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ORIGINAL RESEARCH

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Sex divergences in sustainable nutrition and lifestyle phenotypes among Italian adults

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Abstract

Background: Dietary behaviors and lifestyle factors co-occur in integrated profiles that shape cardiometabolic and mental health risk. Sustainable nutrition, particularly plant-forward eating, has become a relevant dimension of dietary quality, yet its adoption varies across population subgroups and may differ by sex. This study examined sex divergences in sustainable nutrition and lifestyle profiles among Italian adults and the potential indirect association of sustainability awareness in the relationship between sex and plant-based diet adherence. **Methods**: A cross-sectional study was conducted with 1066 Italian adults using the validated Nutritional and Social Health Habits inventory for Italian people (NutSo-HH-Ita) to assess sustainable nutrition and lifestyle factors. Data were analyzed using independent-samples *t*-tests and Chi-square tests for sex comparisons, mediation analysis to examine the indirect effect of sustainability awareness on the sex–plant-based diet association, and K-means clustering with multinomial logistic regression to identify lifestyle phenotypes and test sex as a predictor of cluster membership, while adjusting for age, education, and income. **Results**: Women showed higher plant-based diet adherence (Cohen's $d = 0.33$; 95% confidence intervals (CI) [0.20, 0.46]) and higher sustainability awareness (Cohen's $d = 0.14$), while men reported higher physical activity (Cohen's $d = 0.21$). Sustainability awareness was statistically associated with a small indirect component in the association between sex and plant-based diet adherence ($p = 0.045$). Cluster analysis identified distinct lifestyle phenotypes, and sex independently predicted phenotype membership after covariate adjustment ($p < 0.001$), with men more likely to belong to a profile characterized by relatively higher activity combined with poorer sustainability engagement and less healthy lifestyle habits. **Conclusions**: Sex differences in sustainable nutrition are embedded within broader lifestyle phenotypes. Integrating sustainability-related predispositions with behavioral phenotyping may support sex-sensitive prevention strategies and help identify "Active-Low Engagement" male subgroup that could be overlooked when evaluating single behaviors in isolation.

Keywords

Men's health; Sustainable nutrition; Sex differences; Physical activity; Cluster analysis; Plant-based diet

1. Introduction

Dietary patterns and lifestyle behaviors represent key determinants of population health, influencing metabolic risk, cardiovascular outcomes, mental well-being, and overall quality of life [1, 2]. In nutritional epidemiology, it is increasingly important to assess health not through single behaviors in isolation, but through integrated behavioral profiles that include dietary choices, physical activity, sleep patterns, and social habits such as alcohol consumption and smoking [3, 4]. These behaviors frequently co-occur and interact, potentially amplifying or offsetting overall health risk [5]. Therefore, a multidimensional approach is necessary to capture the complexity of contemporary lifestyle patterns [6]. Moreover, integrated lifestyle metrics have been associated not only with cardiometabolic outcomes, but also with mental health indicators [7].

In parallel, sustainability has emerged as a central driver of contemporary food choices [8, 9]. Awareness of environmental impacts—such as preference for local products and reduced reliance on animal-based foods—often aligns with dietary patterns richer in plant foods [10–12]. However, the adoption of sustainable nutrition is not uniform and appears shaped by socio-demographic determinants, including sex roles and identity norms [13].

Sex differences are consistently reported: women typically show higher adherence to healthy, plant-based patterns and

stronger engagement with ethical dietary motivations [14]. Conversely, men globally display higher rates of physical activity but also a greater burden of risk-related social habits, such as alcohol and tobacco use [15–17]. These divergences likely reflect deeper sociocultural dynamics; for instance, a robust "meat–masculinity" association suggests that gendered social norms and identity-linked evaluations can influence motivations to reduce meat consumption or adopt plant-forward diets [18–20].

To theoretically frame these divergences, this study adopts the PRECEDE–PROCEED model, which conceptualizes health behaviors as the result of interacting predisposing, enabling, and reinforcing factors [21, 22]. Within this framework, sustainability awareness acts as a key predisposing factor (beliefs and values) influencing dietary quality, while sex serves as a distal determinant that shapes the internalization of these predisposing and reinforcing influences (*e.g.*, social approval or cultural norms) [21, 23, 24]. Consequently, sex differences in plant-based adherence may be partially explained by variations in sustainability-related beliefs, while broader lifestyle configurations emerge from the combined influence of these dynamics [25, 26]. Within this framework, our analysis specifically operationalizes sustainability awareness as a key predisposing factor. While other dimensions of the model, such as social approval (reinforcing) or environmental barriers (enabling), are not directly measured, they provide the necessary theoretical context to interpret our behavioral findings.

Despite this, important research gaps remain. First, many studies focus on individual outcomes without considering the clustering of behaviors that may produce paradoxical phenotypes, such as individuals who are physically active yet nutritionally disengaged [27, 28]. Second, the mediating role of sustainability awareness in linking sex to dietary patterns is often assumed rather than empirically tested [13, 25]. Third, few investigations move beyond mean comparisons to identify comprehensive lifestyle profiles that could inform targeted, sex-sensitive health promotion [5].

Addressing these gaps has significant public-health relevance. The identification of an "active but low engaged" male subgroup addresses a potential "blind spot" in prevention: men whose physical activity may mask cumulative risks from poor diet and social habits. This is particularly urgent in Europe, where men face a higher probability of premature death from non-communicable diseases (NCDs) than women [29, 30]. By testing whether sex differences in sustainable nutrition are embedded within broader lifestyle phenotypes, this study aims to identify male subgroups who appear low-risk by activity alone, but remain exposed to modifiable dietary risks with long-term health and economic consequences [31–33].

This study aims to examine sex differences in sustainable nutrition and lifestyle behaviors among Italian adults, test the mediating role of sustainability awareness in the association between sex and plant-based diet adherence, and identify lifestyle phenotypes via cluster analysis, assessing sex as an independent predictor of cluster membership after adjustment for key sociodemographic covariates.

2. Materials and methods

2.1 Study design and participants

A cross-sectional observational study was conducted with 1066 Italian adults. Participants were recruited through a non-probabilistic snowball sampling method using online platforms. The inclusion criteria were: (a) being aged 18 years or older, and (b) currently residing in Italy.

Prior to data collection, all participants provided digital informed consent. The study was conducted in strict adherence to the ethical standards of the Declaration of Helsinki and current privacy regulations regarding data confidentiality [34, 35]. Ethical approval was granted by Comitato Etico Locale Palermo 1 (protocol: NUTSO-HHITA 00, approved on 17 February 2025) [35].

2.2 Data collection procedures

The recruitment and data acquisition phase was conducted over a 10-month period, spanning from March to December 2025. Using a non-probability snowball sampling technique, the study utilized a Google Forms survey [35]. The questionnaire was distributed via various digital platforms, leveraging a network of collaborators who shared the access link to broaden the participant pool.

While snowball sampling facilitated access to a large diverse group of participants during the study period, it is important to note that this non-probabilistic method may introduce selection bias. Participants who are more health-conscious or active on social media might be over-represented, which may influence the observed prevalence of lifestyle behaviors.

2.3 Measures

The Italian version of the Nutritional and Social Health Habits Inventory (NutSo-HH-Ita) was used to assess lifestyle and nutritional habits. The NutSo-HH-Ita is a multidimensional instrument validated for the Italian population with satisfactory psychometric properties (Comparative Fit Index (CFI) = 0.94; McDonald's omega ranging from 0.51 to 0.86). The inventory is scored on Likert-type scales (typically 1–5), where higher scores indicate a higher frequency of the behavior or stronger agreement with the statement. It comprises four main domains and specific factors: (1) Nutrition and Food Choices Domain: This domain evaluates dietary quality through three factors (Plant-Based Diet: Assesses the consumption frequency of fruit, vegetables, and legumes; Protein Sources: Measures the intake of animal and plant proteins; Unhealthy Food Consumption: Assesses the frequency of consuming processed foods, sweets, and fast food). (2) Nutritional Risk Behaviors Domain (It focuses on maladaptive eating patterns: Eating Disorders Risk: Evaluates concerns regarding body image, loss of control over eating, and feelings of guilt). (3) Sustainability and Media Influence Domain: Explores the environmental and social drivers of food choices (Sustainability Awareness: Measures the importance attributed to organic, local (0-km), and environmentally sustainable food choices; Social Media Influence: Assesses the extent to which social media trends affect food selection). (4) Lifestyle and Well-being Domain: (Assesses

broader health behaviors: Physical Activity: Measures the frequency and intensity of exercise; Sleep Quality: Evaluates perceived sleep quality and restfulness); Social Habits: Assesses behaviors related to alcohol consumption and smoking.

The composite scores for each factor were calculated by summing the responses of the items belonging to that specific dimension. To facilitate comparison across domains with different numbers of items, scores were also expressed as arithmetic means where appropriate, ensuring that higher values consistently represented a higher frequency or intensity of the measured behavior. To ensure interpretative consistency, specific items (*e.g.*, "Eating Disorders Risk" and "Social Habits") were reverse-coded during data preprocessing. Consequently, across all domains, higher scores indicate more favorable health-related behaviors or higher engagement with health-promoting practices. For the current sample, internal consistency was assessed using McDonald's Omega (ω), showing satisfactory reliability: Plant-Based Diet (ω = 0.78), Sustainability Awareness (ω = 0.82), Social Habits (ω = 0.71), and Physical Activity (ω = 0.84). **Supplementary Table 1** summarizes the scoring structure for the inventory factors.

Sociodemographic data (age, sex, education level, income, city of residence, and Body Mass Index (BMI)) were also collected using an *ad-hoc* questionnaire.

2.4 Statistical analysis

Statistical analyses were performed using Jamovi software (Version 2.3). Data preprocessing involved checking for extreme outliers using interquartile range (IQR) filtering. Descriptive statistics were calculated to characterize the sample: continuous variables were expressed as mean and standard deviation (SD), and categorical variables as frequencies and percentages (%) (https://www.jamovi.org).

The normality of the data distribution was assessed using the Shapiro-Wilk test and visual inspection of Quantile-Quantile (Q-Q) plots [36]. Since the variables did not follow a normal distribution ($p < 0.05$), and considering the ordinal nature of the Likert scales, non-parametric tests were prioritized where appropriate. However, given the large sample size (N > 1000), the Central Limit Theorem allows for the robust use of parametric tests in comparing means [37, 38]. The use of parametric tests for Likert-scale data was justified based on the large sample size (N = 1066) and evidence suggesting that *t*-tests provide robust results for Likert scales with 5 or more categories. To further confirm the robustness of these findings, non-parametric Mann-Whitney U tests were conducted for all primary outcomes, yielding consistent results. For the mediation analysis, assumptions of normality of residuals, homoscedasticity, and absence of multicollinearity (Variance Inflation Factor (VIF) <2.0) were verified. Therefore, differences between men and women were analyzed using Independent Samples *t*-tests (Student's *t*-test) for continuous variables. For categorical variables, the Chi-square test or Fisher's exact test was used.

To investigate the mechanisms underlying dietary choices, a Mediation Analysis was conducted using the General Linear Model (GLM) framework within Jamovi, testing the indirect effect of sex on diet through sustainability awareness [39]. Finally, to identify lifestyle phenotypes, a K-Means Cluster Analysis was performed, followed by a Multinomial Logistic Regression to determine the independent predictive value of sex on cluster membership, controlling for sociodemographic covariates (age, education, and income) [40, 41]. The K-Means Cluster Analysis was performed using the seven core factors of the NutSo-HH-Ita inventory: Plant-Based Diet, Protein Sources, Unhealthy Food Consumption, Eating Disorders Risk, Sustainability Awareness, Physical Activity, and Social Habits. All variables were transformed into standardized *Z*-scores to ensure equal weighting. To ensure the global optimum and avoid local minima, the algorithm was run with 100 random initial starts. The selection of the three-cluster solution was based on a combination of statistical and parsimonious criteria: we compared solutions from 2 to 4 clusters, finding that the 3-cluster model provided the best balance between the Silhouette coefficient (0.42) and the Calinski-Harabasz index. Stability was confirmed via a split-sample validation (randomly dividing the sample into two halves), which yielded a high level of agreement (Kappa >0.85) in cluster membership across both subsets. Statistical significance was set at $p < 0.05$ for all analyses.

To address the potential influence of life stages on behavioral profiles, we further stratified the sample into three age groups: Young Adults (18–30 years), Middle-Aged (31–55 years), and Older Adults (>55 years). A Chi-square test was used to examine the distribution of these age groups across the identified clusters to detect age-specific trends in lifestyle phenotypes.

3. Results

3.1 Sociodemographic characteristics of the sample

A total of 1066 Italian adults participated in the study, 28.2% of which were male (n = 301) and 71.8% female (n = 765). The mean age was 39.6 ± 13.1 years, with no statistically significant difference between men and women ($p = 0.060$). Significant sex disparities were observed in anthropometric measures and lifestyle conditions. Men exhibited a significantly higher BMI compared with women (25.82 ± 3.86 *vs.* 23.41 ± 4.26 kg/m^2; $p < 0.001$), placing the average male participant in the overweight category according to the World Health Organization (WHO) adult BMI classification, which defines overweight as BMI ≥25 kg/m^2. Regarding socioeconomic factors, while education levels were similar between sexes ($p = 0.664$), men reported significantly higher income levels ($p = 0.015$). In terms of living arrangements, men were significantly less likely to be responsible for cooking within the household compared with women (24.6% *vs.* 51.2%; $p < 0.001$). The detailed comparative characteristics are presented in Table 1.

3.2 Sex differences in nutritional habits, sustainability, and lifestyle

Significant divergences were revealed between men and women across three main domains of NutSo-HH-Ita: Nutrition & Food Choices, Sustainability & Media Influence,

and Lifestyle & Well-being (see Table 2).

Women demonstrated significantly higher adherence to plant-based dietary patterns compared with men ($p < 0.001$, $d = 0.33$) and a higher frequency of unhealthy food consumption ($p = 0.008$, $d = 0.19$). Conversely, men reported higher levels of physical activity ($p = 0.002$, $d = 0.20$), though this was counterbalanced by less favorable social habits ($p < 0.001$). These results highlight a behavioral asymmetry where male participants excel in exercise but lag in nutritional and social-habit indicators.

The visual analysis confirms two divergent sex profiles (see Fig. 1). The male profile (blue area) is skewed towards Physical Activity and mental resilience against body image issues (represented by high scores in Low Eating Disorder Risk). In contrast, the female profile (orange area) expands significantly towards Sustainability Awareness and Plant-Based Diet, indicating a stronger commitment to nutritional quality and environmental impact, albeit with a higher susceptibility to Social Media Influence. Social habits differed significantly by sex ($p < 0.001$), with men reporting lower scores than women, indicating less favorable alcohol/tobacco-related behaviors.

3.3 Explaining the gap: the mediation of sustainability

To understand the mechanism underlying the poorer nutritional choices observed in men (described in Section 3.2), a mediation analysis was conducted (Table 3). The model tested whether the relationship between Sex and Plant-Based Diet adherence was mediated by Sustainability Awareness.

The mediation model confirmed that sustainability awareness partially explains the nutritional sex gap (Indirect effect $\beta = 0.013$, $p = 0.045$). Although the direct effect of sex remains strong, the mediation path suggests that approximately 8.7% of the total effect of sex on plant-based diet adherence is channeled through sustainability-related values ($P_m = 0.087$).

TABLE 1. Sociodemographic characteristics of the sample (N = 1066 Italian adults).

Variable	Total (N = 1066)	Men (n = 301)	Women (n = 765)	*p*-value
Age (yr, Mean ± SD)	39.58 ± 13.06	40.79 ± 13.28	39.10 ± 12.95	0.060
BMI (kg/m^2, Mean ± SD)	24.09 ± 4.29	25.82 ± 3.86	23.41 ± 4.26	<0.001
Education (University Degree)	57.7%	56.5%	58.2%	0.664
Income (Medium/High Level)	81.1%	84.3%	79.9%	0.015
Role in Cooking (Active Cook)	43.7%	24.6%	51.2%	<0.001

SD: Standard Deviation; BMI: Body Mass Index. p-values were calculated using independent samples t-tests.

TABLE 2. Comparative analysis of scores for NutSo-HH-Ita factors and domains between men and women.

Factor/Domain	Total Sample (N = 1066) Mean ± SD	Men (n = 301) Mean ± SD	Women (n = 765) Mean ± SD	*p*-value	Effect size (Cohen's *d*) [95% CI]
Plant-Based Diet	6.57 ± 2.01	6.10 ± 1.96	6.76 ± 1.99	<0.001	0.33 [0.20, 0.46]
Protein Sources	7.62 ± 1.89	7.51 ± 1.93	7.66 ± 1.88	0.243	0.08 [−0.05, 0.21]
Unhealthy Food Consumption	27.17 ± 2.30	26.86 ± 2.39	27.29 ± 2.25	0.008	0.19 [0.06, 0.31]
Nutrition & Food Choices (Domain)	14.19 ± 3.12	13.61 ± 3.05	14.42 ± 3.12	<0.001	0.26 [0.13, 0.39]
Social Media Influence	5.09 ± 2.18	4.61 ± 2.05	5.28 ± 2.21	<0.001	0.31 [0.18, 0.44]
Eating Disorders Risk	6.16 ± 2.66	5.66 ± 2.37	6.35 ± 2.75	<0.001	0.26 [0.13, 0.39]
Nutritional Risk Behaviors (Domain)	33.33 ± 3.47	32.52 ± 3.15	33.65 ± 3.54	<0.001	0.33 [0.20, 0.46]
Sustainability Awareness	14.69 ± 4.36	14.27 ± 4.04	14.86 ± 4.48	0.040	0.14 [0.01, 0.27]
Sustainability & Media (Domain)	19.79 ± 4.96	18.88 ± 4.63	20.14 ± 5.05	<0.001	0.26 [0.13, 0.38]
Physical Activity	5.88 ± 2.50	6.25 ± 2.47	5.74 ± 2.50	0.002	0.21 [0.08, 0.33]
Sleep Quality	7.45 ± 2.01	7.62 ± 1.82	7.39 ± 2.07	0.067	0.12 [−0.01, 0.25]
Social Habits	18.88 ± 2.25	18.14 ± 2.51	19.17 ± 2.07	<0.001	0.47 [0.33, 0.60]
Lifestyle & Well-being (Domain)	32.22 ± 3.84	32.02 ± 3.77	32.29 ± 3.86	0.283	0.07 [−0.06, 0.20]

SD: Standard Deviation; CI: Confidence Intervals. p-values were calculated using independent samples t-tests. Scores for "Social Habits" and "Eating Disorders Risk" were inverted during preprocessing. Consequently, in this table, higher scores across all variables represent more favorable health behaviors or lower risk.

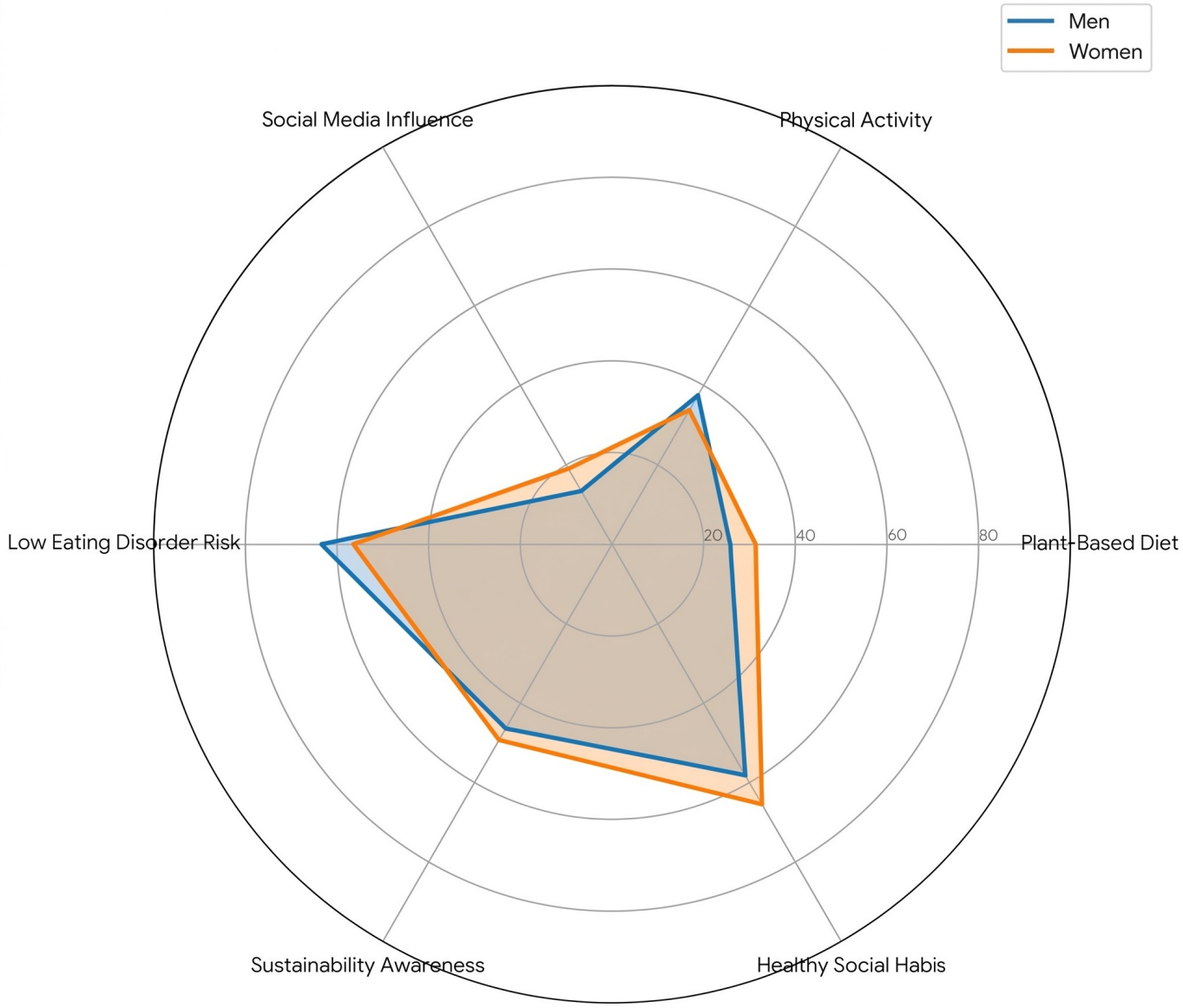

FIGURE 1. Comparative radar chart of normalized scores (0–100) for key lifestyle and nutritional factors between men (blue) and women (orange). All scores are normalized (0–100). Higher scores consistently represent health-promoting behaviors, including lower risk for eating disorders and social habits (tobacco/alcohol).

TABLE 3. Mediation analysis: effects of sex on plant-based diet mediated by sustainability awareness.

Effect Path	Coefficient (β)	SE	*t*-value	*p*-value
Total Effect (c)				
Sex–Plant-Based Diet	0.149	0.031	4.82	<0.001
Direct Effect (c′)				
Sex–Plant-Based Diet	0.136	0.030	4.45	<0.001
Indirect Effect (ab)				
Sex–Sustainability to Plant-Based Diet	0.013	0.006	2.01	0.045
Component Paths				
Path a: Sex–Sustainability	0.060	0.030	1.97	0.049
Path b: Sustainability–Plant-Based Diet	0.208	0.030	6.98	<0.001

Sex was coded as 0 = Men, 1 = Women. Coefficients are standardized (beta). The significant indirect effect indicates that higher sustainability awareness in women partially explains their better dietary habits. SE: Standard Error.

3.4 Lifestyle profiles: characterizing the active-low engagement male

To move beyond single-variable analysis and identify comprehensive lifestyle phenotypes, a K-Means Cluster Analysis was performed. This identified three distinct profiles within the Italian sample (see Table 4 and Fig. 2):

Cluster 1: "The Eco-Active Healthy" (n = 365, 34%). This is the optimal health profile, characterized by the highest scores in Physical Activity, Plant-Based Diet, and Sustainability Awareness.

Cluster 2: "Active-Low Engagement" (n = 271, 25%). This profile represents a specific "active but unhealthy" phenotype. Individuals in this group maintain moderate physical activity levels but exhibit the poorest nutritional habits (lowest Plant-Based Diet scores) and the lowest Sustainability Awareness, combined with the highest intensity of toxic Social Habits (alcohol/tobacco).

Cluster 3: "The Sedentary Traditional" (n = 427, 41%). Defined primarily by the lowest levels of Physical Activity and moderate nutritional scores.

A multinomial logistic regression model (adjusted for age, educational level, and income) confirmed that sex is a significant and independent predictor of lifestyle phenotype membership ($p < 0.001$). Using the "Eco-Active" profile (Cluster 1) as the reference category, men were significantly more likely to belong to the "Active-Low Engagement" profile (Cluster 2) (Odds Ratio (OR) = 2.44; 95% CI [1.71, 3.49]; $p < 0.001$). This indicates that men have 2.4 times higher odds than women of presenting a pattern characterized by physical activity but low nutritional and sustainability engagement. Additionally, younger age (OR = 0.97 per year; $p < 0.001$) and lower educational attainment (OR = 0.46 for higher education; $p < 0.001$) were also associated with significantly higher odds of belonging to this risk-prone profile (see Table 5).

4. Discussion

In this cross-sectional study, we examined sex-related variation in sustainable nutrition and lifestyle behaviors in a large sample (n = 1066) of Italian adults, adopting a multidimensional analytic strategy that integrated sex-stratified between-group comparisons, mediation modeling, and data-driven cluster-based phenotyping. This approach moved beyond single-behavior frameworks by deriving multidimensional behavioral profiles from the joint distribution of dietary, sustainability, and lifestyle variables, and by testing sex as a predictor of profile membership. The sample was predominantly female (71.8%), a distribution that should be interpreted not only as a limitation in terms of sex balance, but also as a feature of online, volunteer-based recruitment strategies that may preferentially attract women in health-related survey research [42–44]. Within this sample, women reported higher adherence to plant-based dietary patterns and greater sustainability awareness, whereas men reported higher physical activity alongside less favorable social-habit indicators, particularly those related to alcohol and tobacco use. Taken together, these results support a profile-based interpretation in which dietary quality, sustainability orientation, and lifestyle behaviors co-occur and should be analyzed as interdependent dimensions of broader behavioral patterns rather than as isolated risk factors.

A key contribution of this study is the identification of an apparent behavioral asymmetry in men: higher physical activity coexisting with lower plant-based adherence and less healthy social habits. The lower adherence to plant-based diets observed in men may be partially explained by theoretical frameworks suggesting that meat consumption is often perceived as a core component of masculine identity [45]. However, since our study utilized a binary sex variable and did not directly measure identity-linked mechanisms, this remains a plausible interpretation rather than a direct empirical finding. This configuration is also consistent with evidence that lifestyle risk factors tend to cluster rather than operate independently, and that favorable levels of one behavior may coexist with concurrent exposure to other risks [5, 6]. This pattern also aligns with reports that men show higher engagement in risk-related social behaviors, such as alcohol use and tobacco smoking, which contribute substantially to non-communicable disease burden [16, 17]. The present findings are also consistent with the higher unhealthy food consumption observed in men, suggesting a broader imbalance in dietary quality rather than a single dietary difference. This is in line with literature showing that diet quality and other lifestyle behaviors often co-aggregate into mixed-risk profiles [5, 28]. From a behavioral perspective, the observed co-occurrence of protective and risk-related behaviors is compatible with frameworks describing compensatory health beliefs, although these cognitions were not directly assessed in the present study and

TABLE 4. Characterization of lifestyle clusters.

Variable (Mean *Z*-Scores/Interpretation)	Cluster 1 "Eco-Active"	Cluster 2 "Active-Low Engagement"	Cluster 3 "Sedentary"	*p*-value
Plant-Based Diet	High	Low	Moderate/Low	<0.001
Physical Activity	High	Moderate	Low	<0.001
Sustainability	High	Low	Moderate	<0.001
Social Habits (Alcohol/Smoking)	Moderate	High Consumption	Low Consumption	<0.001
Dominant Trait	Holistic Health	Active but Risk-Prone	Sedentary	-

The cluster analysis was performed on standardized Z-scores (mean = 0, SD = 1) to ensure equal weighting of all behavioral dimensions.

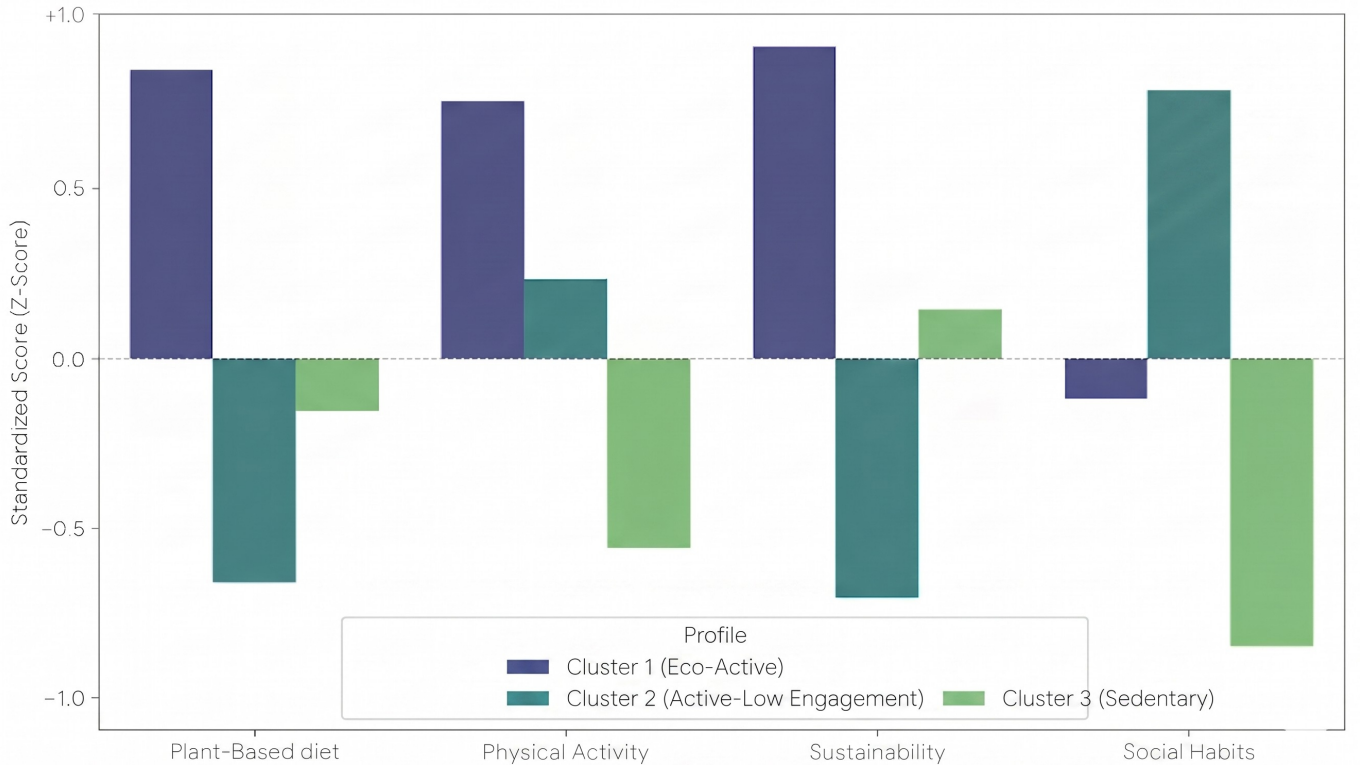

FIGURE 2. Lifestyle phenotypes identified by cluster analysis. Bars represent standardized mean *Z*-scores for key NutSo-HH-Ita variables across the three clusters. Blue = Cluster 1, Eco-Active/Holistic Health; teal = Cluster 2, Active-Low Engagement/Active but Risk-Prone; green = Cluster 3, Sedentary. Positive *Z*-scores indicate values above the sample mean and, after reverse coding, more health-promoting behaviours or lower risk; negative *Z*-scores indicate lower engagement or higher risk.

TABLE 5. Predictors of lifestyle cluster membership (multinomial logistic regression).

Target Cluster (Ref: Eco-Active)	Predictor Variable	Odds Ratio (OR)	95% CI [Lower, Upper]	*p*-value
Active-Low Engagement				
	Sex (Male *vs.* Female)	2.44	[1.71, 3.49]	<0.001
	Age (yr)	0.97	[0.96, 0.98]	<0.001
	Education (Higher *vs.* Low/Mid)	0.46	[0.33, 0.64]	<0.001
	Income (Mid/High *vs.* Low)	1.02	[0.83, 1.26]	0.847
Sedentary-Traditional				
	Sex (Male *vs.* Female)	1.56	[1.13, 2.15]	0.007
	Age (yr)	1.02	[1.01, 1.03]	<0.001
	Education (Higher *vs.* Low/Mid)	0.60	[0.45, 0.80]	0.001
	Income (Mid/High *vs.* Low)	0.82	[0.68, 0.99]	0.043

OR: Odds Ratio; CI: Confidence Intervals; Ref: Reference.

should be tested in future research [46]. Although the cross-sectional design prevents causal inference, the coexistence of higher activity and nutritional disengagement reinforces the need for prevention strategies that move beyond exercise promotion alone and address the multidimensional structure of lifestyle risk [4, 6].

The mediation analysis further provides an exploratory indication of potential mechanisms underlying dietary differences. In line with the PRECEDE–PROCEED framework [21, 22], sustainability awareness is here conceptualized and tested as a predisposing factor. However, the mediation was partial, suggesting that unmeasured determinants—potentially acting as enabling (*e.g.*, culinary skills) or reinforcing factors (*e.g.*, social norms)—likely contribute to the observed gap. The significant indirect effect observed in this study indicates that part of the sex difference in plant-based diet adherence is explained by differential engagement with sustainability-related values, consistent with evidence that sociocultural and psychosocial factors influence the uptake of healthy and sustainable diets [9, 25]. These sex-based divergences in sustainability awareness partially account for the different dietary choices observed. It is possible that these results reflect broader socialization

processes or potential masculinity norms that might distance some men from sustainable behaviors [18, 19, 26, 45], though further research incorporating gender-specific scales is needed to confirm this pathway. However, the mediation was partial, suggesting that additional determinants, such as identity linked motivations, skills and roles related to food preparation, taste preferences, and reinforcing social contexts, may contribute to the observed gap [21, 25].

Importantly, the cluster analysis revealed that lifestyle behaviors aggregate into distinct phenotypes. The significance of this phenotype becomes clearer when placed within the current burden of chronic disease prevention. In the WHO European Region, NCDs continue to generate substantial avoidable mortality and economic losses, and premature NCD mortality remains disproportionately concentrated in men [47]. At the same time, Organisation for Economic Co-operation and Development (OECD) analyses consistently show that poor diet, excess body weight, alcohol, tobacco, and insufficiently integrated prevention contribute heavily to healthcare expenditure and productivity losses across European systems [48]. Against this background, the "active but low engaged male subgroup" pattern should be interpreted as a strategically important prevention phenotype, and it may escape attention in settings where physical activity is implicitly used as a proxy for overall healthfulness, despite the coexistence of nutrition-related and substance-related risks. Our findings therefore add to the literature by suggesting that sex sensitive prevention should not focus only on men's lower engagement with plant-forward eating in isolation, but on the broader mismatch between visible health-oriented behaviors and co-occurring hidden vulnerabilities. This is the critical gap filled by the present study: showing that sustainable nutrition, physical activity, and social habits can combine into a male specific risk configuration with plausible implications for early cardiometabolic prevention and resource allocation [19, 45, 49].

After adjustment for age, education, and income, sex independently predicted cluster membership. Men were less likely to belong to a sedentary profile but were overrepresented in a phenotype characterized by moderate physical activity combined with low sustainability engagement, poorer plant-based adherence, and unfavorable social habits. This is consistent with prior latent class and clustering evidence indicating that physical activity, diet, sleep, smoking, and alcohol use frequently shape identifiable behavioral profiles with differential cardiometabolic relevance [5, 27]. The "active but low engaged male subgroup" configuration is particularly relevant for public health practice because individuals within this group may appear low risk when evaluated solely on activity metrics, despite co-occurring dietary and substance-related risks that are strongly linked to cardiometabolic outcomes [4, 17]. These findings reinforce the value of multidimensional screening approaches capable of capturing interacting lifestyle domains rather than relying on single-behavior indicators [4].

An additional interpretation of our findings is offered by a developmental, life-course perspective. The "active low engaged male subgroup" phenotype should not be seen as a fixed condition, but as a dynamic risk configuration that may change across adulthood. In younger men, the coexistence of relatively favorable physical activity with poorer diet quality, lower adherence to plant-based eating, weaker sustainability-oriented attitudes, and less healthy social habits may reflect an early stage in which protective and harmful behaviors overlap without yet resulting in overt disease. In this phase, physical activity may act as a visible marker of health while masking other relevant exposures such as alcohol use, smoking, and suboptimal diet quality [19, 50–53].

From a life-course perspective, this phenotype may therefore represent an early window of vulnerability rather than a simple behavioral paradox. Its relevance lies in the fact that apparently protective behaviors, such as being physically active, may coexist with risk factors that accumulate over time. This may be especially important in men, since sex differences in cardiovascular risk appear early and persist through midlife, with premature cardiovascular disease occurring earlier in men than in women [54].

Midlife is likely the stage at which this phenotype becomes most clinically relevant. Evidence suggests that behaviors such as physical activity, diet quality, and smoking in midlife are strongly associated with successful aging, frailty, disability, and chronic disease in later life. Thus, men who remain physically active but maintain unhealthy dietary and social habits may enter midlife with a substantial burden of cumulative cardiometabolic risk [55].

In older age, the meaning of this profile may shift again. Male vulnerability may progressively move from a pattern in which risk is partly masked by activity to one characterized by sedentary behavior and possible functional decline. However, this makes the nutritional dimension even more important, since physical activity alone may not be sufficient to prevent deterioration if it is not supported by adequate nutrition. Recent evidence also shows that combined exercise and nutrition strategies are more effective than isolated interventions, and that health behaviors in older adults continue to cluster into multidimensional profiles [55].

Overall, this developmental interpretation suggests that prevention in men should not focus on physical activity alone, but should adopt age-sensitive and multidimensional strategies: addressing masculinity norms and risk-taking in younger men, identifying hidden cardiometabolic vulnerability in midlife, and integrating physical activity, nutrition, and functional preservation in older age [5].

From a prevention perspective, the observed sex-related differences in sustainability awareness, plant-based adherence, and cluster membership suggest that intervention strategies may need to account for heterogeneity in motivational and sociocultural determinants of dietary change. Prior evidence indicates that determinants of sustainable diet intentions vary by gender and across cultural contexts, supporting the rationale for tailoring communication and intervention components accordingly [13, 25]. In particular, given the lower sustainability orientation and the overrepresentation of men in the phenotype combining moderate physical activity with less favorable dietary and social-habit indicators, future intervention studies should test whether alternative framings (*e.g.*, emphasizing functional and health-related outcomes of plant-forward eating) improve acceptability and engagement in male subgroups where plant-based eating may be perceived as less congruent with masculine norms [18, 19]. Importantly,

these implications remain hypothesis-generating and should be evaluated using longitudinal and experimental designs to determine which mechanisms (*e.g.*, values, norms, roles in food preparation) most effectively shift profile-level risk.

The study is strengthened by the large sample size, the use of a validated multidimensional instrument capturing co-occurring dietary, sustainability-related, and lifestyle behaviors, and an integrative analytic strategy combining sex-stratified comparisons with mediation modeling and standardized cluster-based phenotyping, complemented by covariate-adjusted multinomial regression to test sex as an independent predictor of profile membership.

Several limitations must be acknowledged. First, the cross-sectional design of this study allows for the identification of associations and phenotypes but strictly precludes any causal or temporal inferences. Second, the use of non-probability snowball sampling via online recruitment represents a significant constraint on generalizability. This method typically attracts individuals within similar social or digital networks, potentially leading to a sample with higher-than-average education or health interest. Our sample was predominantly female and highly educated; therefore, the male participants included may not be representative of the broader Italian male population. Consequently, the "active but low engaged" phenotype identified here should be interpreted as an exploratory characterization of this specific cohort rather than a stable, established subtype at the population level. It is also important to emphasize that while we use the PRECEDE–PROCEED model as an organizing structure, our data-driven approach only directly tests predisposing beliefs. Discussions regarding identity-linked motivations or social reinforcement remain theoretical interpretations intended to guide future research. Finally, it should be noted that this study utilized a binary sex variable (male/female). While the results show significant sex divergences, we did not directly measure gender-related constructs such as masculinity/femininity norms or gender identity. Therefore, the discussion of gendered social mechanisms remains an interpretative framework and not a direct empirical finding of this study.

Our findings suggest potential practical implications at multiple levels of prevention, provided these patterns are replicated in longitudinal and more representative cohorts. First, in men, physical activity may not always serve as a sufficient proxy for an overall healthy lifestyle, since an active appearance may coexist with poor diet quality and unfavorable alcohol- or tobacco-related habits. As a result, screening strategies based only on exercise or body weight could risk underestimating risk in male subgroups whose behavioral profile is only partially protective. A potentially more appropriate approach to investigate would involve multidimensional assessment including physical activity, diet quality, sustainability-oriented food choices, and substance-related social habits.

Second, dietary prevention strategies for men should be explored as not only sex-sensitive, but also phenotype-sensitive. Evidence suggests that plant-based or sustainable eating may be perceived by some men as less compatible with traditional masculine norms, reducing acceptability and engagement [19, 45]. Therefore, interventions targeting "active but low engaged male subgroup" might see increased effectiveness if plant-forward eating is framed in terms of outcomes that are more salient to this subgroup, such as cardiovascular performance, metabolic fitness, recovery, strength maintenance, and long-term functional capacity, rather than only through general healthy-eating advice or sustainability messaging [49].

Third, this phenotype merits further consideration in public health planning because it lies at the intersection of two major prevention priorities: reducing chronic disease burden and improving early risk detection. While further research is needed to establish cost-effectiveness, identifying men who appear protected because they are physically active, but who also accumulate nutritional and social-habit-related risks, could eventually improve prevention targeting and cost-effectiveness. Thus, the "active but low engaged male subgroup" profile represents a potentially actionable subgroup for future tailored interventions in primary care, workplace health promotion, and community-based men's health programs [19, 45, 49].

Future health-promotion programmes could test phenotype-sensitive strategies for the Active-Low Engagement male subgroup, combining physical-activity messaging with tailored dietary counselling, reduction of alcohol- and tobacco-related risks, and plant-forward dietary framing centred on cardiovascular performance, metabolic health, recovery, and long-term functional capacity. Such interventions should be evaluated prospectively before being translated into routine public-health practice.

5. Conclusions

Sex differences in sustainable nutrition are embedded within broader lifestyle profiles. Sustainability awareness showed a small indirect association with the sex difference in plant-based eating, suggesting it is a relevant correlate that may partially account for the observed differences within this cohort. Cluster analysis identified distinct potential phenotypes, including an "active but low engaged male subgroup" characterized by moderate physical activity combined with lower sustainability engagement and poorer dietary and social behaviors. These findings suggest the potential value of multidimensional, sex-sensitive prevention strategies that address dietary quality and risk-related habits alongside physical activity. However, it is essential that longitudinal and more representative studies be conducted to confirm causal pathways and generalizability. In particular, the identification of an "active but low engaged male subgroup" phenotype suggests a possible prevention blind spot: men who are sufficiently active may still carry a relevant cumulative risk burden when diet quality, sustainability-related food choices, and alcohol/tobacco-related habits are considered jointly. Recognizing this subgroup may support more precise and potentially more cost-effective sex-sensitive prevention strategies in the context of the persistent European burden of non-communicable diseases, provided these associations are validated in broader populations.

AVAILABILITY OF DATA AND MATERIALS

The data presented in this study are available upon reasonable request to the corresponding author.

AUTHOR CONTRIBUTIONS

MP and ES—conceptualization; methodology; supervision. ES—software; formal analysis; visualization; project administration. VM, ALC, AB, MP and ES—validation. ALC—resources. SS and ES—data curation. VM and ES—writing–original draft preparation. All authors have read and agreed to the published version of the manuscript. All authors contributed to the investigation. All authors participated in writing, reviewing and editing the manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The research strictly followed ethical principles outlined in the Declaration of Helsinki and Ethical approval was granted by Comitato Etico Locale Palermo 1 (protocol: NUTSO-HHITA 00, approved 17 February 2025). Prior to participating, explicit informed consent was obtained from all individuals, ensuring they were fully informed about the study's objectives, procedures, and potential risks, and emphasizing the voluntary nature of their participation.

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CONFLICT OF INTEREST

None of the authors had any financial, personal or professional conflict of interest in relation to the results of this study.

SUPPLEMENTARY MATERIAL

Supplementary material associated with this article can be found, in the online version, at https://oss.jomh.org/files/article/20718235030765404 16/attachment/Supplementary%20material.docx.

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