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Associations between inflammation–related dietary patterns and obesity: A cohort study among Tibetan adults

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Abbreviations

DPs: dietary patterns
T1: lowest tertiles
T3: highest tertiles
OR: odds ratio
CI: confidence Intervals
NCDs: non-communicable diseases
RRR: reduced rank regression
FFQ: food frequency questionnaire
BMI: body mass index
hs-CRP: high-sensitivity C-reactive protein
PNI: prognostic nutritional index
SSB: sugar-sweetened beverages

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Conflict of interest

None declared.

Abstract

Substantial changes resulting from the interaction of environmental and dietary factors contribute to an increased risk of obesity, while their specific associations with obesity remain unclear. Identify inflammation-related dietary patterns (DPs) and explore their associations with obesity among urbanized Tibetan adults under significant environmental and dietary changes.Totally, 1826 subjects from the suburbs of Golmud City were enrolled in an open cohort study, of which 514 were followed up. Height, weight, and waist circumference were used to define overweight and obesity. DPs were derived using reduced rank regression with 41 food groups as predictors and hs-CRP and prognostic nutritional index as inflammatory response variables. Altitude was classified as high or ultra-high. Two DPs were extracted. DP-1 was characterized by having high consumptions of sugar-sweetened beverages, savory snacks, and poultry, and a low intake of tsamba. DP-2 had high intakes of poultry, pork, animal offal, and fruits, and a low intake of butter tea. Participants in the highest tertiles (T3) of DPs had increased risks of overweight and obesity (DP-1: OR=1.37, 95% CI: 1.07, 1.77; DP-2: OR=1.48, 95% CI: 1.18, 1.85) than those in the lowest tertiles (T1). Participants in T3 of DP-2 had an increased risk of central obesity (OR=2.25, 95% CI: 1.49, 3.39) than those in T1. The positive association of DP-1 with overweight and obesity was only significant at high altitudes, while no similar effect was observed for DP-2. Inflammation-related DPs were associated with increased risks of overweight and/or obesity.

Keywords: inflammatory-related dietary patterns; reduced rank regression; overweight; obesity; Tibetan Plateau

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Introduction

Increasing obesity and its complications pose a tremendous health burden worldwide. According to the 2020 National Report on Chronic Disease and Nutrition in Chinese Residents, the prevalence of overweight or obesity reached 50.7% [(1)]. Moreover, our previous research findings indicated a higher prevalence of obesity among Tibetan adults compared to the national average [(2)]. Substantial changes resulting from the interaction of environmental and dietary factors may contribute to the increased risk of obesity.

Dietary pattern analysis, rather than the analysis of single nutrients or food, proves to be valuable in examining the associations between diet and obesity, as well as diet-related diseases [(3)]. Diet plays an important role in modulating inflammatory responses and development [(4)]. Although the precise mechanism is not yet fully understood, it is widely accepted that dietary factors and dietary patterns (DPs) alter gut microbiome profiles (e.g., diversity, composition, and metabolic activity), which can affect the progression of obesity and related non-communicable diseases (NCDs) (e.g., diabetes and cardiovascular diseases) [(5)].

Recent evidence has suggested that diets rich in pro-inflammatory components, such as processed meats and high-energy beverages, are associated with an increase in inflammatory profiles, consequently elevating the risks of obesity and related NCDs [(6, 7)]. Healthy diets, such as the Mediterranean diet and plant-based DPs identified using an exploration analysis were characterized by high amounts of vegetables and unrefined cereals, and associated with lower inflammation and reduced risk of obesity [(8-11)]. As a result, investigating the inflammatory potential of DPs and their effects on obesity has become an area of special interest. However, neither priori (e.g., healthy eating index, recommended food score, and diet quality index) nor exploratory approaches (e.g., principal component analysis [PCA], factor, and cluster analyses) can utilize the information of the biological pathways for diseases and the underlying dietary data. Consequently, novel hybrid approaches, such as the reduced rank regression (RRR) model, have been proposed to identify DPs that are more closely related to obesity risk [(12, 13)].

The Tibetan Plateau, characterized by its high altitude of over 4000 meters above sea level, experiences low temperatures and hypobaric hypoxia. It stands as one of the world's highest inhabited regions. Since 2005, under initiative by the Chinese government, native pastoralists on the Tibetan Plateau have resettled and moved to urban areas [(14)]. As a result, there have been substantial and swift changes in their diet and other lifestyle, partially contributing to increased risks of obesity [(15)]. Urbanization has diversified DPs with greater access to western foods, fruits, and vegetables [(16)]. While some studies have investigated dietary patterns among residents of the Tibetan Plateau using a priori or exploratory approaches [(16-19)], their specific and prospective associations with obesity remains unclear.

This study aimed to identify inflammation-associated DPs using inflammatory factors as response variables with RRR methods and explore their associations with obesity in an urbanized Tibetan adult cohort.

Methods and Materials

Study population and study design

This community-based prospective open cohort study has been conducted since 2018 in two settled Tibetan communities located in the suburbs of Golmud City, which is the fourth largest city on the Tibetan Plateau, situated at an elevation of 2800 meters above sea level. These settlements comprised approximately 4000 individuals who were resettled from their original pastoral areas at an elevation 4000 meters above sea level. Since 2007, some have completely abandoned their nomadic lives and settled in towns, while others retain their nomadic habits and travel between pastoral areas and towns. Additionally, certain individuals continue to engage in animal husbandry in pastoral areas.

The baseline survey was conducted in November and December 2018, and 1003 adults (≥18 years) were enrolled. Between December 2021 and May 2022, a follow-up study was conducted with 1611 adults completing the survey (514 followed up and 1097 newly included) in the two settled Tibetan communities. Participants were excluded if they met the following criteria: 1) age missing or less than 18 years (n = 5); 2) non-Tibetan ethnicity (n = 31); 3) missing anthropometric data (n = 16); 4) missing biomarkers (n = 124); and 5) incomplete food frequency questionnaire (FFQ; n = 98). Finally, 1826 participants were included in this study, of whom 514 attended both waves and provided the necessary data, resulting in 2578 person-years observations.

This study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving human subjects/patients were approved by the Ethics Committee of the Qinghai University Medical College (No.2021-15). Written informed consent was obtained from all participants.

Outcome variables

Height and weight were measured using a calibrated, fully automated height and weight scale provided by the local health center (IPR-scale08 model, Improvau Science& Technology Co., China). Waist circumference was measured using a non-stretching soft tape at the midpoint between the rib margin and the iliac bone. The average of the two measurements was used. Body mass index (BMI) was calculated as = weight (kg)/ height (m) ^{2}.

Overweight and obesity were defined based on Chinese national standards (BMI: normal weight, 18.5–23.9 kg/m^2; overweight, 24.0–27.9 kg/m^2; overweight and obesity, ≥ 24.0 kg/m^2; and general obesity, ≥ 28.0 kg/m^2) [20]. Central obesity was defined as waist circumference ≥ 90 cm in men or ≥ 85 cm in women [20].

Exposure variables

1) Dietary intakes

Dietary intakes data were collected using a 41-item FFQ by trained and qualified investigators at each wave through face-to-face interviews. A second quality control review of the completed FFQ was conducted on the same day of the survey. If necessary, a second round of face-to-face or telephonic interviews was conducted to ensure accuracy. The FFQ included the frequency of consumption of 26 food groups, such as tsamba (a kind of dough

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made with roasted barley flour and butter with water), refined carbohydrates, fried pasta, whole grains, vegetables, fresh fruits, meat, processed foods, Tibetan cheese, butter tea, milk tea, beverages, and snacks. The FFQ was modified from that used in the 2015 China Nutrition and Health Survey [21] and validated for the Tibetan population [19].

2) High–sensitivity C–reactive protein (hs-CRP) levels and prognostic nutritional index (PNI)

Blood samples were collected from the participants at the Second People's Hospital of Golmud after an overnight fast of at least 10 hours. Plasma samples were collected in heparin-containing tubes, while serum samples were collected in plain tubes without anticoagulants. Serum albumin and lymphocyte levels were assessed using an automated biochemical analyzer (Beckman Coulter AU 480, Brea, CA, USA) following standard procedures. The lymphocyte count was calculated through a leucogram using the lymphocyte percentage and the value of the lymphocytes (ml). Serum hs-CRP levels were determined using an immunoturbidimetric assay with a lower limit of detection of 0.1 mg/L. The PNI was calculated using the following formula: albumin (g/L) + 5 × total lymphocyte count × 10^9/L[22].

Covariate assessment

Smoking status was classified as never smoked, past smokers and current smoker. Alcohol drinking status was classified as never drunk, past drinker, or current drinker. Physical activity levels were categorized as light, moderate, or vigorous, depending on individuals' intensities in occupational and leisure time physical activity over the past year. Based on the cutoff point of having lived in ultra-high pastoral areas, the altitude levels were categorized into high (≤4 months/year) or ultra-high latitude (>4 months/year).

Statistical analyses

First, we derived inflammation-related DPs from 26 food groups using RRR. Subsequently, we calculated dietary scores for each participant at both waves and examined their associations of DPs with the risks of overweight, general obesity, and central obesity.

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In the RRR analysis, we used 26 food groups as predictor variables and log-transformed hs-CRP levels and PNI as response variables. The number of factors extracted using the RRR is equal to the number of intermediate response variables (i.e. 2 in the current analysis). Food groups with factor loadings ≥|0.30| were considered significant contributors to the identified DPs. Pearson's correlation coefficients were used to assess the associations between DP scores and responses. DP scores for all participants were calculated from a linear combination of standardized intakes for all food groups, which were weighted by factor score coefficients automatically generated by the statistical software. We then categorized the participants into three groups based on tertiles (T1 to T3) of DP scores in ascending order.

Mixed effects models were used to obtain odds ratios (ORs) and 95% confidence intervals (CIs) for overweight, general obesity, and central obesity, respectively. Four multivariable models were fitted: Model 1 was adjusted for age and gender; Model 2 was further adjusted for marital status, education, insurance, smoking status, drinking status, and physical activity; Model 3 was additionally adjusted for altitude; Model 4 was the same as model 3 but included those who attended both two waves of the survey. The models were selected to sequentially control for key demographic, socioeconomic, lifestyle, and environmental factors, enabling a clearer analysis of the association between dietary patterns and obesity. Model 4 further strengthens the findings by focusing on participants with complete longitudinal data to generate the longitudinal association. In these models, fixed effects are exposures that do not change throughout the study, such as age, gender, marital status, education, insurance, smoking status, drinking status, physical activity, and altitude. Random effects were included to account for individual-level variability, ensuring that within-participant variations were appropriately modeled. In the subgroup analyses, the multiplicative interaction between inflammation-related DPs and covariates (gender, age, education, smoking, drinking, physical activity, and altitude levels) was included by adding a product term to the regression model, and the ORs were reported. We also performed sensitivity analyses to confirm the effect of latitude, using six months as the cutoff point, on the associations between diet and overweight and/or obesity.

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Statistical analyses were performed using Stata software (version 17.0; Stata Corporation, College Station, TX, USA). The RRR analysis was conducted using the user-written program rrr in Stata. For all analyses, two-sided *P* values of .05 were considered statistically significant.

Results

Dietary patterns and food groups

Two inflammation-related DPs were derived using RRR methods. DP-1 explained 0.73% of the variation in hs-CRP and 5.00% of the variation in PNI, whereas DP-2 explained 3.37% of the variation in hs-CRP and 5.38% of the variation in PNI from 1391 participants in 2022 (**Supplement Table 1**). DP-1 was characterized by high intakes of sugar-sweetened beverages (SSB), savory snacks, and poultry; and a low intake of tsamba. DP-2 was characterized by high intakes of poultry, pork, animal offal, and fresh fruits; and a low intake of butter tea **(Figure 1)**.

Baseline characteristics across the tertiles of DPs

In 2018 and in 2022, a total of 1826 participants were surveyed in our study at baseline and/or follow-up, with 514 participants being followed-up for a total of 1542 person-years. **Table 1** summarized the demographic and lifestyle characteristics of 1,826 participants in 2018 and 2022 according to the tertiles of DPs. The mean age of participants was 43.1 years with a standard deviation of 14.4 years. Participants with higher DP-1 scores were younger, highly educated, married, more likely to be smokers or drinkers, and less likely to exhibit general obesity (T1vs T3:40.7% vs. 28.0%) or central obesity (T1vs T3:61.6% vs. 43.5%). Conversely, participants who scored higher on DP-2 were older and more likely to exhibit general obesity (T1vs. T3:29.8% vs. 38.6%) or central obesity (T1vs T3:46.2% vs. 61.7%). Moreover, participants with higher scores on both DPs were more likely to live at high altitudes and participate in light or medium physical activity.

Furthermore, we compared differences among the individuals who completed two waves, those who attended only once, and those who dropped out in 2022. We found that individuals

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who attended both waves were older, had lower education levels, were less likely to drink alcohol, and had a higher BMI than the other two groups (**Supplemental Tables 2-3**). Due to the unique characteristics of the study subjects (e.g., residing at high altitudes and actively participating in pastoral activities), the follow-up rate was 51.4%.

Associations of DPs with overweight and/or obesity

The associations between DPs and overweight and/or obesity risks are presented in **Table 2**. After adjusting for sociodemographic factors, lifestyle factors, and altitude, higher DPs scores were associated with a higher risk of being overweight and obesity. The odds ratios (95% confidence intervals) (ORs, 95%CIs) across tertiles for DP-1 were 1.00, 1.28 (1.03, 1.58), 1.37 (1.07, 1.77), and for DP-2 were 1.00, 1.19 (0.96, 1.48), and 1.48 (1.18, 1.85), respectively. A higher DP-2 score was associated with an increased risk of overweight and central obesity. The ORs (95% CIs) across the tertiles were 1.00, 1.72 (0.93, 3.17), and 2.83 (1.47, 5.46) for overweight, and for central obesity were 1.00, 1.18 (0.81, 1.72), and 2.25 (1.49, 3.39), respectively. Additionally, the association of overweight and central obesity with DP-2 was consistent among those who had data from the two waves; the ORs (95% CIs) across the tertiles for overweight were 1.00, 1.07 (0.36, 3.17), and 4.17 (1.20, 14.46), and for central obesity were1.00, 1.36 (0.74, 2.48), and 2.74 (1.45, 5.19), respectively, while the associations between DP1 and overweight or overweight and obesity, as well as DP2 and overweight and obesity disappeared.

To examine the influence of altitude levels, we conducted sensitivity analyses by categorizing altitude levels into high and ultra-high altitude using 6 months of those living in the patrol area as the cut-off point. The associations were similar to those using 4 months as the cut-off point (Data not shown).

Subgroup analyses observed a significant interaction between DP-1 and altitude levels in relation to the risks of being overweight (*P* for interaction =.007) and overweight and obesity (*P* for interaction =.006). (**Figure 2**). Specifically, the positive associations of DP-1 with the risks of overweight [OR 95% CI, 3.48 (1.60, 7.58)] and overweight and obesity [OR 95% CI,

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3.21 (1.80, 5.73)] were only significant at high altitude level, respectively. However, no such effects were observed for DP-2 **(Table 3).**

Discussion

Principal results

The present study is the first to derive two inflammation-related DPs using RRR methods in a cohort study among urbanized Tibetan adults. The findings highlighted the significant role of DPs associated with inflammation in obesity risk, and that altitude levels may impact these associations. Specifically, DP-1 predicted a higher PNI and was characterized by higher intakes of SSB, savory snacks, and poultry and a low intake of tsamba. DP-2 predicted higher levels of circulating hs-CRP and PNI, characterized by high intakes of poultry, pork, animal offal, and fresh fruits, and a low intake of butter tea. The hs-CRP is a well-established marker of chronic low-grade inflammation, closely linked to cardiovascular and metabolic diseases, while PNI serves as a combined marker of nutritional and immune status, frequently used to assess prognosis in inflammatory and cancer-related conditions [23, 24]. Participants who scored higher on either DP were more likely to have an increased risk of being overweight and/or obesity. Furthermore, participants with higher DP-2 scores were more likely to have central obesity. Finally, altitude might modify the associations between DP-1 and overweight and/or obesity. This study provides valuable insights into the complex interplay among diet, inflammation, and weight status in Tibetans.

Compared to research conducted on DPs in the general population, there is limited evidence available for the Tibetan population. One study in particular identified four dietary patterns using PCA among Tibetan residents [17]. Two other studies identified three DPs using PCA among an urbanized Tibetan population [19, 25]. However, these three studies relied on cross-sectional data and applied PCA. Supportively, our previous study also identified three DPs in urbanized Tibetan population. RRR is an innovative approach in nutrition epidemiology that incorporates prior knowledge of diseases and their pathways. This approach maximizes the variability in response variables and bolsters the evidence of causality between diet and diseases. Our study identified two distinct DPs associated with inflammation using the RRR with the response variables hs-CRP and PNI. Elevated hs-CRP, which indicates low-grade inflammation, is considered a potential risk factor for obesity and visceral adiposity [26], and the PNI, which reflects the interplay among inflammation, immunological status, and nutrition, is regarded as a promising biomarker with predictive and prognostic value for obesity [27]. In our study, both DPs explained the greater variation in PNI than in hs-CRP, and DP-2 explained the greater variation in hs-CRP than DP-1.

Poultry emerged as the second-highest positively loading item in both DPs identified in our study. Interestingly, previous research has reported that high intakes of chicken or pork proteins for 12-weeks led to a significant increase in systemic inflammatory factors in rats [28]. These findings were further supported by the results from the UK Biobank Study in population [29].Moreover, inflammation-related DPs in other studies have been characterized by high intakes of refined grains, processed meat, SSB, and sweet snacks, which were consistent with our findings [30-32]. Nevertheless, DPs with lower intakes of vegetables and fruits were positively associated with inflammation [30, 31], which was contrasting to the findings in DP-2. Our study identified DP-2 as a dietary pattern associated with a high intake of fresh fruits. This inconsistency may be explained by the cooking habits of vegetables in the Tibetan population. The primary cooking methods for vegetables are frying or stir-frying, which typically involves a greater amount of cooking oil and may result in excessive energy intake. These practices have been found to be closely associated with inflammation [33]. However, our dietary surveys did not consider oil intake, and further studies are warranted to clarify this. Finally, both DPs identified foods with Tibetan characteristics such as low intakes of tsamba and butter tea. Tsamba is made from barley and rich in dietary fiber and phytochemicals such as β-glucan; butter tea, another popular Tibetan beverage, has been found to have the highest levels of conjugated linoleic acids and omega-3 fatty acids, which are known for their anti-inflammatory properties [34, 35].

Participants with higher scores in both DPs were more likely to be overweight and obesity. Higher DP-2 scores were also associated with an increased risk of central obesity. These findings were consistent with the Melbourne Collaborative Cohort Study, a population-based study conducted in Australia, which found that a higher dietary inflammatory score at baseline predicted general and central obesity [36]. Similar results were reported in a Korean Genome and Epidemiology study using a dietary inflammatory index to evaluate dietary characteristics [37]. However, it is worth noting that dietary intakes in these previous studies collected solely at a single time point.

Interestingly, we observed that the association between overweight and obesity and DP-1 was evident only among individuals living in high altitude, but not in ultra-high altitude levels. This phenomenon may be attributed to an additional increase in energy expenditure that compensates for heat loss and maintains body temperature in an ultra-high altitude environment. Additionally, the adaptation to the low-pressure, low-oxygen environment at ultra-high altitude may have altered their gut microbiota and energy metabolism, potentially leading to negative results at ultra-high altitude level. However, it is important to note that the sample size at ultra-high altitude was limited, comprising only 22.9% of the total study population. As a result, further studies are necessary to elucidate the underlying mechanisms behind these observations. It is noteworthy that when dividing the altitude into two groups using a 6-month living in the ultra-high altitude as the cutoff point, there were no significant changes in the associations between DPs and weight status. To ensure a relatively balanced sample size between groups, we used a 4-month cutoff point; however, these results should be interpreted with caution.

The characteristics of our DPs and their associations with overweight and obesity suggest that changes in the living environment pose new challenges. Numerous studies have indicated an elevated risk of NCDs, particularly obesity and other metabolic disorders, during the urbanization process [19, 25, 38]. Dietary patters, as a critical part of lifestyle, have undergone profound changes, especially in a transitioning economy such as China, where consumers are switching from traditional Chinese food, largely characterized by grains and vegetable, to processed or prepared food that contain condensed energy and sodium. Urbanized Tibetans migrating from pastoral areas (ultra-high altitude) to urban areas (high altitude) have greater access to a diverse range of foods; however, this shift may contribute to an increased prevalence of overweight and obesity. Urbanization, accompanied by changes in living altitude levels, may interactively lead to a substantial decline in the consumption of traditional foods (e.g., low intakes of tsamba and butter tea) and an increase in the consumption of industrial foods (e.g., high intakes of higher intakes of SSB, and savory snacks), leading to unhealthy DPs.

Supportively, our previous study also identified three DPs in urbanized Tibetan population. We found that individuals with pastoral DP (higher intakes of Tibetan cheese, tsamba, and butter/milk tea) were less likely to have central obesity, and modern DP (pulses, poultry, offal, and processed meat) was positively associated with elevated blood pressure and elevated triglycerides; additionally, the associations may be modified by altitude levels [(39)]. These findings, along with our own, highlight the potentially adverse effects of urbanization on our population. Although our research focused on Tibetan adults, their diets exhibited similar overall changes from traditional to modern as observed in other indigenous or rural populations experiencing urbanization. Hence, we suggested that individuals who have undergone lifestyle changes to maintain a high intake of their traditional foods and a low intake of processed foods to stay healthy. Further studies are warranted to address this phenomenon and related mechanisms more comprehensively.

Limitations and strengths

This study has some limitations. First, the subjects were enrolled via voluntary participation rather than random sampling, whereas age and gender distributions were similar to those who did not participate. Second, the dietary survey did not capture specific food intake amounts. Nevertheless, previous studies have shown that food portion measurement is usually poorly assessed by FFQs and that food intake frequency, rather than portion size, matters most for individual differences [(40)]. Third, the follow-up period was relatively short and the cohort sample size was limited. However, the associations of DP2 with both overweight and central obesity were consistently observed, even when the analysis was restricted to individuals who attended both waves. Fourth, their nomadic status was not captured, although the altitude levels, to some extent, indicated the status. Finally, the follow-up rate is 51.4%. Those individuals who were followed up were older, had lower education levels, were less likely to be current drinker, and had a higher BMI. Thus, the findings may not be generalizable to the larger urbanized Tibetan population, which might have introduced selection bias. According to our knowledge, our study is the first open cohort among Tibetan population. Further cohort studies are encouraged, and cautions are needed when interpreting the results.

Despite these limitations, this cohort study of a special study population is a valuable contribution to the field. This is the first prospective cohort study to identify inflammation-related DPs using RRR and to explore their associations with obesity. The findings have important implications for public health policies and interventions.

Conclusions

In conclusion, the urbanized Tibetan population is currently experiencing a nutritional transition that has heightened their vulnerability to overweight and/or obesity. These findings underscore the importance of implementing dietary interventions tailored to the specific ethnic context. Inflammation-related DPs, particularly those characterized by high consumptions of animal and ultra-processed foods, in combination with living at high-altitudes, may further exacerbate the risks. This emphasizes the significance of adopting a balanced diet that takes into account environmental changes to mitigate these risks. It also emphasizes the importance of promoting the quality and quantity of plant-based (e.g., diversified grain like whole-grain, vegetables) and traditional Tibetan food (e.g., tsamba, butter tea) in dietary recommendations.

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Authorship

Xiaomin Sun was responsible for idea article conceptualization. Wenxiu Jian was responsible for data analysis. Yingxin Chen was responsible for first draft writing. Xiao Tang, Rui Li, Bin Zhang, Haijing Wang, Lei Zhao, and Yangrui Zhang were responsible for rewriting. Tanisawa Kumpei and Zumin Shi were responsible for rewriting and checking the reasonableness of the statistical methods. Youfa Wang and Wen Peng were responsible for overseeing the whole process of writing the article, and finalizing the rewrite.

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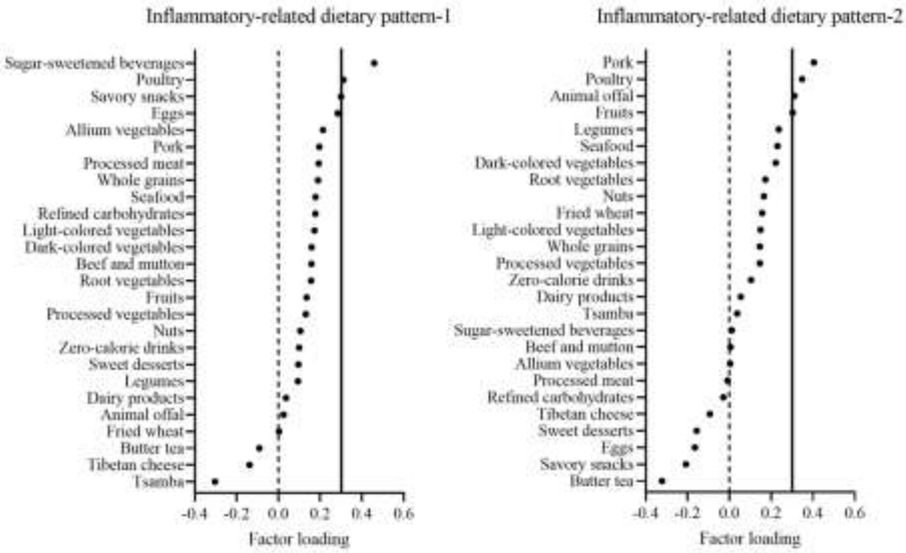

Figure 1. Factor loading matrix of dietary patterns derived from reduced rank regression among 1397 Tibetan adults in 2022

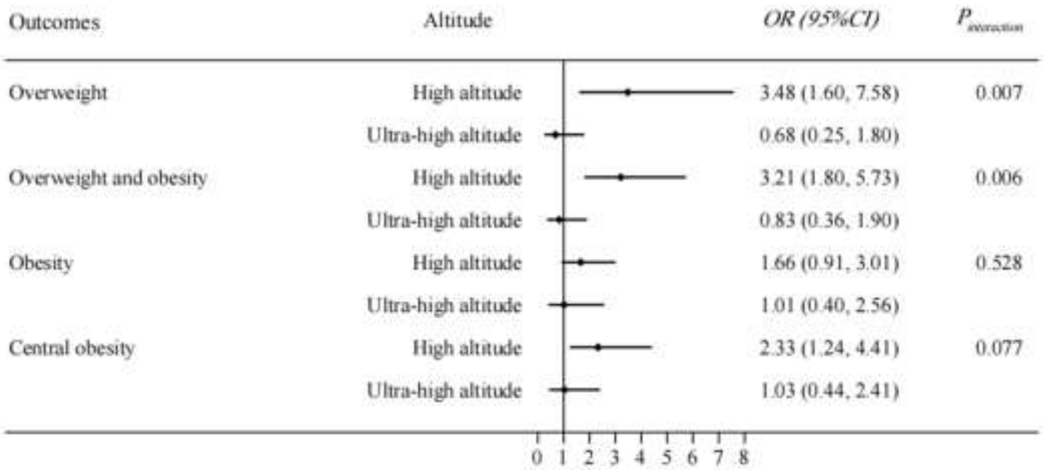

Figure 2. Odds ratios (ORs) and 95% confidence intervals (CIs) of weight status (overweight; overweight and obesity; obesity; central obesity) according to the dietary pattern-1 from stratified analyses by altitude among 1826 Tibetan adults

Mixed effect logistic models adjusted for gender, age, marital status, insurance, education, smoking, drinking, physical activity.

Table 1. Baseline characteristics of Tibetan adults according to tertiles of dietary pattern scores in 2018 and 2022 (n = 1826)

Characteristics	Dietary Pattern-1				Dietary Pattern-2			
	T1 (Low)	T2	T3 (High)	P	T1 (Low)	T2	T3 (High)	P
n	659	619	548	-	555	622	649	-
Gender				.004				.410
Men	272 (41.3)	289 (46.7)	278 (50.7)		242 (43.6)	293 (47.1)	304 (46.8)	
Women	387 (58.7)	330 (53.3)	270 (49.3)		313 (56.4)	329 (52.9)	345 (53.2)	
Age (years)	49.5±13.7	44.7±13.8	37.4±13.9	<.001	41.1±15.1	45.6±14.3	45.6±14.2	<.001
Age group (years)				<.001				<.001
18~44	237 (36.0)	307 (49.6)	380 (69.3)		325 (58.6)	283 (45.5)	316 (48.7)	
45~59	271 (41.1)	229 (37.0)	133 (24.3)		167 (30.1)	238 (38.3)	228 (35.1)	
≥ 60	151 (22.9)	83 (13.4)	35 (6.4)		63 (11.4)	101 (16.2)	105 (16.2)	
Education				<.001				.090
Never attended school	558 (84.8)	470 (76.3)	284 (52.8)		380 (69.2)	470 (76.1)	462 (71.6)	
Uncompleted primary school	49 (7.4)	50 (8.1)	49 (9.1)		46 (8.4)	48 (7.8)	54 (8.4)	
Primary school or above	51 (7.8)	96 (15.6)	205 (38.1)		123 (22.4)	100 (16.2)	129 (20.0)	
Marital status				<.001				.070
Unmarried	48 (7.3)	62 (10.0)	116 (21.2)		86 (15.5)	73 (11.7)	67 (10.3)	
Married	582 (88.3)	534 (86.3)	413 (75.4)		451 (81.3)	525 (84.4)	553 (85.2)	
Other	29 (4.4)	23 (3.7)	19 (3.5)		18 (3.2)	24 (3.9)	29 (4.5)	
Insurance				<.001				<.001
NRCMS	516 (78.3)	433 (70.0)	273 (49.8)		389 (70.1)	442 (71.1)	391 (60.2)	
URBMI	126 (19.1)	162 (26.2)	241 (44.0)		138 (24.9)	158 (25.4)	233 (35.9)	
UEBMI	3 (0.5)	8 (1.3)	17 (3.1)		8 (1.4)	11 (1.8)	9 (1.4)	
Other	14 (2.1)	16 (2.6)	17 (3.1)		20 (3.6)	11 (1.8)	16 (2.5)	
Smoking status				<.001				.250
Never smoked	590 (89.7)	496 (80.5)	387 (71.9)		436 (79.4)	516 (83.5)	521 (80.8)	
Past smoker	24 (3.6)	27 (4.4)	25 (4.6)		22 (4.0)	21 (3.4)	33 (5.1)	
Current smoker	44 (6.7)	93 (15.1)	126 (23.4)		91 (16.6)	81 (13.1)	91 (14.1)	
Alcohol drinking				<.001				.720

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Never	609 (92.6)	530 (86.0)	419 (77.9)		467 (85.1)	530 (85.8)	561 (87.0)	
Past drinker	21 (3.2)	28 (4.5)	37 (6.9)		30 (5.5)	26 (4.2)	30 (4.7)	
Current drinker	28 (4.3)	58 (9.4)	82 (15.2)		52 (9.5)	62 (10.0)	54 (8.4)	
Physical activity				.410				<.001
Light	411 (62.5)	366 (59.5)	329 (61.2)		336 (61.2)	350 (56.6)	420 (65.2)	
Medium	167 (25.4)	185 (30.1)	151 (28.1)		130 (23.7)	201 (32.5)	172 (26.7)	
Heavy	80 (12.2)	64 (10.4)	58 (10.8)		83 (15.1)	67 (10.8)	52 (8.1)	
Altitude levels				.730				.010
High altitude	483 (79.4)	409 (78.7)	328 (80.8)		306 (74.6)	436 (80.3)	478 (82.3)	
Ultra-high altitude	125 (20.6)	111 (21.3)	78 (19.2)		104 (25.4)	107 (19.7)	103 (17.7)	
BMI (kg/m^2)	26.7±5.2	26.4±5.0	25.1±4.6	<.001	25.2±5.0	26.4±5.1	26.6±4.9	<.001
Body weight status (Yes, %)				<.001				<.001
Normal (18.5-23.9 kg/m^2)	206 (32.1)	203 (33.8)	218 (41.8)		238 (44.9)	202 (33.5)	187 (29.7)	
Overweight (24.0-27.9 kg/m^2)	174 (27.1)	176 (29.3)	158 (30.3)		134 (25.3)	174 (28.9)	200 (31.7)	
Obesity (≥28.0 kg/m^2)	261 (40.7)	221 (36.8)	146 (28.0)		158 (29.8)	227 (37.6)	243 (38.6)	
Central obesity	405 (61.6)	353 (57.2)	238 (43.5)	<.001	256 (46.2)	341 (55.0)	399 (61.7)	<.001

Abbreviations: T: Tertiles; BMI: body mass index; NRCMS: New Rural Cooperative Medical Scheme; URBMI: Urban Resident Basic Medical Insurance; UEBMI: Urban Employee Basic Medical Insurance.

Central obesity: waist circumference≥90cm for men or waist circumference≥85cm for women. Smoking status was classified as never smoked, past smokers and current smoker. Alcohol drinking status was classified as never drunk, past drinker, or current drinker. Physical activity levels were categorized as light, moderate, or vigorous, depending on individuals' intensities in occupational and leisure time physical activity over the past year. The altitude levels were categorized into high (2800 meters above sea level) or ultra-high latitude (4000 meters above sea level) based on the cutoff point of having lived in ultra-high pastoral areas for less than or at least four months every year.

Data were presented as mean ± SD for continuous variables and as *n* (%) for categorical variables.

Table 2. Associations between inflammatory-related dietary patterns and weight status among Tibetan adults (n=1826)*

	Dietary Pattern-1				Dietary Pattern-2			
	T1	T2 OR (95%CI)	T3 OR (95%CI)	P for trend	T1	T2 OR (95%CI)	T3 OR (95%CI)	P for trend
Overweight								
Model 1	1.00	1.45 (0.78, 2.71)	2.11 (1.10, 4.05)	.026	1.00	1.75 (0.96, 3.20)	2.90 (1.52, 5.53)	.001
Model 2	1.00	1.51 (0.82, 2.78)	2.14 (1.10, 4.16)	.028	1.00	1.65 (0.92, 2.94)	2.64 (1.42, 4.88)	.002
Model 3	1.00	1.91 (0.99, 3.68)	2.27 (1.08, 4.75)	.033	1.00	1.72 (0.93, 3.17)	2.83 (1.47, 5.46)	.002
Model 4	1.00	2.09 (0.62, 7.04)	2.12 (0.54, 8.33)	.297	1.00	1.07 (0.36, 3.17)	4.17 (1.20, 14.46)	.034
Overweight and Obesity								
Model 1	1.00	1.14 (0.94, 1.38)	1.26 (1.04, 1.54)	.023	1.00	1.14 (0.95, 1.38)	1.36 (1.12, 1.65)	.002
Model 2	1.00	1.17 (0.96, 1.42)	1.29 (1.04, 1.60)	.022	1.00	1.14 (0.95, 1.38)	1.37 (1.12, 1.67)	.003
Model 3	1.00	1.28 (1.03, 1.58)	1.37 (1.07, 1.77)	.016	1.00	1.19 (0.96, 1.48)	1.48 (1.18, 1.85)	.001
Model 4	1.00	1.32 (0.97, 1.81)	1.23 (0.86, 1.75)	.267	1.00	1.02 (0.74, 1.40)	1.36(0.98, 1.89)	.098
Obesity								
Model 1	1.00	1.02 (0.83, 1.25)	0.95 (0.77, 1.18)	.623	1.00	1.03 (0.86, 1.24)	1.09 (0.88, 1.35)	.426
Model 2	1.00	1.03 (0.84, 1.27)	0.96 (0.77, 1.19)	.665	1.00	1.03 (0.85, 1.24)	1.07 (0.86, 1.33)	.540
Model 3	1.00	1.03 (0.83, 1.29)	1.02 (0.79, 1.32)	.872	1.00	1.10 (0.89, 1.37)	1.17 (0.92, 1.49)	.193

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Model 4	1.00	1.08 (0.79, 1.48)	0.93 (0.65, 1.31)	.684	1.00	1.11 (0.83, 1.47)	1.09 (0.77, 1.53)	.603
Central obesity								
Model 1	1.00	1.17 (0.80, 1.70)	0.85 (0.57, 1.26)	.336	1.00	1.12 (0.78, 1.62)	1.99 (1.36, 2.92)	.001
Model 2	1.00	1.19 (0.81, 1.75)	0.84 (0.55, 1.29)	.345	1.00	1.10 (0.76, 1.59)	1.97 (1.34, 2.91)	.001
Model 3	1.00	1.23 (0.85, 1.77)	1.10 (0.72, 1.68)	.679	1.00	1.18 (0.81, 1.72)	2.25 (1.49, 3.39)	<.001
Model 4	1.00	1.23 (0.68, 2.24)	0.99 (0.50, 1.98)	.990	1.00	1.36 (0.74, 2.48)	2.74 (1.45, 5.19)	.002

Values were odds ratios (ORs) and 95% CIs from mixed-effect logistic models using the data collected during 2018-2022. *, n= 514. T, tertile. Model 1 was adjusted for gender and age. Model 2 was further adjusted for marital, insurance, education, smoking status, drinking status and physical activity. Model 3 was further adjusted for altitude levels based on the cutoff point of having lived in pastoral areas for at least four months. Model 4 was the same as model 3 but included those who attended both two waves of the survey. P for trend was based on a logistic regression analysis for the categorical variables, assigning median values to the tertile categories of each dietary pattern. Overweight and obesity were defined as BMI≥24.0kg/m^2, overweight as 24.0-27.9 kg/m^2, and obesity as ≥28.0kg/m^2. Central obesity was defined as waist circumference ≥90cm in men or waist circumference ≥85cm in women. Smoking status was classified as never smoked (never smoked and not currently smoking), past smokers (formerly smoked in their lifetime and currently a nonsmoker) and current smoker (currently smoked). Alcohol drinking status was classified as never drunk (never drunk and not currently drinking), past drinker (formerly drunk in their lifetime and currently a nondrinker), or current drinker (currently drunk). Physical activity levels were categorized as light, moderate, or vigorous, depending on individuals' regular activity over the past year. The altitude levels were categorized into high (2800 meters above sea level) or ultra-high latitude (4000 meters above sea level) based on the cutoff point of having lived in pastoral areas for at least four months.

Table 3. Odds ratio (OR) and 95% confidence intervals (CIs) of overweight, obesity and central obesity with dietary pattern-2 from stratified analyses among Tibetan adults (n=1826)

Analysis stratified by		Overweight		Overweight and obesity		Obesity		Central obesity	
		OR (95%CI)	P	OR (95%CI)	P	OR (95%CI)	P	OR (95%CI)	P
Gender	Men	1.20 (0.49, 2.92)	.484	1.36 (0.55, 3.37)	.128	1.19 (0.48, 2.94)	.524	2.49 (1.01, 6.13)	.530
	Women	1.96 (0.94, 4.09)		2.94 (1.30, 6.65)		1.49 (0.70, 3.16)		3.69 (1.64, 8.28)	
Age group	18-44	0.99 (0.44, 2.19)	.497	2.11 (1.01, 4.39)	.864	2.96 (1.26, 6.96)	.084	3.01 (1.41, 6.41)	.334
	45-59	4.53 (1.60,12.85)		5.20 (1.57, 17.19)		0.83 (0.31, 2.18)		5.52 (1.83, 16.71)	
	≥60	1.93 (0.44, 8.52)		2.93 (0.48, 17.89)		1.10 (0.28, 4.37)		8.85 (1.27, 61.65)	
Education	Never attended school	1.98 (1.00, 3.89)	.242	0.45 (0.13, 1.54)	.070	1.26 (0.65, 2.45)	.949	3.44 (1.69, 7.00)	.602
	Uncompleted primary school	2.89 (0.38, 21.69)		2.63 (1.31, 5.30)		10.39 (0.83,129.79)		7.11 (0.50, 101.18)	
	Primary school or above	0.61 (0.17, 2.10)		4.21 (0.21, 83.61)		0.76 (0.19, 3.04)		1.88 (0.50, 7.05)	
Smoking status	Never smoked	1.57 (0.83,2.97)	.923	1.19 (0.29, 4.81)	.176	1.58 (0.84, 3.00)	.277	4.30 (2.16, 8.54)	.343
	Past smoker	10.03 (0.69, 144.93)		2.40 (1.26, 4.58)		0.31 (0.02, 4.04)		0.12 (0.01, 2.69)	
	Current smoker	1.44 (0.34, 6.15)		2.41 (0.20, 28.65)		0.84 (0.16, 4.32)		2.33 (0.48, 11.28)	
Alcohol drinking	Never	1.66 (0.90, 3.07)	.843	2.40 (1.26, 4.58)	.421	1.49 (0.81, 2.76)	.331	3.71 (1.94, 7.10)	.775
	Past drinker	1.90 (0.16, 21.88)		2.41 (0.20, 28.65)		1.04 (0.09, 11.58)		0.35 (0.03, 3.59)	
	Current drinker	3.35 (0.35, 31.99)		0.85 (0.07, 10.09)		0.21 (0.02, 2.27)		5.56 (0.46, 67.79)	
Physical activity	Light	1.37 (0.70, 2.68)	.129	2.31 (1.10, 4.87)	.406	1.57 (0.80, 3.10)	.858	4.50 (2.13, 9.51)	.925
	Medium	1.58 (0.44, 5.62)		0.96 (0.27, 3.42)		0.63 (0.17, 2.33)		0.61 (0.17, 2.18)	
	Heavy	5.60 (0.83, 37.70)		10.47 (1.50, 73.02)		1.93 (0.30, 12.26)		13.77 (1.96, 96.77)	
Altitude levels	High altitude	1.52 (0.79, 2.91)	.944	2.09 (1.02, 4.29)	.948	1.29 (0.67, 2.50)	.747	3.59 (1.77, 7.28)	.460
	Ultra-high altitude	1.65 (0.54, 5.04)		1.82 (0.61, 5.40)		1.17 (0.37, 3.70)		2.16 (0.72, 6.50)	

Overweight and obesity were defined as BMI≥24.0kg/m^2, overweight as 24.0-27.9 kg/m^2, and obesity as ≥28.0kg/m^2. Central obesity was defined as waist circumference ≥90cm in men or waist circumference ≥85cm in women. Smoking status was classified as never smoked, past smokers and current smoker. Alcohol drinking status was classified as never drunk, past drinker, or current drinker. Physical activity levels were categorized as light, moderate, or vigorous, depending on individuals' intensities in occupational and leisure time physical activity over the past year. The altitude levels were categorized into high (2800 meters above sea level) or ultra-high latitude (4000 meters above sea level) based on the cutoff point of having lived in ultra-high pastoral areas for less than or at least four months every year.