	-123.2 ± 371.0
Iron (mg/d)	16.3 ± 6.2	14.6 ± 6.1	-1.7 ± 6.1	18.3 ± 6.5	16.2 ± 6.6	-2.1 ± 6.8	14.7 ± 5.4	13.3 ± 5.4	-1.4 ± 5.5
Zinc (mg/d)	9.7 ± 3.0	8.6 ± 2.8	-1.1 ± 3.1	11.0 ± 3.1	9.5 ± 3.0	-1.4 ± 3.5	8.7 ± 2.5	7.8 ± 2.5	-0.9 ± 2.8

†Pair's t-test was used for changes in the two baseline and reassessment phases. All reported associations were statistically significant ($P < 0.05$)
††Unusual total energy intake (i.e., < 500 or > 3500 kcal per day for women and i.e., < 800 or > 4200 kcal per day for men) was excluded from the analysis

Table 3. Changes in the Percentage of Adequate Mineral Intake by Gender

Nutrient	EAR	Adequate intake, (%)								
		Total, n = 32220			Male, n = 14428			Female, n = 17792		
		Baseline (2015)	Reassessment (2021)	Difference (2021-2015)	Baseline (2015)	Reassessment (2021)	Difference (2021-2015)	Baseline (2015)	Reassessment (2021)	Difference (2021-2015)
		Minerals								
Calcium (mg/d)	M = 800, F = 900	63.58	47.67	-15.91	79.55	63.73	-15.82	50.62	34.64	-15.98
Iron (mg/d)	M = 6, F = 8	95.26	90.97	-4.29	99.49	97.74	-1.75	91.83	85.48	-6.35
Zinc (mg/d)	M = 9.4, F = 6.8	72.41	56.37	-16.04	67.51	47.85	-19.66	76.38	63.27	-13.11

M = Male, F = Female; EAR = Estimated Average Requirement

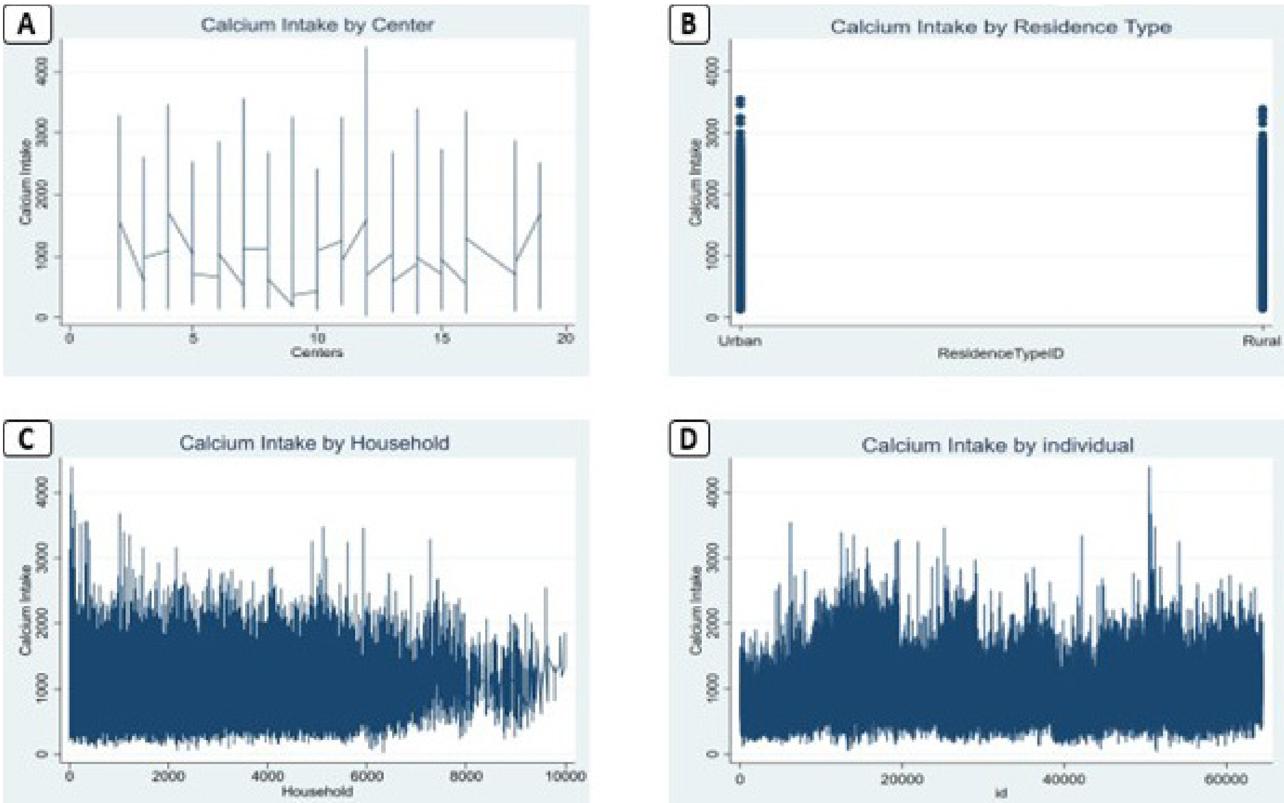

Figure 3. Comparison of calcium intake across four hierarchical levels. Panels A–D correspond to interview center (A), residence type (B), household (C), and individual (D) levels, respectively. The plots illustrate between-cluster variability in calcium intake at each level and support the four-level multilevel structure. Corresponding variance components and intraclass correlation coefficients are reported in Table 4

(1.9%) for iron, and 0.13 (1.5%) for zinc. This suggests that environmental and living conditions partially influence nutrient intake.

Household: The variance between households was 32,693.67 (19.9% of total variance) for calcium, 7.60 (18.4%) for iron, and 2.39 (27.9%) for zinc. This substantial variance highlights the important role of family-level factors in determining nutrient intake.

Individual: The variance component at the individual level (between-individual variation within households) was estimated to be negligible and close to zero (Calcium: 7.28×10^{-7}, Iron: 3.04×10^{-13}, Zinc: 6.59×10^{-11}).

Residual variance: The residual variances were 74,210.56 (45.2% of total variance) for calcium, 17.40 (42.1%) for iron, and 4.61 (53.7%) for zinc. These values represent unexplained variability due to unmeasured factors or

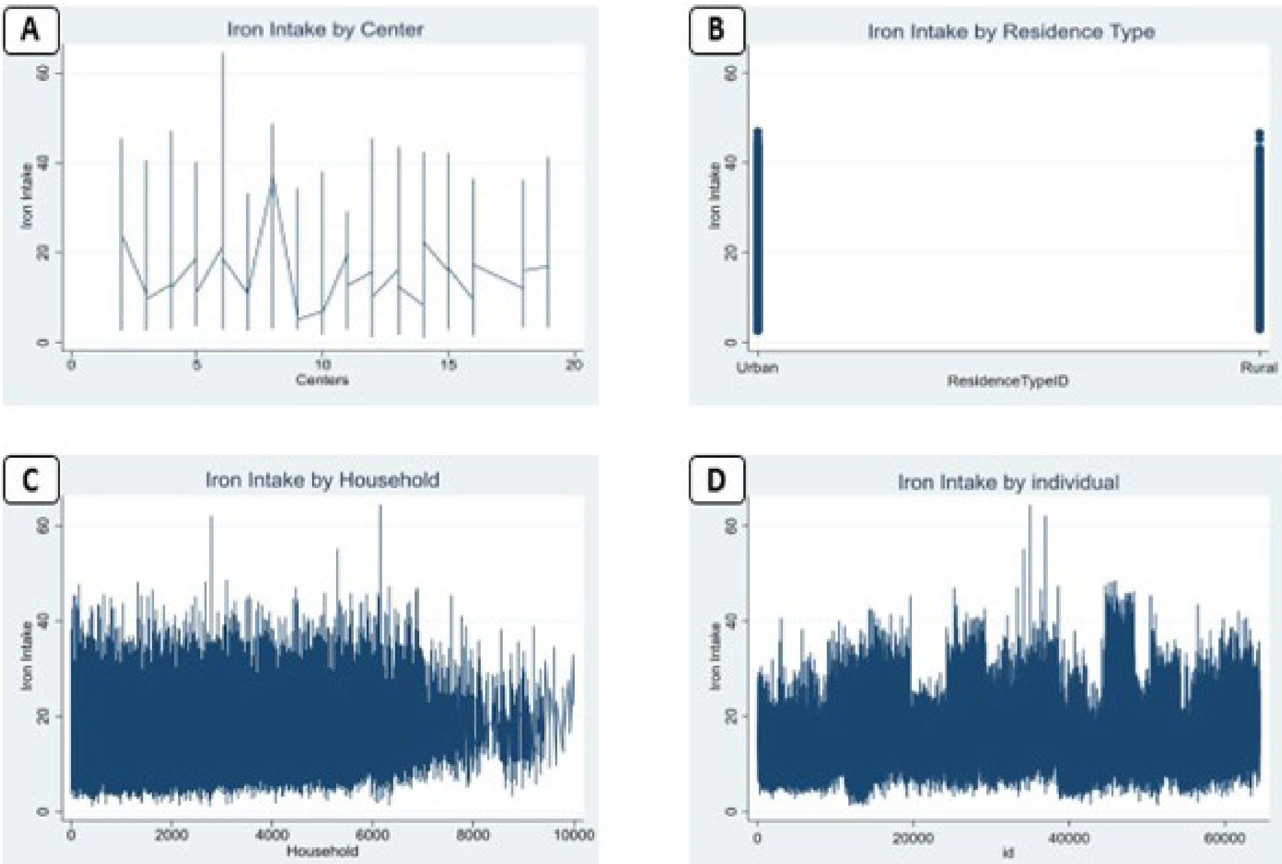

Figure 4. Comparison of iron intake across four hierarchical levels. Panels A–D correspond to interview center (A), residence type (B), household (C), and individual (D) levels, respectively. The plots illustrate between-cluster variability in iron intake at each level and support the four-level multilevel structure. Corresponding variance components and intraclass correlation coefficients are reported in Table 4

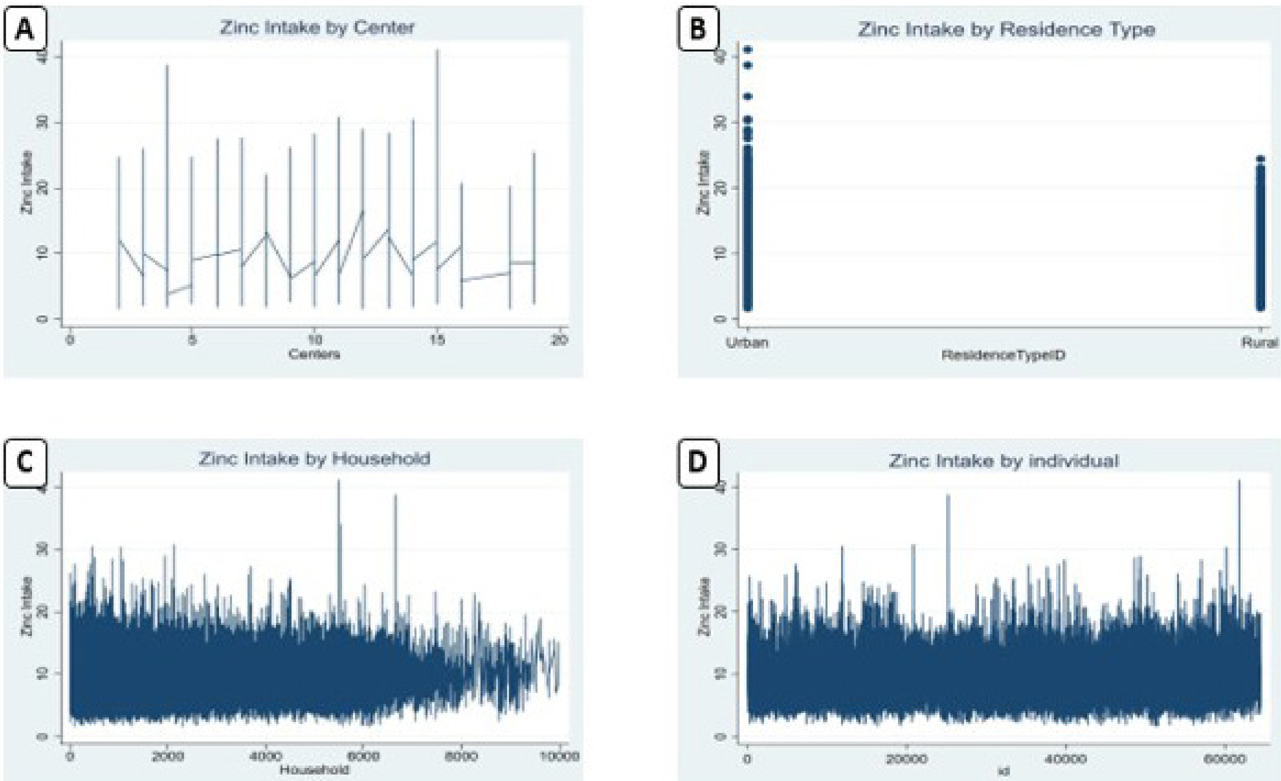

Figure 5. Comparison of zinc intake across four hierarchical levels. Panels A–D correspond to interview center (A), residence type (B), household (C), and individual (D) levels, respectively. The plots illustrate between-cluster variability in zinc intake at each level and support the four-level multilevel structure. Corresponding variance components and intraclass correlation coefficients are reported in Table 4

Table 4. Multivariate multi-level analysis of the association between independent variables and mineral intake (calcium, iron and zinc)

Multilevel Effects	Calcium Coef (95%CI)	*P* value	Iron Coef (95%CI)	*P* value	Zinc Coef (95%CI)	*P* value
Fixed effects						
Individual-level factors						
Age (year)	-0.98 (-1.41, -0.54)	**<0.001**	-0.04 (-0.05, -0.03)	**<0.001**	-0.002(-0.004, -0.0004)	**0.006**
Gender						
Male	Ref		Ref		Ref	
Female	-184.25 (-190.41, -178.10)	**<0.001**	-3.20 (-3.30, -3.10)	**<0.001**	-1.89 (-1.94, -1.85)	**<0.001**
Time						
Baseline	Ref		Ref		Ref	
Reassessment	-151.37 (-193.80, -108.94)	**<0.001**	-1.85 (-2.59, -1.10)	**<0.001**	-1.25(-1.57, -0.93)	**<0.001**
Marital Status						
Single	Ref		Ref		Ref	
Married	33.40 (10.33, 56.47)	**0.005**	0.59 (0.23,0.94)	**0.001**	-0.03 (-0.12, 0.06)	0.569
Widowed	-14.78 (-32.09, 2.51)	0.195	0.03 (-0.20, 0.27)	0.762	-0.11 (-0.22, 0.003)	0.057
Divorced	-10.54 (-34.30, 13.21)	0.884	0.07 (-0.25, 0.41)	0.662	-0.04 (-0.19, 0.11)	0.589
Other	-0.10 (-83.59, 83.38)	0.809	-0.33 (-1.50, 0.83)	0.572	-0.27 (-0.82, 0.26)	0.317
Education						
Illiterate	Ref		Ref		Ref	
Up to Diploma	-1.90 (-6.58, 2.78)	0.577	-0.03 (-0.09, 0.03)	0.319	0.001 (-0.02, 0.03)	0.903
Up to Bachelor's Degree	1.14 (-6.90, 9.19)	0.254	-0.04 (-0.15, 0.06)	0.452	0.16 (0.11, 0.21)	**<0.001**
Master's Degree and above	6.16 (-8.02, 20.36)	0.864	-0.18 (-0.52, 0.16)	0.309	0.24 (0.14, 0.33)	**<0.001**
Socioeconomic Status						
The lowest	Ref		Ref		Ref	
Low	8.42 (0.05, 16.79)	**0.048**	0.10 (-0.02, 0.23)	0.100	0.17 (0.14, 0.21)	**<0.001**
Middle	10.29 (1.15, 19.43)	**0.027**	0.17 (0.03, 0.31)	**0.013**	0.29 (0.25, 0.33)	**<0.001**
High	21.80 (11.95, 31.64)	**<0.001**	0.23 (0.08, 0.38)	**0.002**	0.38 (0.34, 0.42)	**<0.001**
The Highest	24.60 (13.33, 35.88)	**<0.001**	0.33 (0.16, 0.51)	**<0.001**	0.56 (0.51, 0.61)	**<0.001**
Smoking Status						
Never smoker	Ref		Ref		*	
Current smoker	-4.79 (-13.72, 4.13)	0.293	-0.005 (-0.14, 0.13)	0.933	*	
Former smoker	-41.01 (-47.64, -34.39)	0.179	0.22 (0.06, 0.38)	**0.006**	*	
Physical Activity (MET)	*		0.03 (0.02, 0.04)	**0.001**	0.01 (0.012, 0.018)	**0.001**
Body Mass Index						
Normal	Ref		Ref		Ref	
Underweight	-71.08 (-91.34, -50.82)	**<0.001**	-0.33 (-0.51, -0.15)	**<0.001**	-0.10 (-0.18, -0.01)	**0.013**
Overweight	32.75 (26.09, 39.40)	**<0.001**	0.52 (0.42, 0.62)	**<0.001**	0.06 (0.03, 0.08)	**<0.001**
Obesity	56.48 (48.67, 64.29)	**<0.001**	0.87 (0.75, 0.99)	**<0.001**	0.10 (0.07, 0.14)	**<0.001**
DMF	-1.10 (-1.32, -0.87)	**<0.001**	-0.02 (-0.02, -0.01)	**<0.001**	-0.007 (-0.008, -0.005)	**<0.001**
Sleep Duration (Hour)	*		-0.01(-0.02, 0.002)	**0.012**	-0.004 (-0.008, -0.0001)	**0.040**
Hypertension						
No	Ref		Ref		*	
Yes	-11.25 (-19.27, -3.23)	**0.006**	0.05 (-0.01, 0.13)	**0.109**	*	
Diabetes						
No	Ref		Ref		Ref	
Yes	38.88 (33.84, 43.92)	**<0.001**	0.59 (0.52, 0.66)	**<0.001**	0.04 (-0.02, 0.10)	0.186
Cardiovascular Disease						
No	Ref		Ref		Ref	
Yes	-14.19 (-22.07, -6.31)	**<0.001**	-0.30(-0.42, -0.18)	**<0.001**	-0.24 (-0.30, -0.18)	**0.001**

Table 4. Continued.

Multilevel Effects	Calcium Coef (95%CI)	*P* value	Iron Coef (95%CI)	*P* value	Zinc Coef (95%CI)	*P* value
Fixed effects						
Metabolic Syndrome						
No	Ref				Ref	
Yes	7.90 (3.52, 12.27)	**<0.001**	0.17(0.11, 0.24)	**<0.001**	0.03 (0.002, 0.06)	**0.028**
Random effects	**Estimate (95% CI)**	**SE**	**Estimate (95% CI)**	**SE**	**Estimate (95% CI)**	**SE**
Variance between Interview center	39296.76 (17502.06, 88231.63)	16216.70	13.10 (6.36, 26.98)	4.83	1.01 (0.47, 2.16)	0.39
Time	7867.42 (3908.51,15836.29)	2808.13	2.42 (1.20, 4.86)	0.86	0.44 (0.22, 0.89)	0.15
Variance between Residence Type	10320.9 (4472.67, 23815.94)	4403.23	0.78 (0.32, 1.92)	0.35	0.13 (0.05, 0.32)	0.06
Variance between Household	32693.67 (31519.81,33911.24)	609.93	7.60 (7.33, 7.89)	0.14	2.39 (2.31, 2.47)	0.04
Variance between Individuals	7.28×10^{-7} (1.37×10^{-53}, 3.86×10^{40})	4.0×10^{-5}	3.04×10^{-13} (7.8×10^{-131}, 1.2×10^{105})	4.20×10^{-11}	6.59×10^{-11} (1.12×10^{-90}, 3.87×10^{69})	6.18×10^{-9}
Variance Residual	74210.56 (73213.66 ,75221.04)	512.07	17.40 (17.16, 17.64)	0.12	4.61 (4.55, 4.67)	0.03
Variance	**ICC (%)**		**ICC (%)**		**ICC (95% CI)**	
Level 1: Individuals	0.00		0.00		0.00	
Level 2: Household	19.90		18.38		27.86	
Level 3: Residence Type	6.30		1.89		1.51	
Level 4: Interview center	23.90		31.72		11.71	
Time	4.80		5.86		5.13	
Residual	45.20		42.13		53.73	

Ref: Reference group; (Ref) for categorical variables were as follows: **Male** for gender, **Baseline** for time, **Single** for marital status, **Illiterate** for education, The **lowest** for socioeconomic status, **Never smoker** for smoking status, **Normal weight** for body mass index, **no** for hypertension, diabetes, cardiovascular disease, and metabolic syndrome. CI: Confidence Interval; Items with $P \leq 0.05$ are shown in bold font, indicating statistically significant results. Items with $P > 0.05$ are displayed in regular font. *: Blank cell indicates that the variable had a *P*-value > 0.25 in the univariate analysis and was excluded from the multivariate mixed model analysis

measurement error (Table 4).

Results of ICC

Based on the results of the four-level multilevel linear mixed-effects model, the intraclass correlation coefficients (ICCs) revealed distinct variance distributions across micronutrients. For calcium and iron intake, the interview center level (Level 4) and household level (Level 2) explained the largest proportions of variance, with ICCs of 23.9% and 19.9% for calcium and 31.7% and 18.4% for iron, respectively. For zinc intake, the household level showed the strongest clustering among higher levels (27.9%), while the majority of variance remained at the residual level (53.7%) (Table 4).

The individual level (Level 1) variance was extremely small and non-significant for all three micronutrients (ICC = 0.0%), indicating no meaningful between-individual variability after accounting for fixed effects and higher-level clustering. Strong between-household clustering was observed, with individuals within the same household showing similar micronutrient intake patterns. Residence type level variance was modest (1.5–6.3% across nutrients). These findings highlight the critical role of household and interview center factors in determining nutrient intake (Table 4).

Discussion

Calcium, iron and zinc changes review

This study examines changes in calcium, iron and zinc intake between the two phases of the PERSIAN cohort study (baseline and reassessment phase) over a six-year period (2015–2021). The findings indicate that the daily intake of calcium, iron and zinc in the studied population decreased during the reassessment phase. The adequate intake (AI) of calcium for individuals over 30 years old is generally recommended to be between 1000 and 1200 mg/day.[50] The reduction of 142 mg/day during the reassessment phase in the population covered in this study, resulting in an intake of 890 mg/day, is significantly below the adequate intake level, which raises concerns. These concerns may lead to a range of biological malfunctions in severe cases, such as abnormalities in blood clotting, muscle contraction, nerve signal transmission, enzymatic activity, cell membrane function, intercellular adhesion, and hormone secretion.[45] Moreover, such deficiency can increase the risk of chronic diseases, including osteoporosis, hypertension, and certain types of cancer.[51]

A decrease of 1.7 mg/day in iron and 1.1 mg/day in zinc intake during the reassessment phase also raises potential nutritional concerns. Although the daily iron intake of 14.6 mg/day for the overall population during the reassessment phase exceeds the recommended daily intake (RDI) for men (8.45 mg/day), it remains inadequate for women aged 30 to 50 years, who require 18.45 mg/day.[52] In this study, the estimated average iron intake for women in this age group was only 13.3 mg/day, significantly lower than international reference values. Notably, women in this age group comprised 58% (17,792 individuals) of the study population. This discrepancy highlights nutritional inadequacy for a substantial portion of the population, potentially leading to adverse health outcomes linked to iron deficiency. Iron deficiency is the most common cause of anemia worldwide and affects approximately one billion people.[53, 54] It is the leading cause of years lived with disability among women.[54]

During the reassessment phase, the daily zinc intake was 9.5 mg/day for men and 7.8 mg/day for women, whereas the RDI recommends 11.4 mg/day for men and 8.4 mg/day for women. This reduction in zinc intake may raise concerns about the nutritional status of the studied population. Zinc deficiency can lead to disorders such as impaired protein synthesis [55], a weakened immune system [56], male infertility [57], and an increased risk of Alzheimer's disease, depression [58], and diabetes.[56] Therefore, attention to meeting the daily requirements of this essential nutrient seems necessary. In a study conducted by Yan et al. (2024) on the population over 20 years old in the United States, it was found that calcium consumption increased from 940 mg to 1020 mg/day between 1990 and 2020. This finding does not align with the results of the current study. However, Yan et al. based on data from the United States National Health and Nutrition Examination Survey (NHANES), also reported that iron intake decreased from 19.17 to 16.38 mg/day and zinc intake decreased from 16.45 to 14.19 mg/day; these declining trends were consistent with the results of the current study.[59] In a study conducted by Gose et al. (2016) on the population over 18 years old in Germany, it was found that the consumption of calcium, iron, and zinc remained stable or increased between 2005 and 2013. Specifically, calcium intake increased slightly, with women consuming an average of 807 mg rising to 809 mg/day, and men from 893 mg/day to 897 mg/day. Iron intake among women also rose from 10.7 mg/day to 11.1 mg/day. Zinc intake remained constant at 9.12 mg/day for women and 11.7 mg/day for men during this period. These findings do not align with the results of the current study.[17] In a study conducted by Balk et al. (2017), presented as a review article, the average calcium intake in adults from various European countries has been was reported as follows: Iceland: 1233 mg/day, Netherlands: 1102 mg/day, Finland: 1097 mg/day, Ireland: 1080 mg/day. This information highlights significant differences in calcium intake levels among various European countries compared to the present study.[60] In a study conducted by Wang et al. (2018) on the population over 18 years old in China, it was found that zinc consumption decreased from 11.3 mg/day to 10.2 mg/day between 2002 and 2015. Although the intake of 10.2 mg/day is still higher than the consumption reported in the current study (8.6 mg/day), the decreasing trend in zinc intake over time aligns with the findings of the present study.[61] In a study conducted by Shalini et al. (2019) on the population over 20 years old in India, it was found that the average intake of calcium, iron, and zinc during the years 2014 to 2016 was 797 mg/day, 11.2 mg/day, and 5.7 mg/day, respectively. The results of this study were lower than those of the current study.[62] However, in a study conducted by Babaali et al. (2020) on the population aged 20 to 50 years in Shiraz, Iran, it was found that the average zinc intake during the years 2013 to 2014 was 12.92 mg per day, which does not align with the results of the present study.[63] Additionally, in a study conducted by Valaei et al. (2017) on Iranian households between the years 2000 and 2002, it was found that overall, 80% of households consumed less calcium than the standard recommended amount in their diets, and this rate for iron deficiency ranged between 40% and 70%. This means that many households did not receive enough calcium and iron relative to the amount of energy (calories) they consumed.[64] In a study conducted by Hashemian et al. (2015), data from the Golestan cohort for individuals over 40 years old was analyzed from 2004 to 2008. The findings indicated that the average daily intake of calcium and zinc was 700.7 mg and 9.8 mg/day, respectively. These results differ significantly from those of the present study [65]. However, in a study conducted by Seifi et al. (2025) based on FNS results among the adult population (19 to 60 years) and elderly individuals over 60 years in Iran, the average daily intake of calcium, iron, and zinc was reported as 881 mg/day, 10.31 mg/day, and 7.68 mg/day in women, and 842 mg/day, 9.9 mg/day, and 7.8 mg/day in men, respectively. These values indicate that the daily intake of these three micronutrients in the present study was higher [66]

Factors influencing nutritional changes (fixed effects)

With advancing age, various factors shape individuals' dietary behaviors, which can result in either improvements or declines in their health conditions.[67] The results of this study showed that women consumed lower amounts of calcium, iron, and zinc compared to men. This finding is consistent with the generally lower total energy intake and macronutrient consumption observed in women. Men usually require higher energy intake due to greater muscle mass, higher basal metabolic rate, and higher physical activity levels.[68] In a study conducted by Freedman et al. (2024) on individuals over 19 years old, it was found that between 2003 and 2018 in the United States, calcium intake decreased by 24% in men and 14.3% in women. Conversely, iron and zinc intake increased by 68% and 87% in men, respectively, and by 13% and 28% in women[67]. While these results show a decrease in calcium intake, it is important to consider the baseline consumption levels in different populations or countries when interpreting these trends, as the initial intake may vary significantly.[69] On the other hand, osteoporosis, which is partially related to calcium deficiency, is significantly more common in women from countries such as the United States, Germany, Sweden, Denmark, France, the United Kingdom, Russia, and China than in men.[51] Numerous studies have shown that the intake of calcium and zinc has either increased or remained stable over time.[17, 59, 70] For example, in Germany, between 2005 and 2013, calcium intake in men slightly increased from 893 mg/day to 897 mg/day, while zinc intake remained stable at around 11.7 mg/day. In women, calcium intake showed no significant change, rising marginally from 807 mg/day to 809 mg/day. Similarly, zinc intake remained stable during this period, averaging approximately 9.12 mg/day.[17] These findings are not consistent with the results of the present study. However, a published article from China has reported a decreasing trend in the levels of these two minerals.[71] Also, in the Tehran Lipid and Glucose Study (TLGS), conducted on individuals over 18 years of age, it was found that calcium intake decreased from 1206 mg to 898 mg/day during the period from 2007 to 2021. In contrast, zinc intake remained relatively stable (11.2 to 11.0 mg/day).[72]

The findings of the present study demonstrated a clear positive gradient between socioeconomic status (SES) and the intake of calcium, iron, and zinc, with individuals in higher SES categories exhibiting significantly greater intakes compared with those in the lowest SES group. These results highlight the pivotal role of socioeconomic position as a fundamental determinant of dietary quality and micronutrient intake. Consistent with existing literature, individuals with higher SES are more likely to have access to a wider variety of nutrient-dense foods, contributing to more adequate micronutrient consumption. Contrary to the expectation of uniformly inadequate intake across SES strata, our findings reveal persistent and systematic disparities, whereby individuals in lower SES groups remain disproportionately vulnerable to insufficient intake of essential micronutrients. These observations are in line with previous studies reporting higher consumption of both macro- and micronutrients among more affluent populations[45, 70, 73, 74], likely reflecting differences in food affordability, dietary diversity, and health-related behaviors.

In addition to socioeconomic status, body mass index (BMI) was significantly associated with micronutrient intake in the present study. Individuals who were overweight and obese exhibited higher intakes of calcium, iron, and zinc compared with those with normal BMI. A similar pattern has been reported by Knez et al. (2017), who found that obese individuals (BMI ≥ 30.0) had higher intakes of iron (10.4 vs. 9.8 mg/day) and zinc (8.2 vs. 7.6 mg/day) compared with non-obese individuals (BMI < 30.0) in a Serbian adult population.[75] In contrast, Shan Jiang et al. (2020) reported an inverse association between the intake of minerals, including calcium, iron, and zinc, and BMI among American adults, with this relationship being more pronounced in overweight and obese individuals, such that higher BMI was associated with lower micronutrient intake.[76] These inconsistent findings may reflect differences in dietary patterns, cultural contexts, and stages of the nutrition transition across populations.

Several alternative explanations should be considered for the positive association between obesity and micronutrient intake. First, prior studies have shown that obese individuals tend to consume larger absolute volumes of food to meet their energy needs, which may elevate absolute micronutrient intake independently of dietary quality. For instance, Lin et al. (2023) found that obese men in Taiwan had significantly higher adherence to dietary reference intakes for iron and zinc compared to normal-weight peers, a pattern attributed to greater overall food consumption rather than superior diet quality.[77] Although obese people may suffer from micronutrient imbalance due to poor dietary intake characterized by energy-dense and nutrient-poor foods, but we have no evidence of such findings in this report.[78] In fact, the association between intake and obesity is bidirectional but regarding the longitudinal nature of our study the reverse causation is less likely. Although in our analysis we adjusted for most of potential confounding, residual confounding factors can still contribute to the observed association.

Also, this study investigated the relationship between the intake of key minerals—calcium, iron, and zinc—and the prevalence of chronic diseases, specifically type 2 diabetes, cardiovascular disease, and metabolic syndrome. Our findings indicated that diabetic patients consumed higher amounts of calcium and iron. However, a contrasting pattern emerged for cardiovascular disease, where affected individuals showed a lower intake of both minerals compared to those without the condition. In comparison, previous studies have reported inconsistent associations between mineral intake and chronic diseases. Regarding calcium, Rodrigues et al. (2018) observed that individuals with cardiovascular diseases had higher calcium intake compared with healthy subjects in an Australian population.[79] Similarly, Cormick et al. (2021) reported relatively high calcium intake among hypertensive patients, suggesting that dietary modification and supplement use after disease diagnosis may influence calcium consumption.[80] In contrast, recent meta-analytic evidence has suggested that adequate calcium intake may have protective effects against hypertension and impaired glucose metabolism through its role in vascular function and insulin regulation. Samar Amer et al. (2025) further demonstrated an inverse association between dietary calcium intake and the risk of type 2 diabetes and hyperglycemia.[81] For iron and zinc, several recent studies have highlighted their important roles in cardiometabolic disorders. Wang et al. (2024) showed that higher dietary iron intake was associated with a greater risk of type 2 diabetes (20-33%), potentially due to oxidative stress and insulin resistance mechanisms. In addition, recent reviews have emphasized that iron overload may contribute to chronic inflammation and metabolic dysfunction.[82] Conversely, zinc has been widely recognized as a protective micronutrient in cardiovascular and metabolic diseases because of its antioxidant and anti-inflammatory properties. Recent systematic reviews and meta-analyses have shown that adequate zinc intake or supplementation may improve cardiovascular risk factors and reduce the risk of metabolic syndrome and cardiovascular diseases.[83]

Random effects

The model findings indicate that the variance component at the individual level (between-individual variation within households) was negligible and close to zero for calcium, iron, and zinc intakes. This suggests that, after accounting for household membership, there is minimal additional between-individual variation within the same household. In other words, household-level factors explain the majority of between-person differences in micronutrient intake. However, this does not imply that individual differences are unimportant. Substantial residual variance (reflecting within-individual changes over the six-year period as well as measurement variability) was observed, accounting for 45.2%, 42.1%, and 53.7% of the total variance for calcium, iron, and zinc, respectively. In this study, the data have a nested hierarchical structure, where individuals are nested within households, households within residential areas, and residential areas within interview centers.

The random-effects analysis demonstrated that household and interview center levels accounted for an important proportion of the variability in calcium, iron, and zinc intake. Household-level variance explained 19.9% of the total variance in calcium intake, 18.4% in iron intake, and 27.9% in zinc intake, highlighting the important role of shared family conditions such as dietary habits, food accessibility, purchasing power, and lifestyle behaviors in shaping micronutrient intake patterns.

Additionally, the observed variability across interview centers suggests that geographical, cultural, environmental, social, and economic factors may influence dietary behaviors and micronutrient intake. In the present study, 72% of the covered population resided in urban areas, while 28% lived in rural areas. The variability across the 17 interview centers further highlights the heterogeneous nutritional patterns within the Iranian population. According to the results, the Fasa interview center in Fars Province experienced the greatest change, with a decrease of 396.9 mg/day in calcium intake, while the Gilan interview center had the least change with a decrease of 27.5 mg/day over this six-year study period. Additionally, the Fasa interview center experienced the greatest change in iron intake (5.6 mg/day), while the Zahedan interview center had the least change (0.07 mg/day) in iron intake. Similarly, the Bandar Kong interview center in Hormozgan Province experienced the greatest changes in zinc intake (2.59 mg/day), while the Gilan interview center had the least changes (0.005 mg/day) (Appendix, Table S2).

Reasons for changes and differences in calcium, iron and zinc intake

The main sources of iron include grains, vegetables, nuts, eggs, fish, and meat [84]. The sources of calcium are milk, yogurt, and cheese.[85, 86] The main sources of zinc include meat and meat products, fish, legumes, milk and dairy products, and vegetables.[87] During the study period, the consumer price index for urban households changed as follows: for meat and fish from 18.8% to 313%, for milk, cheese, and eggs from 20.5% to 247%, for fruits from 19.8% to 212%, and for vegetables and legumes from 17.9% to 211%.[88] In this period, the inflation rate reached 54% in Yazd, 53% in Shahrekord, 51% in Kermanshah, 51% in Azerbaijan, 50% in Ilam, and 47% in Zahedan.[88] During this period, there was a significant rise in both the unemployment rate and the Gini coefficient.[26, 29] Iran's Gross Domestic Product (GDP) experienced a significant decline, shrinking by more than 20% during this timeframe.[89] Since 2012, the Gini coefficient has steadily increased, surpassing the 40% mark.[90] Additionally, recent years have seen considerable volatility in the dollar exchange rate, which has played a crucial role in driving the prices of goods and services. This escalation in the exchange rate occurred alongside reductions in household purchasing power and changes in food consumption patterns at the population level. Although the intake levels of calcium, iron, and zinc decreased during the reassessment phase, a considerable proportion of the studied population still met the Estimated Average Requirement (EAR) for these micronutrients. Notably, over 90% of the population reached adequate intake levels for iron, and approximately 56% met the EAR for zinc in the reassessment phase. For calcium, although adequacy declined to about 48%, nearly half of the population still maintained sufficient intake. These findings indicate that despite concurrent economic challenges, inflation, and food price increases, a significant portion of individuals continued to consume these essential minerals at adequate levels. In response to these economic pressures, the government has introduced cash subsidy programs aimed at supporting the more vulnerable populations within society. These financial aids are intended to lessen the economic strain on low-income families, enabling them to better manage increasing living expenses and maintain access to essential goods and services. Through these direct monetary transfers, the government seeks to enhance the living standards and overall quality of life for these targeted groups. Although these macroeconomic factors were not measured at the individual level and were not included in the statistical models, they provide a contextual background for the observed dietary changes. Causal inferences regarding the effects of inflation, price increases, or subsidy policies should therefore be avoided. Therefore, it is crucial for policymakers to develop and implement targeted interventions that address both the financial constraints and nutritional needs of the community. Moreover, increasing public awareness and providing education on healthy nutrition are essential steps to empower individuals to make informed food choices despite economic difficulties.

Strengths and limitations

The PERSIAN study is a longitudinal, population-based investigation and represents the initial research assessing nutritional status within the PERSIAN cohort. It benefits from a robust sample size of 32,220 participants. Considering Iran's ethnic diversity, encompassing Persians, Turks/Azeris, Kurds, Lurs, Baluchis, Arabs, and others, samples were drawn from 17 different regions across Iranian provinces. This approach aims to capture a broad spectrum of environmental settings, lifestyle habits, socioeconomic backgrounds, and various exposures influencing health outcomes. Data collection occurred in two phases, spaced six years apart. Despite having only two nutritional assessments, the study period included multiple economic crises in Iran, exacerbating the socioeconomic status of the population. The use of the same FFQ, previously validated, enhances the reliability of comparisons [39]. Assessing changes at the mineral level (calcium, iron, and zinc) provides a detailed perspective on dietary alterations.

However, in assessing dietary intake using the FFQ, like other methods, there are biases such as measurement error, including under-reporting or over-reporting of some food items or the total intake due to recall bias. To minimize such biases, individuals with unusual total energy intake were excluded from the study. Nutritional status varies across different provinces of Iran due to socioeconomic influences and cultural habits. These differences can affect access to food and dietary choices. Several factors may limit the external validity of our findings. First, the reassessment phase included only a predefined subset of approximately 30% of the original cohort participants. Second, individuals with implausible energy intakes were excluded, which may have resulted in a somewhat healthier or more compliant subsample. Third, although the PERSIAN cohort sites were selected to represent major ethnic and geographic diversity across Iran, the specific locations and recruitment procedures may not fully capture all population subgroups. Therefore, caution is warranted when generalizing these results to the entire Iranian adult population. Additionally, we acknowledge that for iron, particularly among premenopausal women, the EAR cut-point method may not provide the most accurate estimate of inadequacy because iron requirements are not normally distributed. The probability approach is recommended for a more precise assessment of iron inadequacy. However, since the main aim of this study was to assess longitudinal changes rather than the precise prevalence of inadequacy, we retained the EAR-based approach. This should be considered when interpreting the adequacy percentages for iron.

Conclusion

This longitudinal analysis of the PERSIAN Cohort reveals a significant decline in the intake of key micronutrients — calcium (142.5 mg/day), iron (1.7 mg/day), and zinc (1.1 mg/day) — among Iranian adults between 2015 and 2021. These reductions coincided with a period of major economic challenges, including high inflation and reduced purchasing power, which may have plausibly contributed to shifts in dietary patterns, although these factors were not directly measured at the individual level.

Using a four-level multilevel model, we demonstrated that household and interview center levels explained a substantial proportion of the variance in micronutrient intake, highlighting the critical role of shared family environments and regional factors. Although the residual individual-level random-effect variance was minimal after accounting for household clustering, individual-level characteristics remained important determinants of micronutrient intake, as reflected by significant fixed effects in the model.

Our findings are consistent with a potential adverse influence of recent macroeconomic conditions on dietary quality in Iran and emphasize the urgent need for targeted nutritional interventions. Policymakers should prioritize strategies to improve access to affordable nutrient-rich foods, with particular attention to vulnerable populations, to mitigate diet-related diseases and reduce nutritional inequalities.

Acknowledgements

We would like to thank managers and staffs of central office of PERSIAN Cohort Study, for helping us to conduct this study.

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Competing Interests

No potential conflict of interest was reported by the authors.

Data Availability Statement

The data analyzed in the study are available from the corresponding author upon reasonable request.

Ethical Approval

While each cohort center received the ethical approval from local universities, for the purpose of this study and pooling all PERSIAN data, the ethics committee of Kermanshah University of Medical Sciences approved the study (IR.KUMS.REC.1403.095).

Funding

This research was supported by Kermanshah University of Medical Sciences (grant number: 92472). The Iranian Ministry of Health and Medical Education has also contributed to the funding used in the

PERSIAN Cohort through Grant no 700/534.

Supplementary Files

Supplementary File.Table S1, S2

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