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Diet Quality Assessed by the Healthy Eating Index Is Nonlinearly Associated with Sweet and Salt Taste Recognition Thresholds in Healthy Adults: Evidence from a Cross-Sectional Study

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ABSTRACT

Background: This study aimed to examine the association between diet quality, assessed by the Healthy Eating Index-2015 (HEI-2015), and recognition thresholds for sweet and salty taste among healthy adults.

Methods: In this cross-sectional study conducted between April 2023 and March 2024, 200 healthy adults were included. Dietary intake was assessed using a validated food frequency questionnaire, and diet quality was quantified using HEI-2015. Recognition thresholds for sweet (sucrose) and salty (NaCl) tastes were measured using a standardized protocol. Multivariable linear and logistic regression models were used to examine the associations, adjusting for demographic factors, energy intake, and serum micronutrient levels.

Results: Higher HEI scores were associated with lower recognition thresholds for both sweet taste (β = -0.018; 95% CI: -0.029, -0.007) and salty taste (β = -0.015; 95% CI: -0.026, -0.004). Participants in the highest HEI tertile had greater odds of being taste-sensitive (sweet: OR = 2.64; 95% CI: 1.38-5.07; salt: OR = 2.09; 95% CI: 1.12-3.91) than those in the lowest tertile. Non-linear analyses indicated stronger associations at HEI scores above approximately 60. A significant interaction between HEI score and serum zinc concentration was observed for sweet taste recognition.

Conclusion: Higher diet quality was associated with greater sensitivity to sweet and salty tastes, suggesting that overall dietary patterns may influence taste perception.

1. Introduction

Taste perception is a fundamental determinant of food choice and dietary behavior, shaping not only individual preferences but also long-term nutritional patterns and health outcomes. Among the basic taste modalities, sensitivity to sweetness and saltiness plays a particularly important role because of its direct relevance to the consumption of sugars and sodium, two dietary components that have been consistently implicated in the global burden of cardiometabolic diseases (Mozaffarian, 2016; World Health Organization, 2012). Subtle variations in taste sensitivity may therefore influence dietary intake beyond conscious decision-making, operating through both physiological and behavioral mechanisms.

A growing body of evidence suggests that taste perception is not a fixed trait but rather a dynamic sensory function that can be modulated by habitual dietary exposure. Repeated consumption of high-sugar or high-sodium foods has been associated with elevated taste recognition thresholds,

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reflecting a form of sensory adaptation that may reinforce preference for more intensely flavored foods (Jayasinghe et al., 2017; Martinelli et al., 2020; Wise et al., 2016). Conversely, dietary modification, particularly reductions in sodium or added sugars, has been shown to enhance taste sensitivity over time, supporting the concept that sensory systems remain responsive to environmental influences (Mohammadifard et al., 2023; Sung et al., 2025). These findings have important implications, suggesting that dietary patterns and taste perception may be linked through bidirectional mechanisms. Despite this progress, much of the existing literature has focused on isolated nutrients or short-term interventions, often conducted under controlled experimental conditions. Although such approaches have provided valuable mechanistic insights, they may not fully capture the complexity of habitual dietary behavior in free-living populations. In this context, dietary pattern-based approaches offer a more holistic framework by enabling the simultaneous consideration of multiple dietary components and their combined effects on physiological outcomes (Nestel & Mori, 2022; Wang et al., 2023). The HEI-2015, in particular, is a widely used and validated measure of overall diet quality that reflects adherence to established dietary guidelines and incorporates both adequacy and moderation components (Kim & Lee, 2007; Krebs-Smith et al., 2018).

However, evidence linking overall diet quality, rather than individual nutrients, to taste sensitivity remains limited and fragmented. A few observational studies have suggested that healthier dietary patterns may be associated with greater taste acuity, but findings have been inconsistent, and the underlying mechanisms remain poorly understood (Diószegi et al., 2019; Kato & Roth, 2012). Moreover, the potential role of micronutrient status in modifying these associations has not been adequately explored. Nutrients such as zinc and iron are known to be involved in taste bud function, epithelial turnover, and neural signaling, raising the possibility that systemic nutritional status may interact with dietary patterns to influence sensory perception (Ikeda et al., 2008; Luo et al., 2022).

Another important, yet underexplored, aspect is the possibility of non-linear relationships between diet quality and taste sensitivity. It is plausible that only sustained adherence to higher-quality diets leads to meaningful changes in sensory function, while modest improvements may have a limited impact. This concept has received little attention in the literature, despite its potential relevance for designing effective dietary interventions.

Taken together, these gaps highlight the need for a comprehensive evaluation of the relationship between overall diet quality and taste perception within a real-world context, while accounting for both behavioral and biological determinants. Therefore, the present study aimed to investigate the association between diet quality, as assessed by the Healthy Eating Index, and recognition thresholds for sweet and salty taste in a sample of healthy adults. In addition, we sought to examine potential non-linear relationships and to explore whether key micronutrients, particularly zinc and iron, modify these associations.

2. Materials and Methods

2.1 Study design and reporting framework

This cross-sectional analytical study was conducted between April 2023 and March 2024 to investigate the association between overall diet quality and taste recognition thresholds in a sample of healthy Iranian adults. The study was conducted and reported in strict accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement, with particular attention to transparent reporting of participant selection, variable definitions, bias control, and statistical methodology.

The study was approved by the Research Ethics Committee of the Urmia University of Medical Sciences (approval number: IR.UMSU.REC.1402.069). All participants provided written informed consent before enrolment. The study was conducted in accordance with the Declaration of Helsinki and relevant institutional guidelines. No financial inducements were offered, and participation did not disadvantage any participant. Participant anonymity and confidentiality were preserved throughout.

2.2 Setting and participants

Participants were recruited from the general population through community-based advertisements and university-affiliated networks between April 2023 and March 2024. Eligibility criteria included: age between 20 and 60 years, absence of chronic diseases (e.g., diabetes, cardiovascular disease, renal disorders), no history of taste or olfactory disorders, no use of medications known to affect taste perception (e.g., zinc supplements, antidepressants), Pregnant or lactating women and individuals with implausible dietary intake (energy intake <800 or >4200 kcal/day) were excluded. A total analytical sample of 200 participants was defined a priori to ensure adequate statistical power for multivariable modeling and subgroup analyses.

2.3 Sample size determination

The sample size was calculated to detect a small-to-moderate effect size ($f^2 = 0.08$) in a multivariable linear regression with up to 10 predictors, assuming $\alpha = 0.05$ and 80% power. The minimum required sample size was estimated at 160 participants. To enhance model stability, allow interaction testing, and comply with contemporary recommendations for regression modeling (minimum 15-20 observations per parameter), the final sample size was set at 200 individuals.

2.4 Dietary assessment and HEI-2015

Habitual dietary intake over the preceding year was assessed using a validated 168-item semi-quantitative food frequency questionnaire (FFQ), administered through face-to-face interviews by trained nutritionists. The FFQ had been

validated in Iranian adults and is considered suitable for estimating the usual intake of common food groups and nutrients in this population. Participants reported their usual frequency of consumption for each food item in standard portion sizes, which were converted into daily gram intakes using established Iranian food composition tables. Mixed dishes were decomposed into their ingredients according to standard Iranian recipes before nutrient analysis. Total energy and nutrient intakes were calculated using Nutritionist IV software adapted for local dietary patterns.

Overall diet quality was evaluated using the HEI-2015, a comprehensive measure of adherence to dietary guidelines. The HEI-2015 comprises 13 components that capture both adequacy and moderation aspects of diet. Adequacy components–including total fruits, whole fruits, total vegetables, greens and beans, whole grains, dairy, total protein foods, seafood and plant proteins, and the ratio of unsaturated to saturated fatty acids–were scored such that higher intake corresponded to higher scores. In contrast, moderation components–refined grains, sodium, added sugars, and saturated fats–were reverse scored, with lower consumption yielding higher scores (Krebs-Smith et al., 2018). In contrast, moderation components-refined grains, sodium, added sugars, and saturated fats-were reverse scored, with lower consumption yielding higher scores. All components were calculated on an energy-adjusted basis (per 1000 kcal) to account for inter-individual variability in total intake. Component scores were summed to generate a total HEI score ranging from 0 to 100, with higher values indicating better diet quality. For analytical purposes, participants were categorized into tertiles representing low, moderate, and high adherence to dietary guidelines.

2.5 Taste sensitivity assessment

Taste sensitivity was evaluated by determining recognition thresholds (RTs) for sweetness and saltiness using sucrose and sodium chloride solutions, respectively, following the ISO 3972:2011 standardized sensory protocol (International Organization for Standardization, 2011). Recognition thresholds were analyzed both as continuous variables, defined as the concentration level at which the tastant was correctly identified, and as categorical variables, with participants classified into higher sensitivity (lower RT) and lower sensitivity (higher RT) groups according to predefined cut-offs. An ascending forced-choice method was used, in which participants were sequentially presented with increasing concentrations of each tastant until the correct taste quality was identified. Testing was performed under standardized conditions to minimize variability, and participants were instructed according to the same protocol across all assessments. Recognition thresholds were recorded as the lowest concentration correctly identified. For analytic purposes, RTs were also categorized into higher-and lower-sensitivity groups based on predefined cut-offs. The use of a standardized ISO protocol enhanced procedural consistency and reproducibility.

2.6 Biochemical measurements

Following an overnight fast of 10-12 h, approximately 10 mL of venous blood was collected from each participant between 07:00 and 09:00 A.M. Under standardized conditions. Blood samples were collected into serum-separator tubes and allowed to clot at room temperature for approximately 30 min. Samples were then centrifuged at 3,000 rpm for 10 min at 4°C. The separated serum was immediately aliquoted into sterile polypropylene microtubes to minimize repeated freeze–thaw cycles and stored at −80°C until biochemical analysis. Samples showing visible hemolysis, lipemia, or other evidence of preanalytical contamination were excluded from the respective biochemical assays.

Serum zinc concentrations were determined using a colorimetric 5-bromo-2-pyridylazo-5-(N-propyl-N-sulfopropylamino) phenol (5-Br-PAPS) method with a commercially available zinc assay kit (Randox Laboratories Ltd., Crumlin, UK). In this method, zinc forms a colored complex with 5-Br-PAPS under alkaline conditions, with the intensity of the resulting color being directly proportional to the zinc concentration in the sample. Absorbance was measured spectrophotometrically at approximately 560 nm using an automated biochemical analyzer (Mindray BS-200, Mindray Bio-Medical Electronics Co., Shenzhen, China).

Serum copper concentrations were measured using a direct colorimetric assay based on the formation of a colored complex between copper ions and 4-(3,5-dibromo-2-pyridylazo)-N-ethyl-N-sulfopropylaniline (Di-Br-PAESA), using a commercially available copper assay kit (Randox Laboratories Ltd., Crumlin, UK). Absorbance was measured at approximately 580 nm using the same automated biochemical analyzer. The copper-to-zinc (Cu/Zn) ratio was subsequently calculated from the measured serum copper and zinc concentrations after conversion to equivalent molar units to ensure dimensional comparability.

Serum iron concentrations were determined using a FerroZine-based colorimetric method (Pars Azmun Co., Tehran, Iran). Briefly, ferric iron bound to transferrin was released in an acidic medium and reduced to the ferrous form. Ferrous iron subsequently reacted with FerroZine to generate a colored complex, the absorbance of which was directly proportional to serum iron concentration. Measurements were performed using the Mindray BS-200 automated clinical chemistry analyzer according to the manufacturer's instructions.

Serum vitamin B12 concentrations were quantified using an automated competitive electrochemiluminescence immunoassay (ECLIA) with the Elecsys Vitamin B12 II assay (Roche Diagnostics GmbH, Mannheim, Germany) on a Cobas e 411 immunoassay analyzer (Roche Diagnostics GmbH). The assay is based on competitive binding of serum vitamin B12 and ruthenium-labeled vitamin B12 to an intrinsic factor-based binding system, with the generated electrochemiluminescent signal being inversely related to the concentration of vitamin B12 in the sample.

Serum folate concentrations were measured using an automated competitive electrochemiluminescence immunoassay with the Elecsys Folate III assay (Roche Diagnostics GmbH, Mannheim, Germany) on the Cobas e 411 platform. Following sample pretreatment to release folate from endogenous binding proteins, serum folate competed with labeled folate for binding sites on folate-binding protein. The resulting electrochemiluminescent signal was used to quantify serum folate concentrations according to the manufacturer's calibration curve.

Serum 25-hydroxyvitamin D [25(OH)D] concentrations were determined using the Elecsys Vitamin D total II competitive electrochemiluminescence binding assay (Roche Diagnostics GmbH, Mannheim, Germany) on the Cobas e 411 analyzer. The assay measures total circulating 25(OH)D, including 25-hydroxyvitamin D2 and 25-hydroxyvitamin D3, and was performed according to the manufacturer's instructions. Serum 25 (OH) D was used as the biochemical indicator of vitamin D status.

All biochemical analyses were performed in the same clinical laboratory by trained laboratory personnel using standardized operating procedures. Laboratory personnel were unaware of participants' HEI scores and taste-recognition measurements at the time of biochemical analysis. Instruments were calibrated according to the manufacturers' recommendations, and calibration was repeated whenever required by the analytical system or following reagent-lot changes.

Internal quality-control procedures were implemented throughout the analytical process. Commercially available control sera at two concentration levels (normal and pathological) were analyzed at the beginning of each analytical batch. An analytical run was accepted only when control values fell within the manufacturer-specified target ranges. Samples yielding values outside the analytical measurement range were appropriately diluted and reanalyzed according to the assay manufacturer's instructions. Approximately 10% of randomly selected samples were analyzed in duplicate to assess analytical reproducibility. The intra-assay coefficients of variation were below 5% and the inter-assay coefficients of variation were below 8% for all biochemical measurements. All samples from an individual participant were analyzed within the same analytical batch whenever possible to minimize inter-batch variability.

2.7 Covariates

Potential confounding variables were identified a priori based on biological plausibility and existing literature. These included age, sex, body mass index (BMI) and total energy intake where available. These covariates were incorporated into multivariable models to reduce residual confounding and improve the validity of the observed associations.

2.8 Bias and data quality control

Several strategies were implemented to minimize bias and enhance data quality. Dietary data were collected by trained personnel using standardized interviewing techniques, and implausible energy reporters were excluded based on predefined criteria. Taste assessments were conducted under controlled conditions using a validated protocol to reduce measurement variability. Furthermore, statistical models were adjusted for key confounders, and sensitivity analyses were performed to assess the robustness of the findings.

2.9 Statistical analysis

All statistical analyses were conducted using Stata software (version 17; StataCorp, College Station, TX, USA). Analyses were pre-specified before data modeling, and all statistical procedures adhered to the SAMPL guidelines to ensure transparency, reproducibility, and appropriate interpretation of effect estimates. All tests were two-sided, and statistical significance was defined as a *P-value* < 0.05; however, given the observational nature of the study, emphasis was placed on the magnitude and precision of effect estimates rather than sole reliance on *P-values*.

Continuous variables were examined for normality using a combination of graphical methods (histograms and Q-Q plots) and the Shapiro-Wilk test. Normally distributed variables are presented as mean ± standard deviation (SD), whereas skewed variables are reported as median with interquartile range (IQR). Categorical variables are expressed as frequencies and percentages. Baseline characteristics were compared across tertiles of the Healthy Eating HEI-2015 using one-way analysis of variance (ANOVA) for normally distributed variables and the Kruskal-Wallis test for non-normally distributed variables. Differences in categorical variables were assessed using the chi-square test.

The primary analytical objective was to evaluate the association between diet quality, as measured by HEI, and recognition thresholds for sweet and salty taste. Recognition thresholds were modeled both as continuous outcomes and as dichotomized variables to reflect clinically interpretable categories of taste sensitivity. For continuous outcomes, multivariable linear regression models were constructed using a hierarchical approach. The initial model (Model 1) was unadjusted. Model 2 included adjustment for core demographic and anthropometric variables (age, sex, and body mass index). Model 3 was further adjusted for total energy intake and relevant serum micronutrients (zinc, iron, copper, vitamin B12, folate, and vitamin D), selected a priori based on biological plausibility and existing literature. Results from linear models are presented as β coefficients with corresponding 95% confidence intervals (CIs), representing the change in recognition threshold per unit increase in HEI.

For categorical outcomes, binary logistic regression models were used to estimate odds ratios (ORs) and 95% CIs for higher taste sensitivity across tertiles of HEI, with the lowest tertile serving as the reference category. Tests for linear trend across tertiles were conducted by modeling the median value of each tertile as a continuous variable. To evaluate the shape of the association between HEI and taste recognition thresholds, restricted cubic spline (RCS)

regression models were fitted using three knots placed at the 10th, 50th, and 90th percentiles of the HEI distribution. Models were adjusted for the same covariates as the fully adjusted linear regression model. The overall association between HEI and each taste recognition threshold was evaluated using a joint Wald test of all spline terms (P-overall). Departure from linearity was assessed using a Wald test of the nonlinear spline term (s), excluding the linear term (P-nonlinearity). A P-nonlinearity < 0.05 was considered evidence of a statistically significant nonlinear association. Effect modification was assessed through the inclusion of multiplicative interaction terms in the fully adjusted models. Specifically, interactions between HEI and serum zinc (for sweet taste) and between HEI and serum iron (for salt taste) were evaluated, given their established biological roles in taste physiology. Where significant or suggestive interactions were observed, stratified analyses were performed to aid interpretation.

Model assumptions and goodness-of-fit were carefully evaluated. Multicollinearity was assessed using variance inflation factors (VIF), with values below 5 considered acceptable. For linear regression models, residual plots were inspected to assess homoscedasticity and normality of residuals. For logistic regression models, calibration was evaluated using the Hosmer-Lemeshow goodness-of-fit test, and discrimination was assessed using the area under the receiver operating characteristic (ROC) curve (AUC). A series of sensitivity analyses was conducted to evaluate the robustness of the findings. These included exclusion of participants with extreme energy intakes, reclassification of taste sensitivity using alternative cut-off points, and modeling micronutrient variables both as continuous measures and as categorical tertiles. The consistency of effect estimates across these analyses was used to support the stability of the results.

Multivariable regression models were used to examine the association between HEI scores and taste recognition thresholds. Covariates were selected a priori based on previous literature and their potential role as confounders in the relationship between diet quality and taste perception. These included demographic factors (age and sex), total energy intake, and selected serum micronutrients that may influence taste function. Adjusting for these variables aimed to reduce potential confounding and provide more robust estimates of the associations.

Missing data were minimal in the present study. Participants with incomplete information on key exposure, outcome, or covariate variables were excluded from the relevant analyses. All statistical analyses were conducted using complete-case data.

3. Results and Discussion

3.1 Participant characteristics and distribution across HEI tertiles

A total of 200 participants were included in the final analysis. The mean age of participants was 34.8 ± 11.6 years, and 51% were male. The mean BMI was 25.7 ± 4.6 kg/m², reflecting a predominantly normal-to-overweight population. The mean HEI-2015 score was 59.3 ± 11.9, with a wide distribution across participants. When categorized into tertiles, the mean HEI values were 44.2 ± 6.1 in the lowest tertile (T1), 58.7 ± 4.3 in the middle tertile (T2), and 72.9 ± 6.5 in the highest tertile (T3), indicating clear separation between groups.

As shown in Table 1, participants in the highest HEI tertile were modestly older (37.1 ± 11.2 vs 32.6 ± 12.0 years, P = 0.021) and had lower total energy intake (2114 ± 612 vs 2438 ± 701 kcal/day, P = 0.008) compared with those in the lowest tertile. They also reported significantly higher consumption of fruits, vegetables, and whole grains, alongside lower intake of saturated fats and sodium (all P < 0.001). No meaningful differences were observed across tertiles for BMI or sex distribution (P > 0.10), suggesting minimal confounding by these factors at baseline.

As expected, substantial differences were observed in dietary intake patterns across HEI categories. Individuals in the highest HEI tertile exhibited a markedly healthier dietary profile, characterized by significantly higher intakes of fruits (356.55 ± 248.32 vs 198.24 ± 165.19 g/day), vegetables (421.33 ± 190.18 vs 312.65 ± 145.28 g/day), whole grains (75.43 ± 36.42 vs 42.17 ± 19.66 g/day), and legumes (45.63 ± 22.97 vs 24.17 ± 19.36 g/day), alongside lower consumption of refined grains (265.46 ± 118.17 vs 326.55 ± 67.43 g/day) (all P < 0.001). Total energy intake was also lower in the highest tertile (2114.61 ± 612.75 vs 2438.37 ± 701.45 kcal/day, P = 0.008), consistent with improved dietary quality. From a macronutrient perspective, participants with higher HEI scores consumed significantly less total fat and saturated fat (P < 0.001), while carbohydrate and protein intake did not differ significantly across tertiles. Notably, dietary components directly relevant to taste perception demonstrated strong gradients across HEI levels. Sodium intake was substantially lower in the highest tertile (2985.67 ± 980.65 vs 4120.47 ± 1280.23 mg/day, P < 0.001), paralleled by lower consumption of added sugars (48.93 ± 19.65 vs 74.42 ± 28.65 g/day, P < 0.001) and higher intake of dietary fiber (29.84 ± 8.53 vs 18.25 ± 6.17 g/day, P < 0.001). With respect to micronutrients, modest but consistent increases were observed across HEI tertiles for several nutrients implicated in sensory function. In particular, copper and folate intakes were significantly higher among individuals with better diet quality (P = 0.004 and P = 0.02, respectively), while zinc and iron intakes showed borderline upward trends. Intakes of vitamin B12 and vitamin D did not differ significantly across tertiles.

3.2 Association between HEI and sweet taste recognition threshold

In continuous analyses, higher HEI scores were consistently associated with lower recognition thresholds for sweetness (i.e., greater sensitivity). In the fully adjusted model (Model 3), each 10-point increase in HEI was associated with a 0.18-unit decrease in sweet RT (β = -0.018 per 1-point increase; 95% CI: -0.029 to -0.007; P = 0.001), indicating a robust

inverse relationship independent of demographic factors, energy intake, and serum micronutrients.

When HEI was modeled categorically (Table 2), participants in the highest tertile demonstrated significantly greater sensitivity to sweet taste compared with those in the lowest tertile (OR = 2.64; 95% CI: 1.38-5.07; *P* = 0.003). A clear dose-response relationship was observed across tertiles (*P* for trend = 0.002), with progressively higher odds of sweet sensitivity from T1 to T3. Notably, adjustment for serum zinc attenuated but did not eliminate the association, suggesting that shared biological pathways may partly explain the observed relationship.

Table 1. Baseline characteristics, dietary intake, and nutrient profile across tertiles of HEI-2015

Variable	T1 (Low HEI)	T2 (Moderate HEI)	T3 (High HEI)	*P-value*
Participants (n)	67	66	67	-
Age (years)	32.6 ± 12.0	34.7 ± 11.5	37.1 ± 11.2	0.021
Male (%)	49%	52%	53%	0.74
BMI (kg/m²)	26.0 ± 4.8	25.8 ± 4.5	25.4 ± 4.4	0.58
Energy intake (kcal/day)	2438.37 ± 701.45	2297.43 ± 653.39	2114.61 ± 612.75	0.008
Carbohydrates (g/day)	334.17 ± 98.29	326.76 ± 91.37	315.31 ± 87.46	0.18
Protein (g/day)	84.68 ± 36.23	82.65 ± 34.87	79.36 ± 31.46	0.42
Fat (g/day)	89.16 ± 25.94	81.64 ± 23.63	72.46 ± 21.19	< 0.001
Saturated fat (g/day)	28.4 ± 9.6	24.1 ± 8.2	20.3 ± 7.5	< 0.001
Fruits (g/day)	198.24 ± 165.19	274.42 ± 210.65	356.55 ± 248.32	< 0.001
Vegetables (g/day)	312.65 ± 145.28	368.74 ± 178.91	421.33 ± 190.18	< 0.001
Whole grains (g/day)	42.17 ± 19.66	68.25 ± 44.34	75.43 ± 36.42	< 0.001
Refined grains (g/day)	326.55 ± 67.43	287.47 ± 54.75	265.46 ± 118.17	< 0.001
Dairy (g/day)	298.62 ± 75.43	329.42 ± 84.66	345.62 ± 102.44	< 0.001
Meat & processed meat (g/day)	104.76 ± 25.82	87.36 ± 28.44	63.42 ± 18.39	< 0.001
Legumes (g/day)	24.17 ± 19.36	33.75 ± 25.82	45.63 ± 22.97	< 0.001
Sodium (mg/day)	4120.47 ± 1280.23	3610.47 ± 1105.76	2985.67 ± 980.65	< 0.001
Added sugars (g/day)	74.42 ± 28.65	61.17 ± 24.73	48.93 ± 19.65	< 0.001
Dietary fiber (g/day)	18.25 ± 6.17	23.61 ± 7.49	29.84 ± 8.53	< 0.001
Zinc (mg/day)	9.15 ± 3.57	9.82 ± 3.87	10.63 ± 4.17	0.09
Iron (mg/day)	14.85 ± 5.93	15.95 ± 6.27	17.04 ± 5.83	0.12
Copper (mg/day)	1.28 ± 0.41	1.46 ± 0.52	1.71 ± 0.68	0.004
Folate (µg/day)	248.63 ± 82.19	276.63 ± 96.53	312.43 ± 118.59	0.02
Vitamin B12 (µg/day)	3.63 ± 1.47	3.84 ± 1.57	4.12 ± 1.78	0.19
Vitamin D (µg/day)	1.23 ± 0.86	1.56 ± 1.17	1.95 ± 1.64	0.22

* Values are expressed as mean ± standard deviation (SD) for continuous variables and percentages for categorical variables. Differences across HEI tertiles were assessed using one-way analysis of variance (ANOVA) for normally distributed variables and the Kruskal-Wallis test for skewed variables. Categorical variables were compared using the chi-square test. HEI tertiles were defined based on the distribution of the study population. All dietary variables were derived from a validated semi-quantitative FFQ and adjusted for total energy intake where appropriate.

Table 2. Association between HEI and sweet taste recognition threshold

Model	β (95% CI)	*P-value*
Model 1	-0.022 (-0.033, -0.011)	< 0.001
Model 2	-0.019 (-0.030, -0.008)	0.001
Model 3	-0.018 (-0.029, -0.007)	0.001

* Model 2 adjusted for age, sex, BMI. Model 3 additionally adjusted for energy and micronutrients

3.3 Association between HEI and salt taste recognition threshold

A similar pattern was observed for salt taste. In multivariable linear regression, higher HEI scores were associated with significantly lower salt RT values. In the fully adjusted model, each 10-point increase in HEI corresponded to a 0.15-unit decrease in salt RT (β = -0.015 per 1-point increase; 95% CI: -0.026 to -0.004; *P* = 0.007).

In logistic regression analyses (Table 3), individuals in the highest HEI tertile had approximately twofold higher odds of being salt-sensitive compared with those in the lowest tertile (OR = 2.09; 95% CI: 1.12-3.91; *P* = 0.020), with evidence of a linear trend (*P* for trend = 0.018).

Table 3. Odds ratios for high taste sensitivity across HEI tertiles

Outcome	T2 vs T1	T3 vs T1	*P-trend*
Sweet	1.62 (0.90-2.93)	2.64 (1.38-5.07)	0.002
Salt	1.48 (0.82-2.68)	2.09 (1.12-3.91)	0.018

* Values are expressed as odds ratios (ORs) with 95% confidence intervals (CIs) derived from binary logistic regression models. The lowest tertile of HEI (T1) was used as the reference category. Models were adjusted for age (years), sex (male/female), body mass index (kg/m²), total energy intake (kcal/day), and serum micronutrients, including zinc, iron, copper, vitamin B12, folate, and 25-hydroxyvitamin D. Higher taste sensitivity was defined as having a recognition threshold (RT) below the median value of the study population. Tests for linear trend across tertiles were performed by assigning the median value of each tertile and modeling this variable as continuous. All tests were two-sided, and *P-values* < 0.05 were considered statistically significant.

3.4 Non-linear dose-response relationships

Restricted cubic spline analyses demonstrated significant overall associations between HEI score and both sweet and salt taste recognition thresholds (sweet: P-overall < 0.001; salt: P-overall = 0.004). Formal tests for departure from linearity also indicated significant nonlinear associations for both taste modalities (sweet: P-nonlinearity = 0.018; salt: P-nonlinearity = 0.036). As illustrated in Figure 1, the

associations were relatively flat at lower HEI scores but became progressively stronger at higher levels of diet quality, with a steeper decline in recognition thresholds observed above an HEI score of approximately 60. Thus, higher HEI scores, particularly within the upper range of the distribution, were associated with lower sweet and salt recognition thresholds, indicating greater taste sensitivity.

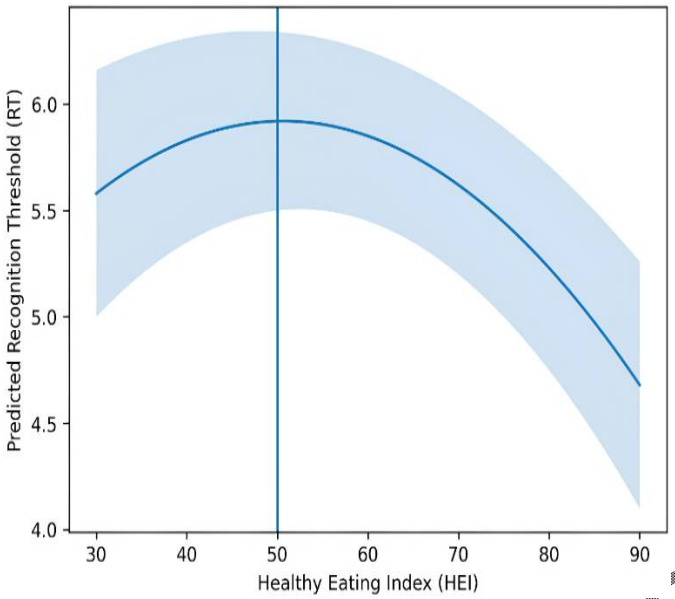

Figure 1. Nonlinear association between HEI-2015 score and taste recognition thresholds estimated using restricted cubic spline regression models. The solid line represents the predicted taste recognition threshold across the range of HEI scores, while the shaded area indicates the 95% confidence interval. The reference value corresponds to the median HEI score. Models were adjusted for age, sex, total energy intake, and serum micronutrients

3.5 Interaction and stratified analyses

A statistically significant interaction was observed between HEI and serum zinc in relation to sweet taste sensitivity (*P* for interaction = 0.028). Stratified analyses (Table 4) indicated that the inverse association between HEI and sweet RT was strongest among participants in the lowest zinc tertile (β = -0.027; 95% CI: -0.041 to -0.013), whereas the association was attenuated in the highest tertile (β = -0.010; 95% CI: -0.022 to 0.002). For salt taste, the interaction between HEI and serum iron approached statistical significance (*P* = 0.061). The association between HEI and salt sensitivity was more pronounced in individuals with higher iron levels, although confidence intervals overlapped.

3.6 Secondary analyses: micronutrients and taste sensitivity

Independent of HEI, higher serum zinc levels were associated with reduced sweet sensitivity (β = +0.014; 95% CI: 0.002-0.026; *P* = 0.021), while higher serum iron was associated with increased salt sensitivity (β = -0.017; 95% CI: -0.030 to -0.004; *P* = 0.014) (Table 5). No consistent associations were observed for copper, vitamin B12, folate, or vitamin D after full adjustment.

Table 4. Interaction between HEI and serum zinc levels in relation to sweet taste recognition threshold

Zinc tertile	β (95% CI)
Low	-0.027 (-0.041, -0.013)
Medium	-0.018 (-0.030, -0.006)
High	-0.010 (-0.022, 0.002)

Values represent β coefficients with 95% confidence intervals (CIs) obtained from multivariable linear regression models stratified by tertiles of serum zinc. Models were adjusted for age, sex, body mass index, total energy intake, and serum micronutrients (iron, copper, vitamin B12, folate, and vitamin D). The *P-value* for interaction was calculated by including a multiplicative interaction term (HEI × serum zinc) in the fully adjusted model. Recognition threshold (RT) was modeled as a continuous outcome. Negative β coefficients indicate greater taste sensitivity (lower RT) with increasing HEI score.

Table 5. Independent associations of serum micronutrients with taste recognition thresholds

Variable	Outcome	β (95% CI)	*P-value*
Zinc	Sweet RT	+0.014 (0.002, 0.026)	0.021
Iron	Salt RT	-0.017 (-0.030, -0.004)	0.014

Values are presented as β coefficients with 95% confidence intervals (CIs) derived from multivariable linear regression models in which each micronutrient was entered simultaneously. Models were adjusted for age, sex, body mass index, total energy intake, and total HEI score. Micronutrients were modeled as continuous variables. Recognition thresholds (RTs) for sweet and salt taste were analyzed as continuous outcomes. Positive β coefficients indicate higher RT (lower sensitivity), whereas negative β coefficients indicate lower RT (higher sensitivity). Statistical significance was defined as $P < 0.05$.

3.7 Model diagnostics and sensitivity analyses

All regression models met the underlying assumptions. Variance inflation factors ranged from 1.3 to 2.6, indicating no evidence of multicollinearity. Residual diagnostics confirmed acceptable homoscedasticity and normality. Logistic models demonstrated adequate calibration (Hosmer-Lemeshow $P > 0.20$) and moderate discrimination, with AUC values of 0.74 for sweet sensitivity and 0.71 for salt sensitivity. Sensitivity analyses, including the exclusion of extreme energy reporters, alternative RT cut-offs, and modeling micronutrients as continuous variables, yielded materially similar results, supporting the robustness of the findings.

The present study provides a comprehensive evaluation of the relationship between overall diet quality, as captured by the HEI, and taste recognition thresholds for sweet and salty stimuli in a cohort of apparently healthy adults. The principal finding is that higher diet quality is consistently associated with greater taste sensitivity, reflected by lower recognition thresholds for both sweetness and saltiness. This relationship persisted after adjustment for a wide range of potential confounders, including demographic characteristics, total energy intake, and circulating micronutrients, suggesting that diet quality exerts an independent and biologically meaningful influence on sensory function.

Importantly, the observed associations were not strictly linear. The spline analyses indicated a threshold-like pattern, whereby meaningful improvements in taste sensitivity were primarily observed at higher levels of HEI. This nuance is particularly relevant because it suggests that modest improvements in diet quality may not be sufficient to induce measurable changes in taste perception; instead, sustained

adherence to a high-quality dietary pattern may be necessary. Such non-linear relationships have been increasingly recognized in nutritional epidemiology, particularly when examining complex phenotypes influenced by cumulative dietary exposures (Hu, 2002; Schulz et al., 2021).

Our findings are broadly consistent with previous studies indicating that habitual dietary patterns shape taste perception. For instance, prior work has shown that individuals consuming diets high in sodium or added sugars tend to exhibit elevated taste thresholds, likely reflecting sensory adaptation to repeated exposure (Bobowski, 2015; Jayasinghe et al., 2017). Conversely, dietary interventions aimed at reducing sodium intake have been shown to enhance salt taste sensitivity over time (Mohammadifard et al., 2023). Similarly, reduced exposure to added sugars has been associated with increased sensitivity to sweetness (Martin & Lim, 2025; Melis et al., 2023). While most earlier studies have focused on single nutrients or short-term interventions, the present study extends this body of evidence by demonstrating that overall diet quality, rather than isolated components, is associated with taste sensitivity in a real-world setting.

From a mechanistic perspective, several mechanisms may explain the observed associations. First, chronic dietary exposure plays a central role in modulating the responsiveness of peripheral taste receptors. Repeated consumption of high-sodium or high-sugar foods can desensitize taste receptors, shifting recognition thresholds upward (Rolls, 2026). In contrast, diets characterized by lower levels of these components, such as those reflected by higher HEI scores, may preserve or restore receptor sensitivity (Melis et al., 2023). Second, micronutrients appear to contribute to taste function through more direct biological mechanisms. Zinc, in particular, is essential for the structural and functional integrity of gustatory cells and has been implicated in taste bud proliferation and signal transduction (Kędziora-Ciechańska & Chałas, 2023; Patil et al., 2023). The interaction observed between HEI and serum zinc in our study lends further support to this pathway, suggesting that dietary quality and micronutrient status may act synergistically rather than independently.

The role of iron in salt taste perception, while less well established, is biologically plausible. Iron is involved in epithelial cell turnover and neural function, both of which are relevant to taste processing (Salvador, 2010). The suggestive interaction between HEI and iron status in relation to salt sensitivity may reflect a similar interplay between systemic nutritional status and sensory function, although this finding should be interpreted cautiously and warrants further investigation. An additional, and often underappreciated, explanation relates to central processing and learned taste preferences. Diet quality may influence not only peripheral receptor sensitivity but also higher-order cognitive and hedonic responses to taste stimuli. Individuals adhering to healthier dietary patterns may develop a preference for less intense taste stimuli, effectively recalibrating their perceptual baseline (Kourouniotis et al., 2016). This behavioral adaptation could, in turn, manifest as lower recognition thresholds in psychophysical testing.

The present study has several notable strengths. First, the use of a comprehensive diet quality index allows for an integrated assessment of dietary patterns, capturing the combined effects of multiple dietary components rather than isolated nutrients. Second, taste sensitivity was assessed using a standardized and validated protocol, enhancing measurement reliability. Third, the analytical approach was rigorous and aligned with current best practices, incorporating multivariable adjustment, assessment of non-linearity, interaction analyses, and extensive sensitivity testing. Together, these elements strengthen the internal validity of the findings and support the robustness of the observed associations.

This study has several limitations that should be considered when interpreting the findings. First, the cross-sectional design precludes any inference regarding causality or the directionality of the observed associations. Second, dietary intake was assessed using a food frequency questionnaire, which, despite prior validation, is subject to measurement error, recall bias, and potential misclassification of dietary exposures. Third, although we adjusted for several potential confounders, residual confounding from unmeasured or imperfectly measured variables cannot be ruled out. Finally, multiple statistical tests were conducted in the present study, which may increase the possibility of chance findings. Therefore, the results should be interpreted with appropriate caution and confirmed in future longitudinal studies and controlled dietary interventions.

From a broader perspective, the findings of this study have potential implications for public health and dietary interventions. Taste perception plays a central role in food choice and dietary adherence. If higher diet quality is indeed associated with enhanced taste sensitivity, this may create a positive feedback loop, whereby healthier diets become more palatable over time. This concept challenges the common perception that healthy foods are inherently less appealing and suggests that sensory adaptation may be an important, yet underutilized, target in nutrition interventions.

4. Conclusion

In conclusion, this study found that higher adherence to a healthy dietary pattern, as measured by the HEI, was associated with greater sensitivity to sweet and salty tastes. These findings suggest a relationship between diet quality and sensory perception. However, because of the cross-sectional design, no causal inferences can be made. Future longitudinal studies and controlled dietary intervention studies are needed to clarify the directionality and underlying mechanisms of these associations.

Authors' Contributions

Arghavan Sabouri: Conceptualization; Writing-original draft preparation; Writing-review and editing. **Mohammad**

Heidari: Conceptualization; Writing-review and editing; Visualization; Supervision. **Saeid Ghavamzadeh:** Writing-review and editing; Supervision. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

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

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Ethical Considerations

The study was approved by the Research Ethics Committee of the Urmia University of Medical Sciences (approval number: IR.UMSU.REC.1402.069). All participants provided written informed consent before enrolment. The study was conducted in accordance with the Declaration of Helsinki and relevant institutional guidelines. No financial inducements were offered, and participation did not disadvantage any participant. Participant anonymity and confidentiality were preserved throughout.

Using Artificial Intelligence

Artificial intelligence is used for grammar checking and language editing to enhance clarity.

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