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Adherence to the planetary health diet reduces dietary costs by 21% supporting affordable healthy eating among older adults in Iran

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Poor dietary patterns among older adults are significantly influenced by socioeconomic status (SES) and food prices, impacting both diet quality and food choice. This study examines how dietary costs relate to the Planetary Health Diet Index (PHDI) and assesses the role of SES in Iran's elderly population. In this cross-sectional study, 398 elderly individuals from southern Tehran were sampled. Dietary data were collected using a validated food frequency questionnaire, and adherence to the PHDI was evaluated based on EAT-Lancet guidelines. Food costs were derived from the Iranian Statistics Center and retail prices. Multivariable linear regression analyzed the relationship between PHDI adherence and dietary cost. PHDI adherence varied significantly across demographics. Higher adherence was observed in females (OR = 0.82, 95% CI: 0.71–0.95) and those with a BMI ≤ 27.5 (OR = 0.84, 95% CI: 0.73–0.97), while single individuals had higher scores (OR = 0.85, 95% CI: 0.74–0.98). Higher PHDI tertiles were linked to lower daily dietary cost, with a significant decrease observed in the highest tertile compared to the lowest (β = − 708,367 Rials, 95% CI: − 1,060,371 to − 356,362). However, this association was not significant among single and low-income participants. The study reveals that higher adherence to the PHDI is associated with reduced dietary costs, a key barrier to obtaining a healthy, balanced diet among older adults, and may thereby support better health outcomes, including malnutrition prevention and functional independence. Future research should focus on longitudinal studies to develop equitable public health strategies that promote affordable and sustainable dietary practices.

Keywords Planetary Health Diet Index, Dietary cost, Socioeconomic status

Abbreviations

SES	Socioeconomic status
FAO	Food and Agriculture Organization
FFQ	Food Frequency Questionnaire
PHDI	Planetary Health Diet Index
IPAQ	International Physical Activity Questionnaire
HEI	Health Eating Index

Poor dietary patterns are not solely the result of individual behaviors; they are significantly shaped by a wide range of contextual factors, including social, commercial, environmental, and cultural influences[1]. Food price is one of the primary factors impacting food choice and diet quality[2]. Some studies demonstrated that higher quality diets which tend to have lower energy content cost more than unhealthy diets[3–6]. Diets rich in whole grains, lean meats, fish, fresh fruits and vegetables tend to have a higher cost per kilocalorie compared to energy-dense diets containing higher levels of fats and sweets[7]. However other studies have indicated that healthy diets are not more expensive than the unhealthy ones[8–11].

In addition to food cost, the existence of a social gradient in diets and health has been widely established[3,12–14]. While individuals with higher SES typically gravitate towards higher-quality diets, those with lower SES often

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opt for energy-dense diets lacking in essential nutrients[15]. Socioeconomic factors may have a greater impact on the dietary decisions of the elderly population, rendering them more susceptible to food insecurity[16]. As demonstrated, poor nutritional quality, is prevalent among older adults with low SES[17,18]. Earlier studies have also demonstrated that the cost of food influences the food choices made by older adults[19–21]. Therefore, it is essential to recognize the factors that might hinder adherence to a high-quality diet within this demographic.

Disorders affecting individuals aged 60 and above account for 23% of the global disease burden[22]. Malnutrition is a widespread issue among older adults, placing significant strain on healthcare, social support, and elder care systems[23]. This population is particularly susceptible due to age-associated physiological changes, limited availability or affordability of nutrient-dense foods, and the presence of multiple chronic conditions[23]. Sustainable diets, such as those promoted by the Planetary Health Diet, have been shown to hold promise in mitigating these risks by promoting nutrient-dense foods that support healthy aging[24,25]. The Planetary Health Diet, proposed by the EAT-Lancet Commission, integrates both human and planetary health, emphasizing nutrient-rich foods that contribute to preventing diet-related chronic diseases while minimizing environmental harm[26]. Numerous studies have demonstrated the co-benefits of a more sustainable diet on both planetary and human health[26–29]. Some studies have explored the affordability of the EAT-Lancet diet, demonstrating that this dietary pattern can be financially accessible, potentially removing a barrier to adherence among the elderly population[30]. However, other research has found contrasting results, highlighting affordability challenges[31,32].

Given that research has shown individuals with higher SES tend to uphold higher-quality diets and experience lower disease risks, epidemiological studies frequently view SES as a potential confounding factor. The current study explored the relationship between diet and food cost stratified by socioeconomic and demographic variables. With the aging demographic and economic crisis contributing to higher food prices in Iran, our aim was to investigate the relationship between two key barriers to geriatric nutrition—socioeconomic status (SES) and food cost—in achieving healthy nutrition and, consequently, mitigating health-related issues in older adults.

Methods

Study population and design

This study is a cross-sectional analysis conducted on 398 elderly individuals living in the southern region of Tehran. Participants were selected from healthcare centers affiliated with Tehran University of Medical Sciences between October 2022 and May 2023, utilizing the simple random sampling method. Individuals aged 60 and above, who reported no chronic illnesses, did not take specific medications, and did not alter their usual diet due to illness or dietitian recommendation, were included in our study.

This study was approved by the Tehran University of Medical Sciences Research Ethics Committee under reference number IR.TUMS.MEDICINE.REC.1401.588, and it adhered to the principles outlined in the Helsinki Declaration. Each participant in the study voluntarily provided written informed consent.

Dietary data

The dietary intake of participants was collected using a validated and reliable semi-quantitative 168-item Food Frequency Questionnaire (FFQ)[33,34]. Participants were asked to provide information about both the frequency and quantity of their consumption of each food item over the past year. This information was collected through a face-to-face interview conducted by a skilled and experienced researcher. The FFQ comprised an extensive list of food items, each with standardized serving sizes, allowing participants to indicate their consumption frequency on a daily, weekly, monthly, or yearly basis. Considering the specified portion size and consumption frequency for each food item, all foods were calculated on a daily basis and then converted to grams per day using household measures[35]. Nutrient values, including energy and other nutritional components for each food item, were computed using Nutritionist 4 software (First Databank, Hearst Corp., San Bruno, CA, USA).

Calculation of PHDI

The Planetary Health Diet Index was derived based on the guidelines outlined in the reference diet proposed by the EAT-Lancet Commission[26]. The method used to calculate the PHDI was developed by Cacau et al.[36]. The PHDI comprises 16 components, with a maximum achievable score of 150. A higher PHDI score indicates a greater adherence to the Planetary Health Diet. Food groups were classified into adequacy, optimum, ratio, and moderation categories. Each food within the adequacy (including nuts and peanuts, legumes, fruits, vegetables, and whole cereals), optimum (including eggs, fish and seafood, tubers and potatoes, dairy, and unsaturated oils), and moderation (including red meat, chicken and substitutes, animal fats, and added sugars) categories can receive a maximum score of 10. Components in the ratio category (representing compositional distribution of dark green vegetables and red and orange vegetables relative to the total vegetable intake), however, are assigned a maximum score of 5 to prevent the overvaluation of a specific dietary aspect during the assessment process. The PHDI utilized the recommended intake ranges and midpoints outlined in the 2500 kcal/d reference Planetary Health Diet[26]. Subsequently, these values were converted into the percentage of calories contributed by each food group to the overall diet.

Food cost

The average food price data were derived from the prices listed on the website of the Iranian Statistics Center, which provided the average price of food items per 1000 g in 2022[37]. This dataset includes the average prices of each food per month in Iran. It offers the mean price for the region as a whole, including cities and rural areas. For food items not found on the Statistics Center website, we then went to retail centers and licensed stores situated in three distinct locations in southern Tehran. We took the average price of the 3 locations for the average price of the particular foods. Following this, the prices of these food items were adapted to correspond to the average price in 2022. This adaptation involved utilizing the Inflation Rate and Consumer Price Index available on the Central Bank website[38]. To ensure the consistency between the prices reported by the Statistical Center of Iran and those obtained from retail centers, a comparison was undertaken for the prices of three primary food items with the highest consumption (rice, pasta, and tea). The variation between the values from the two sources was negligible. Subsequently, the acquired prices, which pertain to the purchased forms, were converted into the prices of the edible amount of the food. To accomplish this, conversion factors outlined in the household scales book were utilized. Ultimately, the cost of food items was computed in Rials per gram for each item listed in the food frequency questionnaire. The cost of each food item consumed in the food frequency questionnaire for different individuals was determined by multiplying the grams consumed by the unit cost (the price of one gram). Finally, the sum of all food costs was regarded as the total daily diet price for each participant.

Sociodemographic characteristics

The general and sociodemographic characteristics of the households were asked through a face-to-face questionnaire. Each participant was interviewed regarding the following variables: gender, age, marital status (single or married), educational attainment (below high school, high school and above), working status (unemployed, retired, worker), household dimension (number of family members), house ownership (owner or rental), possession of specific items (including personal vehicle, washing machine, dishwasher, laptop, internet, microwave), and income (≤ 20 million Rials, 20 to 60 million Rials, and ≥ 60 million Rials).

Assessment of other variables

Participants height and body weight were measured by a trained researcher. Body weight was measured with the participant barefoot and wearing lightweight clothing, using a Seca model digital scale with a precision of 0.1 kg. Height measurement was taken while the individual stood without shoes, aligning their head, buttocks, and heels against the wall, and looking straight ahead horizontally. This measurement was conducted using a tape measure with an accuracy of 0.1 cm.

Lifestyle data incorporated details about smoking habits. Participants were specifically asked about their smoking status, indicating whether they were smokers or non-smokers. The International Physical Activity Questionnaire (IPAQ), utilized to evaluate the physical activity levels of the elderly, has undergone validation and reliability assessments in 12 countries including Iran, up to the year 2000[39,40]. The final results of this assessment confirm the effectiveness of the questionnaire as a suitable tool for measuring physical activity in diverse contexts and languages. Consisting of seven inquiries, this survey evaluates the frequency and duration of an individual's involvement in physical activities. Participants report their engagement levels in four categories over the past week: (1) intense activity; (2) moderate activity; (3) walking; and (4) sitting. To precisely calculate MET (Metabolic Equivalent of Task) per minute, it is essential to express the duration of physical activity in minutes. In the end, by summing up the MET per minute for each person throughout a week, the total weekly physical activity can be ascertained.

Statistical analysis

First, the percentage of calories from all 16 food groups recommended by EAT-Lancet was determined. Then, the PHDI score was calculated as previously described. Participants were then grouped into tertiles based on their PHDI scores.

Mean (SE) values for food cost and PHDI scores were calculated across different demographic variables using analysis of variance (ANOVA) to identify differences in mean values of PHDI among categorical variables such as sex, BMI, smoking status, physical activity, marital status, household dimension, educational attainment, income, and socioeconomic status. Analysis of covariance (ANCOVA) was employed to compare dietary intakes across tertiles of food cost, adjusted for calorie intake (except for energy intake), age, and gender. Linear regression analyses were conducted to estimate the associations between PHDI adherence and food cost, with two models: Model 1 adjusted for energy intake, and Model 2 further adjusted for age, gender, physical activity, marital status, socioeconomic status, smoking status, supplement intake, and BMI. Additionally, linear regression was used to estimate the association between PHDI scores and food costs for every 10-point increase in PHDI. Adjusted mean (SE) values for diet cost were estimated across tertiles of PHDI, stratified by sociodemographic variables to understand the variation in food costs associated with PHDI adherence within different subgroups. We also performed mediation analysis (using the Sobel test) exploring how SES or household size influences the relationship between PHDI adherence and costs and also Mixed-effects models to address potential clustering effects within socioeconomic strata (Data not shown). The analyses were carried out using SPSS version 26 (IBM Corp, Armonk, NY, USA), and statistical significance was determined for P-values below 0.05.

Result

In total, 398 participants, evenly split between males and females (50% each), were enrolled in the study. The average (standard deviation) age of the participants was 63.28 (3.58) years, and their average (SD) weight was 76.43 (10.39) kg.

Table 1 represents the mean (SD) of PHDI and food cost (Rials) across demographic variables. The PHDI and daily food costs varied across different sociodemographic characteristics among 398 elderly participants. Significant differences in PHDI scores were observed between males (55.46 ± 9.71) and females (57.81 ± 9.25), with females demonstrating higher adherence to the Planetary Health Diet (P value = 0.01). Participants with a higher BMI (> 27.5) showed a slightly lower PHDI score (55.84 ± 9.77) compared to those with BMI ≤ 27.5 (58.04 ± 8.99) (P value = 0.02). Marital status also influenced PHDI scores, with single participants scoring higher (58.61 ± 9.81) compared to married individuals (56.13 ± 9.42) (P value = 0.03). However, no significant differences in PHDI were found based on smoking status, physical activity levels, household dimension, education levels, income, or socioeconomic status. Regarding daily food costs, significant differences were

Variable	Percentage	PHDI		Food Cost	
		Mean (SD)	P value[1]	Mean (SD)	P value[1]
Sex			0.01		0.01
Male	50.0	55.46 (9.71)		3,037,975 (138,090)	
Female	50.0	57.81 (9.25)		2,673,874 (145,469)	
BMI			0.02		0.98
≤ 27.5	36.2	58.04 (8.99)		2,857,465 (154,345)	
> 27.5	63.8	55.84 (9.77)		2,855,051 (140,502)	
Smoking status			0.55		0.11
No	79.1	56.78 (9.56)		2,796,033 (147,245)	
Yes	20.9	56.09 (9.50)		3,083,222 (136,997)	
Physical activity			0.21		0.57
Low	48.2	55.85 (10.14)		2,847,243 (137,296)	
Moderate	48.2	57.51 (8.86)		2,835,323 (153,697)	
High	3.5	55.42 (9.74)		325,752 (142,824)	
Marital status			0.03		0.09
Single	20.4	58.61 (9.81)		2,613,420 (152,212)	
Married	79.6	56.13 (9.42)		2,917,889 (143,286)	
Household dimension			0.92		0.10
< 4	20.9	56.73 (8.86)		3,088,987 (181,519)	
≥ 4	79.1	56.61 (9.73)		2,794,514 (134,048)	
Education[2]			0.11		0.95
Low	58.8	56.01 (9.67)		2,859,483 (137,955)	
High	41.2	57.54 (9.31)		2,850,847 (155,996)	
Income			0.89		0.15
Low	4.8	57.63 (10.45)		2,409,204 (101,104)	
Moderate	65.1	56.57 (9.64)		2,809,098 (142,303)	
High	30.2	56.64 (9.54)		3,027,722 (156,471)	
Socioeconomic status			0.41		0.36
Low	26.6	55.64 (9.53)		2,688,881 (126,324)	
Moderate	41.2	56.78 (9.82)		2,891,124 (155,232)	
High	32.2	57.28 (9.20)		2,949,158 (147,283)	

Table 1. Mean scores of PHDI (Planetary Health Diet Index), and individual diet cost (per day) according to sociodemographic characteristics (n = 398). [1]Obtained from the ANOVA. [2]Low = below high school, High = high school and above.

observed only in relation to marital status (P value = 0.09), where single participants had lower mean food costs (2,613,420 ± 152,212) compared to married participants (2,917,889 ± 143,286). Other sociodemographic variables did not show statistically significant differences in daily food costs among the participants.

Table 2 displays dietary intakes across tertiles of individual daily food cost among 398 elderly participants. Participants in the highest tertile of food cost (≥ 3,073,987 Rials) had significantly higher energy intake (2528.66 ± 52.56 kcal/day) compared to those in the lowest tertile (P < 0.001). Between macronutrients, significant differences were observed across food cost tertiles for carbohydrate (P = 0.04) and protein consumption (P = 0.001). Also, iron (14.91 ± 0.24) and magnesium (259.88 ± 4.97 mg/day) intakes were significantly lower in the highest food cost tertile compared to the lowest tertile (P < 0.001). No significant differences were observed for other dietary intakes across the tertiles of food cost.

Table 3 presents the results of multivariable linear regression analyses examining variations in daily diet cost according to PHDI tertiles. After adjusting for energy intake, participants in PHDI tertiles showed a significant inverse relationship between PHDI score and daily diet cost. Specifically, for every 10-point increase in PHDI score, there was a corresponding decrease in daily diet cost by 343,870 Rials (95% CI: − 495,299 to − 192,442; p < 0.001). Across PHDI tertiles adjusted for energy intake, participants in the highest tertile had significantly lower daily diet costs (− 698,638 Rials, 95% CI: − 1,029,070 to − 368,200; p < 0.001) compared to the reference tertile. In the fully adjusted model, this inverse relationship persisted. Participants in the third tertile had lower daily diet costs (− 708,367 Rials, 95% CI: − 1,060,371 to − 356,362; p < 0.001) compared to the first tertile. Hence, moving from the first to the third PHDI category reduced daily food costs by 708,367 Rials, highlighting the cost-effectiveness of higher adherence.

Based on the adjusted mean (SE) values presented in Table 4, significant variations in daily diet costs across tertiles of the PHDI were observed within different sociodemographic subgroups. In the stratified analyses, inverse association between adherence to the PHDI and daily diet costs remained significant across various

	Food cost tertiles			
	1,961,460 ≥ T1 (n = 132)	1,961,460 < T2 < 3,073,987 (n = 133)	T3 ≥ 3,073,987 (n = 133)	P-value[1]
Energy (kcal)	53.44 ± 1886.59	2166.87 ± 52.50	2528.66 ± 52.56	< 0.001
Macronutrients				
Protein (percent of total calories)	13.15 ± 0.19	12.58 ± 0.19	12.13 ± 0.19	0.001
Carbohydrate (percent of total calories)	62.75 ± 0.58	64.43 ± 0.57	62.61 ± 0.57	0.04
Total fat (percent of total calories)	26.47 ± 0.57	26.16 ± 0.56	27.41 ± 0.56	0.26
W3 (gram/day)	0.42 ± 0.02	0.38 ± 0.01	0.39 ± 0.01	0.20
Total fiber (gram/day)	19.35 ± 0.43	18.37 ± 0.41	17.63 ± 0.38	0.43
Food groups				
Vegetable (gram/day)	362.97 ± 14.72	321.27 ± 13.89	327.77 ± 14.60	0.10
Fruit (gram/day)	345.51 ± 15.52	353.33 ± 14.64	359.60 ± 15.39	0.82
Dairy (gram/day)	271.74 ± 18.09	258.42 ± 17.07	266.91 ± 17.94	0.86
Red meat (gram/day)	29.26 ± 1.97	33.32 ± 1.86	36.08 ± 1.95	0.06
Whole grain (gram/day)	64.39 ± 5.11	59.22 ± 4.82	57.17 ± 5.07	0.61
Micronutrients				
Calcium (mg/day)	815.85 ± 25.01	770.93 ± 23.60	783.73 ± 24.81	0.42
Iron (mg/day)	16.49 ± 0.24	15.49 ± 0.23	14.91 ± 0.24	< 0.001
Magnesium (mg/day)	232.74 ± 5.01	230.75 ± 4.72	259.88 ± 4.97	< 0.001
Zinc (mg/day)	7.27 ± 0.15	7.15 ± 0.15	7.47 ± 0.15	0.33
Vitamin C (mg/day)	146.74 ± 5.40	134.28 ± 5.09	133.98 ± 5.35	0.17
Vitamin B12 (mg/day)	2.90 ± 0.11	2.85 ± 0.11	2.99 ± 0.11	0.70

Table 2. Nutrient intakes across tertiles of individual food cost (per day). [1]Obtained from ANCOVA. All values are means ± standard error (SE); energy, protein, carbohydrate and fat are adjusted for age and gender; all other values are adjusted for age, gender and energy intake.

	n	Score (range)	Daily diet cost		
			Mean (SEM[1])	β (95% CI)[2]	P value
PHDI					
For every 10 points increase				− 343,870 (− 495,299, − 192,442)	< 0.001
Tertiles (energy adjusted)					
T1	139	27 to 53	3,222,624 (118,696)	Reference	
T2	121	54 to 60	2,813,249 (127,043)	− 409,375 (− 752,050, − 66,700)	0.01
T3	138	61 to 82	2,523,986 (118,766)	− 698,638 (− 1,029,070, − 368,200)	< 0.001
Tertiles (fully adjusted)[3]					
T1	139	27 to 53	3,210,600 (123,375)	Reference	
T2	121	54 to 60	2,830,272 (128,053)	− 391,373 (− 746,558, − 36,188)	0.03
T3	138	61 to 82	2,521,171 (122,442)	− 708,367 (− 1,060,371, − 356,362)	< 0.001

Table 3. Multivariable linear regression analyses estimating daily diet cost variations according to PHDI tertiles. [1]SEM = standard error of the mean (Obtained from ANCOVA). [2]Obtained from linear regression. [3]Adjusted for age, gender, energy intake, physical activity, marital status, socio-economic status, smoking status, supplement intake and BMI.

demographic subgroups. However, this inverse relationship did not maintain statistical significance within the single and low-income categories. This pattern is visualized in Fig. 1.

To quantify the potential impact of unmeasured confounding, E-values were calculated for the association between PHDI adherence and daily diet cost using linear regression[41,42]. The E-value for the point estimate was 1.84, and for the confidence interval, it was 1.51. These values indicate the minimum strength of association an unmeasured confounder would need to have with both the exposure (PHDI adherence) and the outcome (diet cost) to explain away the observed relationship, after accounting for the variables controlled in the model.

We conducted mediation analysis to explore the potential mediating role of SES and household size on the relationship between PHDI adherence and food costs using Sobel test. The Sobel test indicated no statistically significant mediation effect ($p > 0.05$), suggesting these variables do not mediate the relationship in our sample. Also, to account for potential clustering effects within SES strata we used mixed-effects models. These exploratory analyses did not yield additional insights beyond our primary linear regression and subgroup analyses, which remain the most reliable and interpretable results for our sample.

Variable	Tertiles[1] T1[2]	T2	T3	P-value[3]
Gender				
Male	3,367,805 (155,962)	2,842,157 (183,826)	2,764,475 (184,800)	0.02*
Female	3,006,682 (197,580)	2,775,046 (180,461)	2,350,624 (165,524)	0.03*
Marital status				
Single	3,015,409 (362,501)	2,710,760 (279,472)	2,328,810 (253,126)	0.29
Married	3,275,148 (131,742)	2,885,480 (145,130)	2,527,460 (142,648)	0.001*
Household size				
≥ 4	3,892,108 (343,426)	3,075,172 (352,858)	2,426,989 (315,575)	0.03*
< 4	3,058,239 (128,066)	2,746,470 (133,805)	2,558,658 (130,471)	0.01*
Education				
Low	3,133,423 (148,544)	2,805,479 (163,009)	2,586,261 (164,469)	0.05
High	3,367,079 (223,386)	2,853,486 (215,312)	2,437,454 (191,172)	0.01*
Income				
Low	2,710,719 (417,505)	2,731,973 (350,696)	1,731,127 (364,764)	0.18
Moderate	3,287,097 (155,168)	2,594,427 (151,568)	2,540,836 (153,796)	0.001*
High	3,137,395 (232,533)	3,563,025 (286,898)	2,570,638 (233,456)	0.02*
SES				
Low	3,015,490 (185,555)	2,566,571 (195,777)	2,269,751 (204,561)	0.02*
Moderate	3,288,265 (201,931)	2,875,069 (233,744)	2,539,860 (203,421)	0.04*
High	3,279,312 (256,709)	3,270,103 (235,944)	2,533,382 (238,392)	0.06

Table 4. Adjusted means of daily diet cost according to PHDI tertiles stratified by demographic variables. [1]Adjusted for age, gender, energy intake, physical activity, marital status, smoking status, supplement intake, BMI, socio-economic status with exception for the stratified variable. [2]Presented as Mean ± SEM (standard error of the mean). [3]Obtained from ANCOVA.

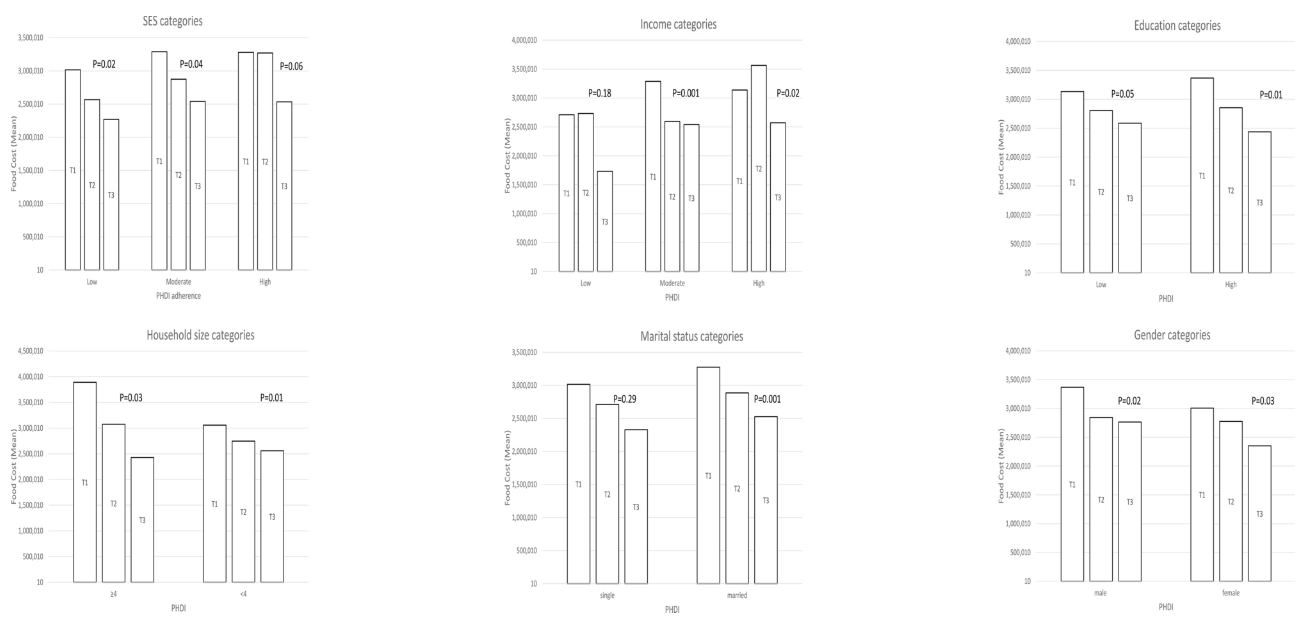

Fig. 1. Adjusted means of daily diet cost according to PHDI tertiles stratified by demographic variables.

Discussion

The main aim of this study was to examine the relationship between adherence to the PHD) and dietary costs among older adults in Tehran, as well as to identify sociodemographic factors linked to these cost differences. Our findings show that higher PHDI scores are generally linked to lower dietary costs. However, this inverse relationship was not significant among single individuals and those with lower incomes. This suggests that while adherence to the Planetary Health Diet can be economically beneficial, these benefits may differ based on individual sociodemographic factors.

The findings of this study highlight the potential of the Planetary Health Diet as a dual-purpose strategy in public health. By promoting nutrient-dense, cost-effective diets, the Planetary Health Diet offers a feasible pathway to improve both individual health outcomes, specifically malnutrition and chronic disease risks among older adults, and societal dietary patterns.

Most studies in the literature have found that healthier diets are generally more expensive. The first demonstration of a linear relationship between diet quality and cost was observed in the 1999 study in the UK Women's Cohort Study[43]. As the diet quality, assessed by the Healthy Diet Index, improved, the daily expenditure on food also increased. This positive relationship between diet quality and cost was reaffirmed in the same cohort of women in 2013[44]. A systematic review of studies investigating the link between diet quality and cost found that healthier diets tend to be more costly[3]. However, it emphasizes that although potato chips, sweets, and biscuits are more costly per kilogram when priced in euros, compared to low-energy–density foods such as apples, tomatoes, and carrots, they are cheaper when evaluated in euros per 100 kcal. This difference arises because apples, tomatoes, and carrots contain more water compared to sweets and fats, as observed by Atwater in 1896.

Studies have demonstrated a direct correlation between higher nutrient density scores and increased cost per calorie[45,46]. Yet, there was significant variability in both nutrient density and cost within the different food groups[47]. For instance, it has been demonstrated that the cost of vegetables varied, with not all being equally expensive. Also, a meta-analysis of food prices collected after the year 2000 revealed a smaller gap of $1.5 (on average across 10 different countries) between the cost of the healthiest dietary patterns and the least healthy ones[6]. In this study, when comparing nutrient-based patterns, the price per day did not show significant differences.

In contrast, our study aligns with a smaller body of research suggesting that it is possible to follow a healthy diet at a lower cost. One study demonstrated that the cost per calorie of a convenience diet was 24% higher than that of a healthy diet[48]. A Japanese study revealed that a higher monetary cost of dietary energy was linked to increased consumption of fat, oil, meat, and energy-containing beverages, while there was a decreased consumption of cereals[49]. Studies investigating the economic effects of enhanced diets have shown that improved diets can significantly reduce food expenditures[50,51]. This research demonstrated that the group that received nutrition education not only lowered their food costs but also boosted their intake of essential nutrients[50]. Furthermore, a study conducted in Spain found that women who were encouraged to adopt a Mediterranean-style diet in Canada did not report an increase in their food expenditures[52].

One possible explanation for the inconsistent results could be differences in how food costs were measured across studies. A study examining the assumption that healthy diets are more expensive, compared prices of healthy and less healthy foods using three distinct metrics: the cost per food energy unit, the cost per edible weight unit, and the cost per average portion[53]. Except for the price of food energy, the study reveals that healthy foods are generally less expensive than less healthy options (defined as foods high in saturated fat, added sugar, and/or sodium, or having minimal nutritional value). Therefore, this research suggests that the choice of metric for assessing food prices significantly influences which foods appear more costly. Indeed, since the price per calorie fails to consider the quantity of food consumed, it is not an accurate proxy for actual out-of-pocket food expenses[54,55].

Another factor contributing to the lower dietary cost associated with higher PHDI scores is the scoring system itself: consuming more meat results in a lower PHDI score, and while dairy intake is beneficial up to a certain threshold, excessive consumption can also reduce the score. In March 2020, fruits, red meat, and dairy products were identified as the top three contributors to the cost of a desirable food basket in Iranian society, accounting for more than half (56%) of its total cost[56]. This suggests that replacing meat with plant proteins and limiting dairy consumption to some extent, as promoted by the PHDI, can result in significant reductions in overall dietary expenses. This hypothesis is supported by one study demonstrating that individuals who follow plant-based diets, especially vegans, incur lower food expenses compared to omnivorous individuals[57].

By conducting subgroup analysis according to marital status and income, the association between PHDI and food cost was weakened, implying that socioeconomic and demographic factors may mediate the relationship between PHDI and food cost. Prior research has firmly established that socioeconomic status and demographic factors can influence the relationship between diet cost and diet quality[4,5,58–61]. In a study investigating the link between monetary value and diet quality, it was found that the positive correlation between the monetary value of the diet and dietary quality, was influenced by socioeconomic factors[61]. This finding highlights the need for targeted interventions to improve diet quality among low-income or socioeconomically disadvantaged groups, as they may face greater barriers to adhering to healthier dietary patterns like the PHDI due to financial constraints.

Given the moderating role of socioeconomic and demographic factors in the relationship between PHDI and food cost, implementing subsidies for nutrient-dense foods could serve as a practical strategy to enhance accessibility and adherence to healthy dietary patterns, particularly among vulnerable populations[62]. Also, community meal planning programs tailored to older adults can play a significant role[63]. These programs could focus on education around cost-effective, PHD-aligned meal preparation and provide resources such as recipe guides and group cooking sessions. Such initiatives would not only improve dietary quality but also foster social engagement among older adults, addressing broader determinants of health[64].

One strength of our study is that it is the first to investigate the relationship between the Planetary Health Diet Index and dietary costs in Iranian population while also considering socioeconomic and demographic factors. Another key strength of this study is the use of the Planetary Health Diet Index (PHDI) to assess adherence to the EAT-Lancet dietary guidelines. This study's scoring system is incremental, setting it apart from other systems that rely on binary assessments[65,66]. Moreover, consumption data for 151 items from the FFQ were paired with both Iranian Statistics Center data and retail prices and the price data were aligned with the same period as the consumption data.

However, there are some limitations worth noting. Firstly, the study utilized a cross-sectional analysis, which enables the identification of associations but does not allow for the establishment of causation. Secondly, food consumption was assessed using a Food Frequency Questionnaire (FFQ), which, while an appropriate tool, has inherent limitations, such as a restricted food list and the potential for dietary misreporting bias, including recall bias. Although interviews were conducted to mitigate this, there is still the possibility of inaccuracies in reporting. Future studies could consider incorporating biomarkers to provide more objective measures of dietary intake and reduce recall bias. Thirdly, we did not assess food consumed away from home, leading to potentially inaccurate food cost estimations. Our method assumes that all foods are purchased at retail prices and prepared at home, which may underestimate the true variability in food prices and the costs associated with individual food consumption. Also, variations in food costs due to home preparation, purchasing food away from home, differences between brand-name and generic or low-cost options, and seasonal price fluctuations are overlooked when using average prices. Also, we did not account for food waste, which could affect the accuracy of our calculations of food costs by potentially underestimating the true expenses associated with dietary habits[67]. Moreover, A key limitation of this study is the adaptation of the PHDI to reflect traditional Iranian dietary habits, which may impact the external validity of our findings. These adaptations, while contextually relevant, may limit comparability with studies using the unmodified PHDI scoring system. Furthermore, while we have acknowledged confounding factors in the study, there could be residual confounding, where unmeasured or inadequately controlled factors might still influence the results. Future research could use longitudinal designs to track changes over time and better capture causal relationships. Finally, we did not include individuals with chronic illnesses, which may affect the generalizability of the findings to the broader geriatric population.

In conclusion, our study sheds light on the complex relationship between adherence to the PHDI, dietary costs, and socioeconomic factors among older adults in Tehran. We found that higher PHDI scores generally correlate with lower dietary costs, with a 343,870 Rial reduction in daily food costs for every 10-point increase in PHDI score, although this association was not significant among single individuals and those with lower incomes. This underscores the variability in economic benefits associated with adopting a Planetary Health Diet, influenced by individual sociodemographic characteristics. The findings of our study will inform policymaking aimed at improving food security and nutritional outcomes for older adults, particularly those facing economic barriers. By adapting a Planetary Health Diet, which emphasizes more plant-based foods and whole grains, and integrating it into Iranian dietary guidelines, we can reduce the environmental impact of diets while also addressing healthcare costs related to malnutrition and chronic disease management. Practical solutions to promote adherence could include creating affordable and culturally relevant meal plans that incorporate locally available ingredients, subsidizing healthy food options such as legumes and whole grains, and implementing community-based nutrition education programs to raise awareness. Additionally, policies that incentivize local production of nutritious foods and reduce taxes on these items could enhance accessibility. These measures not only make the PHDI more achievable for older adults but also help lower healthcare costs by reducing the prevalence of malnutrition and diet-related chronic diseases, ultimately easing the financial burden on the healthcare system. Future research should focus on longitudinal studies for assessing dietary behaviors to inform effective public health policies aimed at promoting affordable, sustainable and nutritious diets for all segments of the population.

Data availability
Data supporting the findings are available from the corresponding author on reasonable request and under conditions that ensure the protection of participant privacy.

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Author contributions
LA, ADM and MKD designed the study. MKD, HA and PNH carried out the sampling. MKD, HA and PNH carried out interviews and imported the data for analysis. MKD performed the statistical analyses. MKD drafted the manuscript. LA and ADM read and commented on the manuscript. LA supervised the study. The final manuscript was approved by all the authors.

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Declarations

Competing interests
The authors declare no competing interests.

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