DIETARY PATTERNS AND NONALCOHOLIC FATTY LIVER DISEASE: A FACILITY-BASED CASE–CONTROL STUDY IN BANGLADESH

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ABSTRACT

Background: Although diet plays a key role in nonalcoholic fatty liver disease (NAFLD) development, evidence regarding dietary patterns and NAFLD among Bangladeshi adults remains limited. This study examined the association between major dietary patterns and NAFLD in Bangladesh. **Methods:** A facility-based case-control study was conducted among 400 adults (200 NAFLD cases and 200 controls) recruited from tertiary healthcare facilities in Dhaka, Bangladesh. NAFLD was confirmed using ultrasonography. Dietary intake over the previous month was assessed using a validated semi-quantitative food frequency questionnaire containing 169 food items. Principal component analysis was applied to derive dietary patterns from 24 nutrients and 26 food groups. Multivariable binary logistic regression models were used to estimate adjusted odds ratios (AORs) for the association between dietary pattern quartiles and NAFLD after adjusting for potential confounders. **Results:** This study found significant differences between cases and controls in terms of physical activity, diabetes prevalence, and body mass index. Furthermore, four food group patterns (energy-dense mixed pattern, fruit and dairy pattern, traditional–processed mixed pattern, and healthy plant-based pattern) and four nutrient patterns (Plant-based micronutrient-rich pattern, animal protein-rich pattern, unsaturated fat-rich pattern, and B-vitamin dominant pattern) were identified, explaining around 67% and 32% of total variance, respectively. The healthy plant-based pattern was inversely associated with NAFLD, with participants in the second quartile having lower odds than those in the lowest quartile (AOR: 0.48; 95% CI: 0.24–0.95). Similarly, unsaturated fat-rich pattern and vitamin E with lower carbohydrate intake were associated with reduced odds of NAFLD in the third quartile (AOR: 0.40; 95% CI: 0.20–0.80). Moreover, the B-vitamin-dominant pattern showed an inverse association in the highest quartile (COR: 0.41; 95% CI: 0.23–0.72), although this association was not significant after adjustment. **Conclusion:** This study indicates that healthier dietary patterns, rich in whole grains, vegetables, fish, good fats, and antioxidant nutrients, are inversely associated with NAFLD in Bangladeshi adults. Evidence-based dietary guidelines should be integrated into the national NCD operational manual to support the prevention of NAFLD in Bangladesh.

KEYWORDS: Nonalcoholic fatty liver disease, Dietary patterns, Principal component analysis, Bangladesh

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Introduction

Nonalcoholic fatty liver disease (NAFLD) is characterized by excessive fat accumulation in more than 5% of hepatocytes in the absence of significant alcohol consumption (Chen *et al.*, 2022). A subset of affected individuals develop nonalcoholic steatohepatitis (NASH), which may progress to cirrhosis, hepatocellular carcinoma, and end-stage liver disease (Alam *et al.*, 2021). NAFLD has emerged as one of the leading causes of chronic liver disease worldwide, affecting approximately 30% of the global adult population and 7.4% of children and adolescents (Paik *et al.*, 2023). In Bangladesh, the prevalence has been estimated at 33.8%, indicating a substantial and growing public health burden (Alam *et al.*, 2018). The increasing prevalence of NAFLD has been closely linked to the global rise in obesity, type 2 diabetes, and other metabolic disorders. Although historically considered a disease of industrialized nations, NAFLD has increased rapidly across many Asian countries, including Bangladesh, owing to rapid urbanization, economic development, and associated lifestyle transitions (Li *et al.*, 2019). Lifestyle modification remains the primary strategy for prevention and management, as sustained weight loss can improve hepatic steatosis, reduce liver enzyme levels, and lower the risk of metabolic complications, including type 2 diabetes (Jensen *et al.*, 2014).

Diet is a key modifiable determinant of NAFLD development and progression. Excessive consumption of saturated fats, refined carbohydrates, and added sugars, particularly fructose, promotes hepatic fat accumulation through increased de novo lipogenesis and inflammatory pathways (Asrih and Jornayvaz, 2014; Carolina M. Perdomo, 2019). However, contemporary nutritional epidemiology increasingly recognizes that overall dietary patterns may better capture the combined effects of foods and nutrients on health outcomes than individual dietary components (Schulz, Oluwagbemigun and Nöthlings, 2021). Accordingly, dietary pattern analysis has become an important approach for investigating chronic diseases, including NAFLD. Evidence from different populations consistently indicates that dietary patterns characterized by high intakes of red and processed meats, refined grains, fried foods, and sugar-sweetened beverages are associated with an increased risk of NAFLD (Salehi-sahlabadi *et al.*, 2021). In contrast, Mediterranean and prudent dietary patterns, which emphasize fruits, vegetables, whole grains, legumes, fish, and unsaturated fats, appear to exert protective effects (Rahideh and Shidfar, 2020). Similar findings have been reported in Asian populations, where dietary patterns rich in coarse grains, tubers, vegetables, and legumes have been associated with lower NAFLD prevalence (Liu *et al.*, 2018). Nevertheless, most available evidence originates from high-income countries or selected East Asian settings, limiting its generalizability to South Asian populations, whose dietary habits, sociocultural contexts, and metabolic risk profiles differ substantially.

Bangladesh is undergoing a rapid nutrition transition characterized by shifts from traditional dietary practices toward increasingly westernized food consumption patterns and more sedentary lifestyles. These changes may contribute to the rising burden of NAFLD, yet evidence on the role of dietary patterns in this context remains limited. Previous studies in Bangladesh have primarily focused on the prevalence of NAFLD and its association with metabolic risk factors such as obesity, diabetes, and metabolic syndrome (Das *et al.*, 2010; Alam *et al.*, 2018). Although a pilot study in Dhaka explored nutrient intake and dietary behaviors among patients with NAFLD, its small sample size and methodological limitations precluded definitive conclusions regarding dietary associations (Hossain *et al.*, 2017). Consequently, the relationship between overall dietary patterns and NAFLD among Bangladeshi adults remains insufficiently understood. Generating context-specific evidence is essential for identifying modifiable lifestyle factors and informing culturally appropriate prevention strategies. Therefore, this study aimed to identify major dietary patterns among Bangladeshi adults and examine their association with NAFLD.

Methodology

Study design and settings

A facility-based case–control study was conducted in Dhaka, Bangladesh, from June 10 to September 17, 2025. Participants were recruited from the Department of Hepatology at Bangladesh Medical University and from two branches of Ibn Sina Diagnostic and Consultation Center located in Dhanmondi and Keranigonj (Figure 1). These facilities were purposively selected due to the availability of confirmed NAFLD cases and standardized diagnostic services.

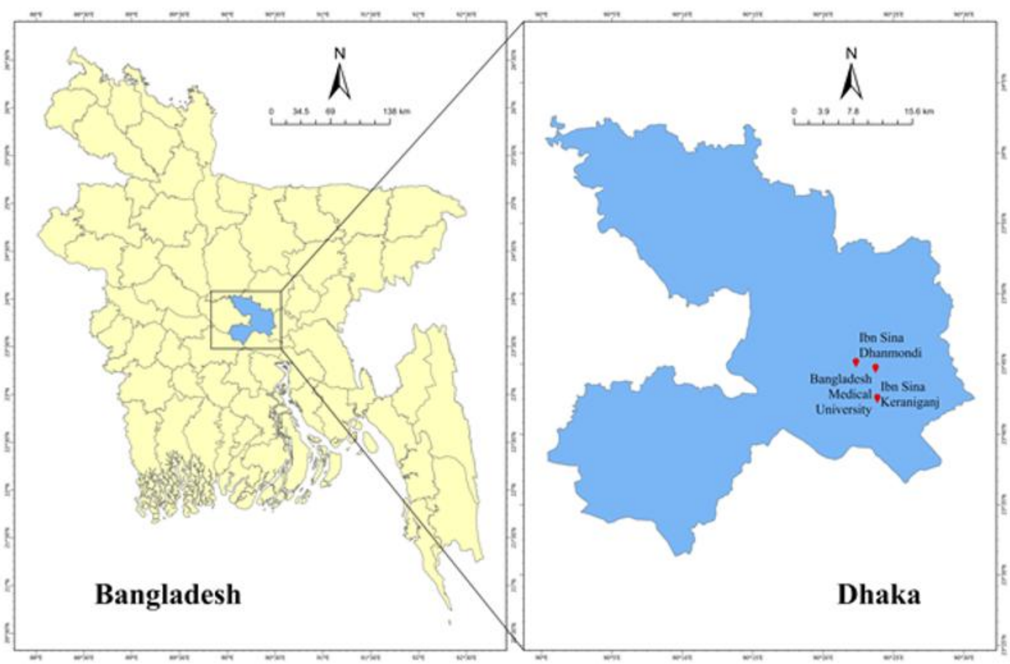

Figure 1. Map of the study area

Study participants

Case definition

Cases were adults aged ≥ 18 years with a confirmed diagnosis of NAFLD. Diagnosis was established through ultrasonographic examination performed by an experienced radiologist who was blinded to laboratory findings and clinical information. Diagnosis was based on standard ultrasonographic criteria indicating hepatic steatosis in the absence of secondary causes. Participants were eligible as cases if they met the diagnostic criteria and provided informed consent. Exclusion criteria included known chronic liver disease, positive hepatitis B surface antigen, positive hepatitis C virus antibody, and significant alcohol consumption defined as ≥ 30 g/day for men and ≥ 20 g/day for women.

Control definition

Controls were apparently healthy adults without evidence of NAFLD or other liver diseases. Eligibility required normal liver enzyme levels and a normal hepatobiliary profile confirmed by ultrasonography. Controls were recruited from individuals attending routine health checkups or accompanying patients at the same facilities, ensuring they originated from a similar catchment population. Exclusion criteria for controls included known liver disease, use of medications associated with steatohepatitis, alcohol consumption exceeding 20 g/day, chronic gastrointestinal disorders, pregnancy or lactation, and unwillingness to participate.

Sample size and sampling

The sample size was calculated using the standard formula for unmatched case–control studies, assuming a 95% confidence level, 80% statistical power, and an estimated exposure prevalence of 33.86% among controls based on previous literature on non-alcoholic fatty liver disease (NAFLD) (Alam *et al.*, 2018). Accordingly, the prevalence of exposure among controls (P_2) was set at 0.3386. Assuming an odds ratio (OR) of 2.0, the proportion of exposure among cases (P_1) was estimated at 0.506 using the following formula: $P_1 = \frac{OR \times P_2}{1+P_2(OR-1)}$. The required sample size was then calculated using: $n = \frac{(Z_{\alpha/2}+Z_\beta)^2[P_1(1-P_1)+P_2(1-P_2)]}{(P_1-P_2)^2}$. Based on these assumptions, the minimum required sample size was approximately 133 participants in each group. However, the final sample size was increased to 200 cases and 200 controls to enhance statistical power. Participants were recruited purposively from the outpatient departments of selected health facilities. Controls were selected from individuals attending routine health checkups or accompanying patients, provided they fulfilled all eligibility criteria.

Data collection procedures

Data were collected by trained research assistants under the supervision of the principal investigator using a pre-tested, semi-structured questionnaire. Face-to-face interviews were conducted to obtain detailed sociodemographic information, including age, sex, education, income, marital status, occupation, religion, and residential status. Information on dietary intake, physical activity, anthropometric characteristics, and clinical history was collected following standardized protocols. Each participant was assigned a unique identification number to ensure confidentiality. All questionnaires, measurements, and laboratory reports were linked using this identifier to maintain data integrity.

Assessment of physical activity

Physical activity was assessed using the Global Physical Activity Questionnaire (GPAQ) version 2 developed by the World Health Organization. The questionnaire captures the frequency and duration of moderate- and vigorous-intensity activities across occupational, transport, and recreational domains, as well as sedentary behavior. Reported duration and frequency of activities were converted into metabolic equivalent task (MET) minutes per week. Total physical activity was calculated as the sum of MET minutes per week across all domains. Participants were categorized into low, moderate, and high physical activity levels according to WHO classification criteria (WHO, 2021).

Anthropometric measurements

Anthropometric measurements were obtained following standardized procedures. Body weight was measured to the nearest 0.1 kg using a calibrated digital scale, with participants wearing light clothing and no shoes. Height was measured to the nearest 0.1 cm using a portable stadiometer. Body mass index (BMI) was calculated as weight (kg) divided by height (m^2).

Dietary assessment

Dietary intake was assessed using a validated semi-quantitative food frequency questionnaire comprising 169 commonly consumed food items in Bangladesh, capturing habitual intake over the preceding month. Participants reported consumption frequency using predefined categories, which were converted into daily intake equivalents. Portion sizes were estimated using standard household measures, and daily intake (g/day) was calculated accordingly. Nutrient intakes were estimated using the Bangladesh Food Composition Table and relevant supplementary databases following standardized procedures described in previous studies (Salehi-sahlabadi *et al.*, 2022; Shaheen *et al.*, 2022). Principal component analysis (PCA) was applied to 24 selected nutrients and 26 Diet Quality Questionnaire (DQQ) food groups to derive dietary patterns (Global Diet Quality Project, 2021). Nutrient intakes were energy-adjusted and expressed per 1000 kcal prior to analysis. Factor extraction was based on the correlation matrix with orthogonal varimax rotation to improve interpretability (Waid *et al.*, 2018). Sampling adequacy was acceptable (KMO = 0.747 for nutrients; 0.654 for food groups), and Bartlett's test of sphericity was significant ($p < 0.001$), indicating that the variables were deemed suitable for factor analysis (Naja *et al.*, 2011). Factors were retained based on eigenvalues >1.5, scree plot inspection, and interpretability (Zhang *et al.*, 2006), resulting in four dominant nutrient patterns and four food group patterns. Individual food groups or nutrients with a factor loading ≥ 0.3 were considered to significantly contribute to the pattern in this study (Denova-Gutiérrez *et al.*, 2016). Factor scores for each participant were calculated using the regression method by summing standardized nutrient intakes weighted by their respective factor loadings (Naja *et al.*, 2011). These scores were categorized into quartiles and used in subsequent regression analyses.

Statistical analysis

Data were analyzed using the Statistical Package for the Social Sciences (SPSS) version 26. Descriptive statistics were used to summarize participant characteristics. Categorical variables were presented as frequencies and percentages, while continuous variables were expressed as means ± standard deviations for normally distributed data or medians with interquartile ranges for skewed distributions. Differences between cases and controls were assessed using chi-square tests for categorical variables and independent samples t-tests or Mann–Whitney U tests for continuous variables, as appropriate. Dietary pattern scores were categorized into quartiles, and multivariable binary logistic regression analyses were performed to estimate odds ratios (ORs) and 95% confidence intervals (CIs) for their association with NAFLD. Three models were constructed for each dietary pattern: Model 1 estimated crude associations; Model 2 was adjusted for age, sex, and BMI; and Model 3 was further adjusted for potential confounders, including physical activity level, area of residence, income, education, family history of NAFLD, marital status, diabetes, and smoking status. Multicollinearity was assessed using variance inflation factors. Model fit was evaluated using the Hosmer–Lemeshow goodness-of-fit test. Statistical significance was set at a two-sided $p < 0.05$ (Barton and Peat, 2014).

Ethical considerations

Ethical approval was obtained from the Institutional Review Board of the Faculty of Biological Sciences, University of Dhaka (Ref. No. 300/Biol.Scs.). Written informed consent was obtained from all participants prior to enrollment. Participation was voluntary, and confidentiality of information was strictly maintained throughout the study.

Results

Background characteristics of the respondents

Table 1 summarizes the sociodemographic and clinical characteristics of the study participants. A higher proportion of cases were ever married compared to controls (92.0% vs 82.5%). Educational attainment differed modestly between groups ($p = 0.047$), with a greater proportion of controls being illiterate, whereas cases more frequently had higher education. Furthermore, the proportion of diabetics was significantly higher among cases (32.0%) compared to controls (12.0%). Similarly, physical activity levels also differed significantly ($p = 0.012$), with cases more likely to report low physical activity. In contrast, smoking was less common among cases than controls (10.0% vs 17.5%). Cases were older than controls (mean age: 39.0 vs 35.0 years). They also had higher mean body weight (70.1 vs 60.0 kg) and body mass index (27.4 vs 24.2 kg/m²).

Table 1. Background characteristics of the study participants (N=400)

Variables	NAFLD (n=200) n (%)	Control (n=200) n (%)	*p*value
Sex			
Male	111 (55.5)	109 (54.5)	0.400
Female	89 (44.5)	91 (45.5)	
Marital status			
Unmarried	16 (8.0)	35 (17.5)	0.004
Ever married	184 (92.0)	165 (82.5)	
Education of the respondents			
Illiterate	22 (11.0)	41 (20.5)	0.047
Primary	71 (35.5)	66 (33.0)	
Secondary	44 (22.0)	38 (19.0)	
Higher secondary	27 (13.5)	32 (16.0)	
Graduate or above	36 (18.0)	23 (11.5)	
Monthly income, BDT			
BDT 10,001-20,000	25 (12.5)	39 (19.5)	0.164
BDT 20,001-30,000	52 (26.0)	55 (27.5)	
BDT 30,001-40,000	50 (25.0)	53 (26.5)	
BDT 40,001-50,000	24 (12.0)	16 (8.0)	

More than BDT 50,000	49 (24.5)	37 (18.5)	
Area of residence			
Urban	134 (67.0)	107 (53.5)	0.006
Rural	66 (33.0)	93 (46.5)	
Diabetes status			
Yes	64 (32.0)	24 (12.0)	< 0.001
No	136 (68.0)	176 (88.0)	
Family history of NAFLD			
Yes	32 (16.0)	37 (18.5)	0.508
No	168 (84.0)	163 (81.5)	
Physical activity			
Low	106 (53.0)	80 (40.0)	0.012
Moderate	51 (25.5)	77 (38.5)	
High	43 (21.5)	43 (21.5)	
Smoking status			
Smoker	20 (10.0)	35 (17.5)	0.029
Non-smoker	180 (90.0)	165 (82.5)	
Age*	39.0 (32.0-48.0)	35.0 (28.0-45.0)	0.003
Weight*	70.1 (62.6-77.8)	60.0 (54.9-66.7)	< 0.001
Height*	159.0 (154.0-165.0)	157.8 (152.5-165.0)	0.646
Body mass index (BMI)*	27.4 (25.3-30.7)	24.2 (21.7-26.6)	< 0.001

Note: NAFLD = Nonalcoholic fatty liver disease; *p*-value from Chi-square test; * Median (IQR) was reported; *p*-value from Mann-Whitney U test

Nutrient intake by the respondents

Median daily nutrient intakes for cases and controls are presented in Table 2. Overall, nutrient intake profiles were largely comparable between the two groups. Total energy intake did not differ significantly between cases and controls (2290.2 vs 2186.8 kcal/day, p = 0.058), although a marginally higher intake was observed among cases. Most macronutrient intakes, including protein, carbohydrates, and different types of fatty acids, did not differ significantly between cases and controls. Among the micronutrients, a significant difference was noted only for sodium intake, which was higher among cases than controls (273.1 vs 246.9 mg/1000 kcal, p = 0.003). In contrast, intakes of calcium, iron, potassium, zinc, and vitamins were comparable between the two groups, with no statistically significant variation observed.

Table 2. Nutrient intakes among cases and controls

Variables	NAFLD (n=200)	Control (n=200)	*p*value
Energy intake (Kcal/d)	2290.2 (1826.4-2873.7)	2186.8 (1775.2-2652.8)	0.058
Protein (g/1,000Kcal)	27.8 (25-30.9)	28.5 (25.6-32.7)	0.205

Saturated fatty acid (g/1,000Kcal)	6.4 (4.9-8.3)	6.8 (5-8.8)	0.512
Monounsaturated fatty acid (g/1,000Kcal)	5.9 (4.9-7.1)	6.2 (5.1-7.3)	0.091
Poly unsaturated fatty acid (g/1,000Kcal)	11.4 (9.0-14.1)	11.7 (9.4-15.5)	0.107
Cholesterol (mg/1,000Kcal)	73.4 (44.6-115.4)	76.1 (41.0-120.9)	0.753
Carbohydrate (g/1,000Kcal)	159.6 (148.2-169.1)	157.3 (145.2-165.3)	0.166
Total dietary fiber (g/1,000Kcal)	11.0 (10.0-12.5)	10.9 (9.6-12.6)	0.309
Calcium (mg/1,000Kcal)	225.1 (168.5-315.4)	231.2 (165.2-319.1)	0.874
Iron (mg/1,000Kcal)	4.7 (3.7-5.7)	4.3 (3.8-5.2)	0.085
Magnesium (mg/1,000Kcal)	143.5 (128.4-173)	144.9 (132.3-164.9)	0.975
Phosphorus (mg/1,000Kcal)	416.5 (380.8-470.2)	426.8 (375.6-490.5)	0.407
Potassium (mg/1,000Kcal)	860.8 (732.4-1027)	872.1 (761.9-1010.4)	0.546
Sodium (mg/1,000Kcal)	273.1 (196.5-380.8)	246.9 (181.7-314.4)	0.003
Zinc (mg/1,000Kcal)	4.2 (3.8-4.6)	4.3 (3.9-4.7)	0.266
Copper (mg/1,000Kcal)	0.8 (0.7-0.9)	0.8 (0.7-0.9)	0.325
Vitamin A (mcg/1,000Kcal)	215 (148.4-347.8)	217.9 (132.4-318.3)	0.314
Vitamin D (mcg/1,000Kcal)	5.3 (3.4-7.6)	5.3 (3.8-7.8)	0.801
Vitamin E (mcg/1,000Kcal)	3.5 (2.8-4.3)	3.6 (3.2-4.2)	0.194
Thiamin (mg/1,000Kcal)	0.5 (0.5-0.6)	0.5 (0.5-0.6)	0.102
Riboflavin (mg/1,000Kcal)	0.4 (0.3-0.5)	0.4 (0.3-0.5)	0.783
Niacin (mg/1,000Kcal)	7.8 (7.0-8.5)	8.1 (7.0-8.8)	0.087
Vitamin B6 (mg/1,000Kcal)	0.6 (0.5-0.7)	0.6 (0.5-0.7)	0.356
Folate (mcg/1,000Kcal)	187.8 (129.4-290.1)	198.6 (131.3-315.7)	0.409
Vitamin C (mg/1,000Kcal)	49.2 (35.0-77.4)	47.7 (34.2-73.5)	0.610

Note: IQR= Inter quartile range; Median (IQR) was reported; *p*-value from Mann-Whitney U test

Dietary pattern of the respondents

Principal component analysis (PCA) identified four major food group patterns, explaining 31.92% of the total variance (Table 4). Pattern 1 (Energy-Dense Mixed Pattern) was characterized by high consumption of grains, roots and tubers, red meat, fish, nuts, fried foods, and sweetened beverages, suggesting a mixed, energy-dense dietary pattern. Pattern 2 (Fruit and Dairy Pattern) included fruits, dairy products, and eggs, reflecting a relatively diverse and nutrient-rich dietary pattern. On the other hand, dark green leafy vegetables, instant noodles, sweets, and poultry dominated Pattern 3 (Traditional–Processed Mixed Pattern), suggesting a mixed pattern combining both health-promoting and ultra-processed food items. In contrast, Pattern 4 (Healthy Plant-Based Pattern) was characterized by higher intake of vegetables and whole grains, along with inverse loadings for soft drinks and fast food, thus representing a comparatively healthier dietary pattern.

Table 4. Factor loading matrix and explained variances for major food group patterns

Food groups	**Food group patterns**			
	Pattern 1	Pattern 2	Pattern 3	Pattern 4
	Energy-dense mixed pattern	Fruit and dairy pattern	Traditional–processed mixed pattern	Healthy plant-based pattern
Foods made from grains	0.512	-	-	- 0.367
Whole grains	-	-	-	0.411
White roots, tubers, and plantains	0.552	-	-	-
Pulses	-	-	-	-
Vitamin A-rich orange vegetables	0.349	-	-	0.459
Dark green leafy vegetables	-	-	0.657	-
Other vegetables	-	-	-	0.616
Vitamin A-rich fruits	-	0.406	-	-
Citrus	-	0.46	-	-
Other fruits	-	0.673	-	-
Baked / grain-based sweets	-	-	-	-
Other sweets	-	-	0.579	- 0.322
Eggs	-	0.390	-	-
Cheese	-	-	-	-
Yogurt	-	0.560	-	-
Unprocessed red meat	0.550	0.335	-	-
Poultry	0.302	-	0.369	-
Fish and seafood	0.473	0.343	-	0.352
Nuts and seeds	0.466	-	-	-
Instant noodles	-	-	0.638	-
Deep fried foods	0.521	-	-	-
Fluid milk	-	-	-	-
Sweet tea / coffee / cocoa	0.566	-	-	-
Fruit juice and fruit-flavored drinks	-	0.320	-	-
Soft drinks	-	-	-	- 0.413
Fast food	0.402	-	-	- 0.334
Explained variance (%)	**12.06**	**7.41**	**6.60**	**5.85**

Note: Extraction Method: Principal Component Analysis; Rotation Method: Varimax with Kaiser Normalization; Factor loadings ≥0.3 were considered to significantly contribute to the pattern in this study.

Four major nutrient patterns were identified, which collectively explained 66.99% of the total variance in nutrient intake (Table 3). Specifically, high loadings of dietary fiber, iron, magnesium, potassium, and several vitamins characterized pattern 1 (Plant-based micronutrient-rich pattern), thereby indicating a nutrient-dense, predominantly plant-based dietary pattern. In contrast, pattern 2 (Animal protein-rich pattern) was mainly driven by protein, phosphorus, zinc, and cholesterol, suggesting a protein-rich pattern with likely contribution from animal-source foods. Furthermore, pattern 3 (Unsaturated fat-rich pattern) exhibited strong positive loadings for unsaturated fatty acids and vitamin E, accompanied by a negative loading for carbohydrates, thus representing a fat-dominant dietary pattern with comparatively lower carbohydrate intake. Finally, pattern 4 (B-vitamin dominant pattern) was characterized by lower sodium and calcium levels, while showing higher loadings for thiamin and niacin with minimal contribution from copper, thereby reflecting a distinct micronutrient-specific dietary pattern.

Table 3. Factor loading matrix and explained variances for major nutrients patterns

Nutrients	**Nutrient patterns**			
	Pattern 1	Pattern 2	Pattern 3	Pattern 4
	Plant-based micronutrient-rich pattern	Animal protein-rich pattern	Unsaturated fat-rich pattern	B-vitamin dominant pattern
Protein	-	0.881	-	-
Saturated fatty acid	-	-	0.646	-
Mono unsaturated fatty acid	-	-	0.869	-
Poly unsaturated fatty acid	-	-	0.795	-
Cholesterol	-	0.700	0.319	-
Carbohydrate	-	-0.495	-0.746	-
Total dietary fiber	0.848	-	-	-
Calcium	0.467	0.624	-	- 0.303
Iron	0.823	-	-	-
Magnesium	0.890	-	-	-
Phosphorus	-	0.923	-	-
Potassium	0.730	0.513	-	-
Sodium	-	-	-	- 0.678
Zinc	0.426	0.803	-	-
Copper	0.333	0.462	-	0.367
Vitamin A	0.799	-	-	-
Vitamin D	0.703	-	-	-
Vitamin E	-	-	0.747	-
Thiamin	0.311	0.533	-	0.491
Riboflavin	0.519	0.571	-	

Niacin	-	-	- 0.519	0.593
Vitamin B6	-	-	-	-
Folate	-	0.461	-	-
Vitamin C	0.769	-	0.343	-
Explained variance (%)	**35.39**	**13.55**	**11.52**	**6.54**

Note: Extraction Method: Principal Component Analysis; Rotation Method: Varimax with Kaiser Normalization; Factor loadings ≥0.3 were considered to significantly contribute to the pattern in this study.

Association between dietary pattern and NAFLD

The associations between food group patterns and NAFLD are presented in Table 5. No significant associations were observed for Patterns 1, 2, or 3 across all models. However, Pattern 4 (Healthy Plant-Based Pattern) demonstrated a protective association. Participants in the second quartile had significantly lower odds of NAFLD compared to the lowest quartile in the fully adjusted model (AOR: 0.48; 95% CI: 0.24–0.95). A similar trend was observed for the third quartile, although the association was borderline significant (p-value = 0.05) (AOR: 0.51; 95% CI: 0.26–1.00). No significant association was observed for the highest quartile.

Table 5. Odds ratio and 95% confidence intervals for the association between food group patterns and NAFLD

	Model 1		**Model 2**		**Model 3**	
Variables	**COR (95%CI)**	***p*-value**	**AOR (95%CI)**	***p*-value**	**AOR (95%CI)**	***p*-value**
Energy-dense mixed pattern						
Q1 (lowest)	1	-	1	-	1	-
Q2	1.00 (0.57-1.74)	1.000	0.90 (0.49-1.67)	0.743	0.92 (0.48-1.78)	0.805
Q3	0.79 (0.45-1.37)	0.396	0.62 (0.33-1.16)	0.138	0.59 (0.30-1.16)	0.127
Q4 (highest)	1.27 (0.73-2.22)	0.396	1.06 (0.57-1.98)	0.863	1.09 (0.55-2.17)	0.809
Fruit and dairy pattern						
Q1 (lowest)	1	-	1	-	1	-
Q2	0.89 (0.51-1.54)	0.671	0.87 (0.47-1.61)	0.658	0.95 (0.49-1.83)	0.870
Q3	0.64 (0.37-1.12)	0.120	0.67 (0.36-1.26)	0.212	0.64 (0.32-1.26)	0.193
Q4 (highest)	1.28 (0.73-2.23)	0.394	1.22 (0.65-2.29)	0.542	1.34 (0.66-2.71)	0.416
Traditional–processed mixed pattern						
Q1 (lowest)	1	-	1	-	1	-
Q2	0.82 (0.47-1.43)	0.479	0.74 (0.40-1.37)	0.334	0.80 (0.41-1.56)	0.515

Q3	0.73 (0.42-1.27)	0.258	0.63 (0.34-1.18)	0.148	0.66 (0.34-1.28)	0.218
Q4 (highest)	0.89 (0.51-1.55)	0.671	0.93 (0.51-1.71)	0.815	0.79 (0.41-1.54)	0.489
Healthy plant-based pattern						
Q1 (lowest)	1	-	1	-	1	-
Q2	0.55 (0.31-0.96)	0.035	0.54 (0.29-1.01)	0.054	0.48 (0.24-0.95)	0.035
Q3	0.55 (0.31-0.96)	0.035	0.52 (0.28-0.97)	0.038	0.51 (0.26-1.00)	0.050
Q4 (highest)	0.92 (0.53-1.61)	0.775	0.74 (0.40-1.39)	0.354	0.64 (0.32-1.27)	0.203

Note: Model 1 unadjusted model; Model 2 adjusted for age, sex, and BMI; Model 3 adjusted for age, sex, BMI, physical activity level, area of residence, income, education, family history of NAFLD, marital status, diabetes, and smoking.

Associations between nutrient patterns and NAFLD are presented in Table 6. A significant inverse association was observed for Pattern 3 (Unsaturated Fat-Rich Pattern), where participants in the third quartile had a lower odd of NAFLD compared to the lowest quartile in the fully adjusted model (AOR: 0.40; 95% CI: 0.20–0.80). No significant associations were observed for the highest quartile. For Pattern 4 (B-Vitamin Dominant Pattern), inverse associations observed in crude analysis with the highest quartile (COR: 0.41; 95% CI: 0.23–0.72) were attenuated after adjustment and became non-significant. Patterns 1 and 2 were not significantly associated with NAFLD across any model.

Table 6. Odds ratio and 95% confidence intervals for the association between nutrient patterns and NAFLD

	Model 1		**Model 2**		**Model 3**	
Variables	**COR (95%CI)**	***p*-value**	**AOR (95%CI)**	***p*-value**	**AOR (95%CI)**	***p*-value**
Plant-based micronutrient-rich pattern						
Q1 (lowest)	1	-	1	-	1	-
Q2	1.00 (0.57-1.74)	1.000	0.76 (0.41-1.40)	0.380	0.76 (0.39-1.48)	0.423
Q3	0.75 (0.43-1.32)	0.321	0.58 (0.31-1.08)	0.083	0.51 (0.26-1.00)	0.051
Q4 (highest)	1.56 (0.89-2.73)	0.119	1.40 (0.75-2.61)	0.285	1.25 (0.64-2.47)	0.516
Animal protein-rich pattern						
Q1 (lowest)	1	-	1	-	1	-
Q2	1.08 (0.62-1.89)	0.777	0.92 (0.49-1.71)	0.783	0.74 (0.38-1.45)	0.383
Q3	1.17 (0.67-2.05)	0.571	1.07 (0.57-2.00)	0.830	1.03 (0.52-2.02)	0.934
Q4 (highest)	0.67 (0.38-1.17)	0.157	0.59 (0.32-1.12)	0.105	0.61 (0.31-1.23)	0.169

Unsaturated fat-rich pattern						
Q1 (lowest)	1	-	1	-	1	-
Q2	1.00 (0.57-1.75)	1.000	1.09 (0.59-2.01)	0.790	1.12 (0.57-2.20)	0.743
Q3	0.55 (0.31-0.96)	0.034	0.53 (0.29-0.99)	0.046	0.40 (0.20-0.80)	0.009
Q4 (highest)	0.82 (0.47-1.43)	0.479	0.76 (0.41-1.41)	0.381	0.63 (0.32-1.24)	0.178
B-vitamin dominant pattern						
Q1 (lowest)	1	-	1	-	1	-
Q2	0.56 (0.32-0.99)	0.047	0.77 (0.41-1.43)	0.401	0.73 (0.37-1.42)	0.351
Q3	0.52 (0.30-0.92)	0.024	0.61 (0.33-1.13)	0.116	0.64 (0.33-1.25)	0.189
Q4 (highest)	0.41 (0.23-0.72)	0.002	0.55 (0.30-1.04)	0.064	0.57 (0.29-1.13)	0.106

Note: Model 1 unadjusted model; Model 2 adjusted for age, sex, and BMI; Model 3 adjusted for age, sex, BMI, physical activity level, area of residence, income, education, family history of NAFLD, marital status, diabetes, and smoking.

Discussion

This case–control study identified four major food group patterns and four major nutrient patterns among NAFLD patients. After adjusting for potential confounders, food group pattern 4 (characterized by high intakes of whole grains, vitamin A–rich orange vegetables, other vegetables, fish, and seafood) and nutrient pattern 3 (characterized by high intakes of saturated fatty acids, monounsaturated fatty acids, polyunsaturated fatty acids, cholesterol, vitamin E, and vitamin C) demonstrated a protective association with NAFLD. This study found no significant associations between the other identified dietary patterns and NAFLD.

To our knowledge, several studies conducted outside our country have examined the association between dietary patterns and NAFLD have consistently reported significant relationships between the two. For example, a study from Iran found that adherence to an “ordinary and traditional” dietary pattern was positively associated with NAFLD risk (Dehghanseresht *et al.*, 2020). Similarly, research from China reported that an “animal food” dietary pattern was associated with a higher prevalence ratio of NAFLD (Yang *et al.*, 2015). In Korea, adherence to a prudent dietary pattern was associated with a lower risk of NAFLD, whereas a flour-based food and meat-rich pattern was linked to an increased risk of the disease (Fu and Shin, 2023). Additionally, a systematic review and meta-analysis has shown that adherence to a Mediterranean dietary pattern, characterized by high intakes of fruits, vegetables, whole grains, fish, and olive oil, is associated with a reduced risk of NAFLD (Hassani Zadeh, Mansoori and Hosseinzadeh, 2021). Furthermore, an Iranian study identified four major nutrient patterns among patients with NAFLD, of which only the fourth pattern, characterized by higher intakes of fructose, vitamin A, pyridoxine, vitamin C, and potassium, was significantly associated with lower odds of the disease (Salehi-sahlabadi *et al.*, 2022).

In our study, adherence to food group pattern 4 was associated with a reduced risk of NAFLD. This pattern was defined by high intakes of whole grains, vitamin A–rich orange vegetables, other vegetables, fish, and seafood. Whole grains are rich in dietary fiber, which has been shown to improve insulin sensitivity, regulate postprandial glycemic response, and reduce hepatic lipogenesis, thereby lowering the risk of hepatic steatosis (Zelber-Sagi, Salomone and Mlynarsky, 2017). Similarly, vegetables, particularly vitamin A–rich orange vegetables, provide carotenoids, vitamin C, and other antioxidant phytochemicals that may attenuate oxidative stress and hepatic inflammation, which are central mechanisms in NAFLD progression (Romero-Gómez, Zelber-Sagi and Trenell, 2017). Fish and seafood are important sources of omega-3 polyunsaturated fatty acids, which have been reported to suppress hepatic triglyceride synthesis, enhance fatty acid oxidation, and improve liver fat metabolism (European Association for the Study of the Liver (EASL), European Association for the Study of Diabetes (EASD) and European Association for the Study of Obesity (EASO), 2016). Overall, these findings indicate that adherence to a diet rich in whole grains, vegetables, and fish may be protective against NAFLD through favorable effects on insulin sensitivity, hepatic lipid metabolism, and inflammatory and oxidative pathways, supporting the role of healthy dietary patterns in NAFLD prevention.

Among the four major nutrient patterns identified in our study, only pattern 3 was found to be inversely associated with NAFLD. This pattern was characterized by a high intake of both saturated and unsaturated fatty acids, vitamin E, and vitamin C. The observed association is consistent with previous research.

For example, a study among Iranian adults reported that higher adherence to a nutrient pattern characterized by fructose, vitamin A, pyridoxine, vitamin C, and potassium was associated with lower odds of NAFLD (Salehi-sahlabadi *et al.*, 2022). Similarly, a study among Japanese adults found that a nutrient pattern rich in vitamin A precursors, vitamin C, potassium, vitamin B2, vitamin E, folate, iron, and fiber may help prevent NAFLD (Tien *et al.*, 2022). Additionally, another study demonstrated that nutrient patterns rich in fiber, potassium, and vitamins, as well as patterns containing saturated fatty acids, calcium, and vitamin B2, were associated with reduced metabolic risk (Iwasaki *et al.*, 2019).

The inverse association between nutrient pattern 3 and NAFLD may be attributed to its combined antioxidant and metabolic effects. Vitamin C and vitamin E are well-established antioxidants that reduce oxidative stress and lipid peroxidation in the liver, thereby attenuating hepatocellular injury and inflammation, which are key mechanisms in NAFLD progression (Raza *et al.*, 2021). In addition, unsaturated fatty acids may improve hepatic lipid metabolism and insulin sensitivity, contributing to reduced fat accumulation in the liver (Baratta *et al.*, 2017; Della Corte *et al.*, 2017). Moreover, vitamin C can act synergistically with vitamin E by regenerating its active form, further enhancing antioxidant protection against hepatic oxidative damage (Dungubat *et al.*, 2025). Collectively, these mechanisms suggest that the overall nutrient synergy within this pattern may confer protection against NAFLD development.

Nutrient patterns 1, 2, and 4 did not show a statistically significant association with NAFLD in the present study. Although higher adherence to nutrient patterns 2 and 4 was associated with reduced odds of NAFLD, these associations did not reach statistical significance. Pattern 2, characterized mainly by higher intakes of protein, phosphorus, zinc, folate, potassium, and cholesterol, reflects a protein-rich dietary pattern likely driven by animal-source foods. The non-significant inverse association observed may be explained by the opposing biological effects of its components. For instance, higher protein and dietary cholesterol intake have been linked to increased risk of NAFLD (Tang and Mann, 2019; Mazidi, Ofori-Asenso and Kengne, 2020), whereas nutrients such as folate, potassium, and phosphorus have been reported to exert protective effects against hepatic fat accumulation and metabolic dysfunction (Tien *et al.*, 2022). Therefore, the combined presence of both potentially harmful and beneficial nutrients within the same pattern may have attenuated any overall significant association with NAFLD.

Policy implications

The findings suggest that NAFLD prevention in Bangladesh should focus on promoting overall healthy dietary patterns rather than individual nutrients. Policies should emphasize increased intake of fruits, vegetables, and antioxidant-rich foods, along with healthier fat sources, while reducing consumption of energy-dense and cholesterol-rich foods. National Nutrition Policy 2015 promotes healthy dietary practices and emphasize the prevention of nutrition-related chronic diseases (MoHFW, 2015). Bangladesh Multisectoral Action Plan for Prevention and Control of Non-Communicable Diseases 2018–2025 also mentioned unhealthy diet as a major modifiable risk factor for NCDs (DGHS, 2018). However, future action plans should provide more comprehensive guidance on dietary strategies for the prevention and management of NAFLD. Furthermore, evidence-based recommendations derived from the identified dietary patterns should be integrated into national dietary guidelines and nutrition promotion programs to support population-level NAFLD prevention. Strengthening dietary interventions within these existing policy frameworks could contribute to reducing the growing burden of NAFLD and related metabolic disorders. NAFLD prevention should be integrated into ongoing NCD control initiatives under the Directorate General of Health Services (DGHS), particularly through strengthened nutrition counseling and lifestyle modification services at the primary healthcare level. Community-based awareness campaigns, school-based nutrition education programs, and workplace wellness interventions should be expanded to encourage healthy eating behaviors and increase public awareness of NAFLD as a preventable lifestyle-related disease. Given the multisectoral nature of dietary risk factors, collaboration among the health, education, agriculture, and food sectors is essential to create supportive food environments and promote healthier dietary choices across the population.

Strengths and limitations

Our study has several strengths. To the best of our knowledge, this is the first case-control study in Bangladesh to examine both food group and nutrient patterns in relation to NAFLD risk. Data were collected from three separate centers, which helped ensure the inclusion of participants from diverse demographic backgrounds, thereby improving the generalizability of the findings. However, several limitations should also be acknowledged. As with all case-control studies, there is an inherent risk of selection and recall bias. In addition, dietary patterns were derived using factor analysis, and the results may be influenced by subjective methodological decisions, including the number of factors retained and the interpretation of factor loadings. Although a validated semi-quantitative food frequency questionnaire was used, measurement error arising from self-reported dietary intake and recall inaccuracies is inevitable. Underreporting of alcohol consumption due to cultural and religious norms in Bangladesh may also have resulted in some misclassification of alcoholic and non-alcoholic fatty liver disease; however, the extent of such misclassification is likely to be limited in this study population. Finally, despite adjustment for a range of potential confounders, residual confounding from unmeasured or imperfectly measured factors cannot be entirely ruled out.

Conclusion

This study provides evidence on the association between dietary patterns and the risk of NAFLD among adults in Dhaka, Bangladesh. Higher adherence to a food group pattern characterized by greater consumption of whole grains, vitamin A–rich vegetables, other vegetables, fish, and seafood, as well as to a nutrient pattern enriched with fatty acids, vitamin C, and vitamin E, was inversely associated with the odds of NAFLD. In contrast, other identified nutrient and food group patterns did not show statistically significant associations, which may be explained by the coexistence of both protective and adverse dietary components within the same patterns. Overall, the findings suggest a potential protective role of healthier dietary patterns against NAFLD in this population. Public health strategies should prioritize integrating dietary quality improvement into existing national nutrition and NCD prevention programs. NAFLD prevention efforts should be strengthened through enhanced nutrition counseling and lifestyle modification services at the primary healthcare level, community based and targeted awareness program. However, given the multifactorial nature of dietary risk factors, a multisectoral approach is essential to effectively reduce the burden of NAFLD.

Author contributions

All authors made a significant contribution to this work, including involvement in the study's conception and design, data collection, analysis, and interpretation. Each contributed to drafting and revising the manuscript, reviewed it critically for important intellectual content, and approved the final version for publication.

Conflicts of interest

The authors declare no conflicts of interest.

Data availability statement

Data and materials are available upon reasonable request to the corresponding author.

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