Original Article

Nutrient Disparities Explain Regional Differences in Cardiometabolic Risks: A Decomposition Analysis of the Northwest and Lingnan Regions Using 2015–2017 China Nutrition and Health Surveillance Data

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Abstract

Objective Pronounced dietary disparities exist across China. The Lingnan region exemplifies a healthy dietary pattern in southern China, whereas Northwest China has a higher cardiometabolic burden. This study compared dietary and nutrient intakes between the Northwest and Lingnan regions and quantified the contribution of nutrient gaps to regional differences in cardiometabolic risk. The aim was to inform national dietary guidelines and promote healthy dietary patterns such as that of Lingnan.

Methods We analyzed cross-sectional data from 13,841 adults in the China Nutrition and Health Surveillance 2015–2017. Dietary intake was assessed using three 24-hour recalls. Multivariable logistic regression was used to estimate regional odds ratios (*ORs*) for cardiometabolic outcomes, with Lingnan as the reference. Oaxaca–Blinder decomposition quantified the contribution of differences in nutrient intake to regional disease disparities.

Results Compared with the Lingnan region, whose healthy dietary pattern features high vegetable and seafood intake, the Northwest region had significantly lower intakes of vegetables, seafood, carotenoids, vitamin C, and niacin, and higher carbohydrate intake. The Northwest exhibited elevated risks of obesity (*OR* = 1.98, 95% confidence interval [*CI*]: 1.78–2.21), hypertension (*OR* = 1.11, 95% *CI*: 1.02–1.20), hypertriglyceridemia (*OR* = 1.16, 95% *CI*: 1.05–1.29), and Low HDL-C (*OR* = 1.69, 95% *CI*: 1.56–1.82). Decomposition analyses revealed that lower intakes of carotenoids, vitamin C, and niacin in the Northwest jointly explained 81.6% of the hypertension gap and 40.7% of the hypertriglyceridemia gap (both $P < 0.05$), but did not account for obesity (−21.5%) or low HDL-C (6.0%) disparities.

Conclusion Compared with Lingnan, the Northwest has lower intakes of vegetables, seafood, and related key micronutrients (carotenoids, vitamin C, and niacin), were associated witha higher burden of hypertension and hypertriglyceridemia. These nutrients showed outcome-specific protective associations, with the strongest associations for hypertension and hypertriglyceridemia. These findings provide further evidence supporting the health benefits of the Lingnan dietary pattern and highlight the importance of targeted dietary interventions—incorporating locally available carotenoid-, vitamin C-, and niacin-rich foods—to correct nutrient deficiencies and reducing cardiometabolic diseases risk in Northwest China, with important implications for the refinement of national dietary guidelines.

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Key words: Regional differences; Nutrient intake; Oaxaca–Blinder decomposition; China; Lingnan; Northwest; Cardiometabolic risk

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INTRODUCTION

China's vast geographic and sociocultural heterogeneity has fostered distinct regional dietary patterns[1,2]. A prominent example is the "south–north divide," where climatic conditions, agricultural practices, and culinary traditions contribute to divergent health outcomes[3]. The Lingnan region (Guangdong, Guangxi, Hainan) has attracted particular scientific interest: its distinctive dietary tradition emphasizes fresh vegetables, aquatic products, light cooking methods, and soup-based nourishment. In 2023, the Guangdong Nutrition Society formally codified this tradition as the "Cantonese Dietary Pattern," highlighting its eight core features—including abundant vegetables and fruits, adequate aquatic products, light and fresh flavors with minimal oil and salt, and the integration of food and nourishment[4]. Accumulating evidence links this dietary pattern to favorable cardiometabolic profiles[5]. In contrast, people in the Northwest region (Shaanxi, Gansu, Xinjiang, Qinghai, Ningxia) follow a staple food-based diet shaped by its arid environment and historical constraints[6].

Cardiometabolic risk (CMR) refers to a cluster of interrelated risk factors—including obesity (particularly abdominal obesity), hypertension, dyslipidemia (elevated triglycerides and low HDL-C [high-density lipoprotein cholesterol], and hyperuricemia—that collectively predispose individuals to type 2 diabetes and cardiovascular disease[7]. These conditions now constitute the leading causes of mortality and disability in China, making the identification of modifiable dietary determinants an urgent public health priority. Prior research has typically examined single nutrients or food groups in relation to isolated CMR components. Studies have associated seafood intake with hyperuricemia in coastal populations[8], while diets high in refined carbohydrates have been linked to metabolic dysfunction in northern China[9]. However, a critical gap remains: no study has systematically compared the comprehensive nutrient profiles of these two macro-regions and quantified the extent to which specific nutrient differences contribute to observed CMR disparities. The Oaxaca–Blinder decomposition method has been widely applied in health disparities research to quantify the contributions of various factors to observed group differences. Internationally, this approach has been used to examine socioeconomic and racial disparities in obesity, hypertension, and healthcare utilization. In China, decomposition analyses have been employed primarily to examine urban–rural disparities in health outcomes and healthcare access, but their application to nutritional epidemiology—specifically, quantifying how specific nutrient differences contribute to regional cardiometabolic risk disparities—remains limited. Addressing this gap is essential for moving beyond broad geographic generalizations toward evidence-based, region-specific prevention strategies.

This study therefore uses a quantitative, multilevel approach with three objectives: (1) to compare food intakes and energy-adjusted nutrient intakes between the Lingnan and Northwest regions; (2) to assess regional differences in a comprehensive panel of cardiometabolic risk factors; and (3) to use decomposition analyses to quantify the contribution of specific nutrient gaps to regional CMR disparities.

MATERIALS AND METHODS

Data Collection and Study Sample

This cross-sectional study used data from the China Nutrition and Health Surveillance 2015–2017 (CNHS 2015), a nationally representative survey led by the Chinese Center for Disease Control and Prevention (China CDC). The survey used a complex, multistage, stratified cluster sampling design to select a representative sample of noninstitutionalized Chinese adults (aged 18 years and older) across all 31 provincial-level administrative divisions. This rigorous design ensured the sample accounted for variations in urban or rural residence, geographic region, and level of economic development. A total of 189,005 participants completed the core components of the 2015 survey. Detailed sampling and inclusion/exclusion criteria have been published previously[10].

For the present comparative analysis, we focused

on participants from two contrasting macro-regions: the Lingnan region (encompassing Guangdong, Guangxi, and Hainan provinces; *n* = 6,701) and the Northwest region (encompassing Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang provinces/ autonomous regions; *n* = 7,140). Participants with incomplete dietary data or implausible energy intake reports (< 500 or > 5,000 kcal/day) were excluded. All participants provided written informed consent. The protocol for CNHS 2015 was reviewed and approved by the Ethical Review Committee of the Chinese Center for Disease Control and Prevention (No. 201519-B).

Basic Information Survey and Physical Examination

Trained health professionals conducted face-to-face interviews using standardized electronic questionnaires to collect data on age, sex, ethnicity, residence (urban/rural), education level, smoking status (categorized as current daily, occasional, former, or never smoking), alcohol consumption frequency (often [≥ 1 time/week], seldom [< 1 time/week], never), and physical activity level (PAL). Medical history, including self-reported physician diagnoses of hypertension, diabetes, and dyslipidemia, was also recorded. Height and weight were measured while participants wore light indoor clothing and no shoes. Body mass index (BMI) was calculated as weight (kg) divided by height squared (m^2). Waist circumference (WC) was measured at the midpoint between the lowest rib and the iliac crest. Resting systolic and diastolic blood pressure (BP) were measured three times on the right arm using a validated electronic sphygmomanometer after a 5-minute seated rest; the average of the last two readings was used for analysis.

Laboratory Tests

After an overnight fast (≥ 10 hours), venous blood samples were collected. All laboratory analyses were performed at the central laboratory of the China CDC or qualified provincial CDC laboratories following strict quality control procedures. The study used an automatic biochemical analyzer (Hitachi 7600, Tokyo, Japan) to measure liver and renal function, including fasting plasma glucose (FPG), plasma lipids, including total cholesterol (TC), triglycerides (TG), HDL-C, low-density lipoprotein cholesterol (LDL-C), and plasma uric acid (UA). Glycated hemoglobin (HbA1c) was determined by a high-performance liquid chromatography (HPLC) method using a Trinity Biotech Premier Hb9210 analyzer (Dublin, Ireland).

Dietary Assessment

Three consecutive 24-hour dietary recalls (including two weekdays and one weekend day) were conducted by trained interviewers to obtain detailed information on recent intake. Nutrient intakes were calculated by matching the foods and quantities consumed to entries in the China Food Composition Table (Standard Edition, 2015).

Definition of Obesity, Hypertension, Diabetes Mellitus, and Hyperlipidemia

According to the Chinese criteria for adults[11], obesity was defined as a BMI ≥ 28.0 kg/m^2. Hypertension was defined as systolic blood pressure (SBP) ≥ 140 mmHg and/or diastolic blood pressure (DBP) ≥ 90 mmHg, and/or self-reported current use of antihypertensive medication[12]. Diabetes mellitus was defined according to the American Diabetes Association (ADA) standards[13]. Participants were classified as having diabetes if they had FPG ≥ 7.0 mmol/L (126 mg/dL), HbA1c ≥ 6.5%, or a self-reported prior physician diagnosis of diabetes. Dyslipidemia was assessed through both individual lipid abnormalities and a composite measure. The following individual dyslipidemia components were defined according to the 2016 Chinese Adult Lipid Guidelines[14]: hypercholesterolemia (TC ≥ 6.2 mmol/L), hypertriglyceridemia (TG ≥ 2.3 mmol/L), low HDL-C < 1.0 mmol/L, and high LDL-C ≥ 4.1 mmol/L. The composite definition of dyslipidemia was met if a participant had any of the four individual abnormalities. Hyperuricemia (HUA) was defined as a serum UA concentration exceeding 420 μmol/L in men and 360 μmol/L in women[15].

Statistical Analysis

All analyses accounted for the complex survey design. Sampling weights were applied, and variance estimation was performed using Taylor series linearization. Data were analyzed using SAS version 9.4 and R software. Continuous variables are presented as mean ± SD and were compared between regions using the two-sample Student's *t* test. Categorical variables are presented as frequencies (percentages) and were compared using the chi-square test. Given the large sample size (*n* > 6,000 per region), the *t* test is robust to potential deviations from normality according to the central limit theorem[16]. For heavily skewed food group variables, sensitivity analyses using Wilcoxon rank-sum tests were also performed and yielded consistent results. The nutrient residual model was

used to adjust for total energy intake. Each nutrient intake was regressed on total energy intake, and residuals were saved for analysis. The residuals were added to the predicted nutrient intake at the mean energy intake to obtain energy-adjusted values, which were used in all subsequent models. Energy-adjusted mean differences (Lingnan−Northwest) and 95% *CIs* were estimated from linear regression models adjusted for age, physical activity level, ethnicity, sex, education, smoking, and drinking status. The Bonferroni correction was applied, with significance set at $P < 0.001$. Covariates in all multivariable models were prespecified based on prior knowledge and included age (continuous), sex (male/female), ethnicity, residence (urban/rural), education level, physical activity level, smoking status, alcohol consumption, and BMI (except for the obesity model). Total energy intake was not included as a separate covariate because nutrient variables were adjusted for energy using the residual method. Multivariable logistic regression was used to calculate odds ratios (*ORs*) and 95% *CIs* for each cardiometabolic disease, with Lingnan as the reference. Statistical significance was set at $P < 0.05$. A linear probability model was used for binary outcomes given the large sample size[17,18]. The decomposition was performed jointly for all the three selected nutrients. Sensitivity analyses using the Fairlie nonlinear decomposition confirmed consistent results. Oaxaca–Blinder decomposition analyses were performed using the 'oaxaca' package in R to quantify the contribution of nutrient differences to regional disease disparities. This method partitions the total disparity into an explained component (attributable to between-region differences in nutrient intake) and an unexplained component (attributable to differences in nutrient-disease associations across regions)[19,20]. Standard errors and 95% *CIs* were estimated using nonparametric bootstrapping with 500 iterations. As a sensitivity analysis, the first-stage regressions were re-estimated using a logit model; the resulting decomposition estimates were virtually identical to those from the linear probability model for all outcomes (Supplementary Table S1).

RESULTS

Participant Characteristics

As shown in Table 1, significant differences in sociodemographic characteristics and health status were observed between the Lingnan and Northwest regions. Compared with Lingnan participants, Northwest participants were more likely to be middle-aged (45–60 years), reside in rural areas, and have lower educational attainment (all $P < 0.05$). Regarding lifestyle factors, former smoking and moderate physical activity levels were more common in the Northwest, whereas frequent alcohol consumption was more common in Lingnan ($P < 0.001$). Cardiometabolic profiles also differed markedly: the Northwest region exhibited higher rates of obesity, hypertension, hypertriglyceridemia, and low HDL-C, while the Lingnan region showed markedly higher burdens of hyperuricemia, hypercholesterolemia, and high LDL-C (all $P < 0.001$). Diabetes prevalence was comparable between groups ($P = 0.627$).

Comparison of Food Intake between the Two Regions in China

Marked differences in food consumption patterns were observed between Lingnan and Northwest China (Table 2). Participants in Lingnan had significantly higher intakes of rice (249.68 *vs.* 53.96 g/d), vegetables (287.01 *vs*. 182.51 g/d), red meat (101.14 *vs.* 23.73 g/d), poultry (30.27 *vs*. 5.88 g/d), and seafood (50.80 *vs.* 2.71 g/d) (all $P < 0.001$). Conversely, participants in the Northwest had higher intakes of wheat products (243.26 *vs.* 26.74 g/d) and milk products (30.93 *vs.* 10.47 g/d) (both $P < 0.001$). No significant difference was observed for egg intake ($P = 0.216$). These patterns reflect the regions' distinct dietary traditions: Lingnan's coastal location favors seafood, vegetable, and rice consumption, while the Northwest's agricultural heritage emphasizes wheat-based staples.

Regional Differences in Nutrient Intake

Crude nutrient intakes and energy-adjusted between-region differences in Table 3 and Figure 1. The Lingnan diet was characterized by significantly higher intakes of total fat (+13.1 g/d), protein (+6.9 g/d), sodium (+179.5 mg/d), calcium (+61.1 mg/d), zinc (+1.8 mg/d), selenium (+3.9 μg/d), carotenoids (+1,166.1 μg/d), and vitamin C (+27.9 mg/d). Conversely, the Northwest diet was higher in carbohydrates (−44.0 g/d), dietary fiber (−1.5 g/d), vitamin E (−29.0 mg/d), thiamin (−0.1 mg/d), magnesium (−19.8 mg/d), and copper (−0.2 mg/d) (all $P < 0.001$).

Regional Disparities in Chronic Disease Risks

Our analysis identified significant regional disparities in chronic disease risks between

Northwest and Lingnan China (Figure 2A,Table 4). Models were adjusted for age, sex, ethnicity, education, physical activity, smoking, alcohol consumption, and BMI (except for obesity). The Northwest region showed significantly higher risks of obesity (*OR* = 1.98, 95% *CI*: 1.78–2.21, *P* < 0.001), hypertension (*OR* = 1.11, 95% *CI*: 1.02–1.20, *P* = 0.012), hypertriglyceridemia (*OR* = 1.16, 95% *CI*: 1.05–1.29, *P* = 0.004), and low HDL-C (*OR* = 1.69, 95% *CI*: 1.56–1.82, *P* < 0.001). Conversely, the Northwest region had significantly lower risks of hyperuricemia (*OR* = 0.23, 95% *CI*: 0.21–0.26, *P* < 0.001), hypercholesterolemia (*OR* = 0.31, 95% *CI*: 0.27–0.35, *P* < 0.001), and high LDL-C (*OR* = 0.29, 95% *CI*: 0.26–0.33, *P* < 0.001). No significant differences were observed for diabetes mellitus (*OR* = 0.91, 95% *CI*: 0.79–1.04, *P* = 0.148) or dyslipidemia (*OR* = 1.07, 95% *CI*: 1.00–1.15, *P* = 0.058). Subgroup analyses (Figure 2B) identified interactions between region and several demographic characteristics; however, the interaction between age and region for obesity was not statistically significant (*P* for interaction = 0.083). Residence and region showed a significant interaction for hyperuricemia (*P* for interaction < 0.001), and sex and region showed significant interactions for lipid disorders.Age-specific patterns (Figure 2C) showed that obesity risk varied with age in the Northwest region, with the highest risk observed in the ≥ 60 years group. Regional odds ratios stratified by residence (Figure 2D) indicated that rural residents in both regions generally had higher disease risks than urban residents, with significant urban–rural interactions for most diseases (all *P* for interaction < 0.001 except obesity *P* = 0.071).

Decomposition Analysis

Oaxaca–Blinder decomposition analyses

Table 1. Characteristics of participants in the Lingnan and Northwest regions

Characteristics	Lingnan Region		Northwest Region		χ^2	*P*
	N	*n*/%	*N*	*n*/%		
Total	6,701	100.0	7,140	100.0		
Sex					3.61	0.057
Male	3,066	45.8	3,382	47.4		
Female	3,635	54.2	3,758	52.6		
Age (years)					34.96	< 0.001
18–45	2,206	32.9	2,332	32.7		
45–60	2,380	35.5	2,838	39.7		
≥ 60	2,115	31.6	1,970	27.6		
Ethnicity					1.37	0.242
Han	5,435	81.1	5,735	80.3		
Ethnic minorities	1,266	18.9	1,405	19.7		
Residence					52.26	< 0.001
Urban	2,616	39.0	2,366	33.1		
Rural	4,085	61.0	4,774	66.9		
Smoking status					18.55	0.003
Current daily smoker	1,561	23.3	1,614	22.6		
Occasional smoker	168	2.5	140	2.0		
Former smoker	355	5.3	487	6.8		
Never smoker	4,610	68.9	4,899	68.6		
Alcohol consumption					76.09	< 0.001
Often	1,780	26.6	1,451	20.3		
Seldom	673	10.1	755	10.6		
Never	4,241	63.4	4,932	69.1		

Continued

Characteristics	Lingnan Region		Northwest Region		χ^2	*P*
	N	*n*/%	*N*	*n*/%		
Education					39.24	< 0.001
Primary school or below	3,204	47.8	3,682	51.6		
Junior or senior high school	3,285	49.0	3,328	46.6		
University or above	212	3.2	130	1.8		
PAL					120.14	< 0.001
Low	3,378	50.4	2,985	41.8		
Moderate	2,477	37.0	3,267	45.8		
High	846	12.6	888	12.4		
Obesity					140.05	< 0.001
Yes	567	8.5	1,068	15.0		
No	6,134	91.5	6,072	85.0		
DM					0.24	0.627
Yes	513	7.7	530	7.4		
No	6,188	92.3	6,610	92.6		
Hypertension					20.78	< 0.001
Yes	2,370	35.4	2,794	39.1		
No	4,331	64.6	4,346	60.9		
HUA					662.01	< 0.001
Yes	1,597	23.8	566	7.9		
No	5,104	76.2	6,574	92.1		
HyperTC					360.04	< 0.001
Yes	1,073	16.0	427	6.0		
No	5,628	84.0	6,713	94.0		
HyperTG					31.56	< 0.001
Yes	854	12.7	1,150	16.1		
No	5,847	87.3	5,990	83.9		
Low HDL-C					270.89	< 0.001
Yes	2,118	31.6	3,230	45.2		
No	4,583	68.4	3,910	54.8		
High LDL-C					387.45	< 0.001
Yes	1,147	17.1	457	6.4		
No	5,554	82.9	6,683	93.6		
Dyslipidemia					34.38	< 0.001
Yes	3,252	48.5	3,821	53.5		
No	3,449	51.5	3,319	46.4		

Note. PAL, physical activity level; DM, diabetes mellitus; HUA, hyperuricemia; HyperTC, hypercholesterolemia; HyperTG, hypertriglyceridemia; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol. For smoking and alcohol in Lingnan, percentages use non-missing data (*n* = 6,694; 7 missing). In Northwest, smoking was complete (*n* = 7,140); alcohol percentages use *n* = 7,138 (2 missing).

quantified the contribution of regional differences in carotenoid, vitamin C, and niacin intake to observed cardiometabolic disparities. These three nutrients were selected based on significant regional intake differences (P < 0.001), consistent directions of association with disease risk, and established antioxidant and lipid-modulating roles. All models were adjusted for age, sex, ethnicity, education, physical activity, smoking, and alcohol consumption, with additional BMI adjustment for hypertension, hypertriglyceridemia, and low HDL-C. Standard errors and 95% *CIs* were estimated via nonparametric bootstrapping with 500 iterations (Table 5).

For hypertension, these three nutrients jointly explained 81.6% of the regional disparity (explained component: 0.0309, 95% *CI*: 0.0187–0.0432, P < 0.05), indicating that over four-fifths of the Northwest's excess hypertension burden **is statistically explained by** lower intakes of these protective micronutrients. For hypertriglyceridemia, the explained proportion was 40.7% (0.0139, 95% *CI*: 0.0047–0.0231, P < 0.05), suggesting that additional factors maycontribute to the residual disparity. **For obesity, the negative explained proportion (−21.5%, P < 0.05) indicates that the selected micronutrient differences do not explain the higher obesity prevalence in the Northwest; other factors may contribute.** For low HDL-C, the explained proportion was small and nonsignificant (6.0%, P = 0.213), consistent with evidence that HDL-C is more strongly influenced by dietary fat quality and physical activity than by these micronutrients.

Collectively, these findings indicate a pattern specific to both the nutrient and the outcome: carotenoid, vitamin C, and niacin deficiencies in the Northwest robustly explain its excess hypertension and partially explain its hypertriglyceridemia burden, but do not account for obesity or low HDL-C disparities.

Stratified Oaxaca–Blinder decomposition analyses by sex and residence revealed generally consistent patterns with the main analysis (Supplementary Table S2). For hypertriglyceridemia, the three nutrients explained a larger proportion of the regional gap in men (72.6%) than in women (22.5%), and in urban (54.8%) than in rural areas (33.5%). For low HDL-C, explanatory proportions remained modest across all strata (4.7%–15.7%). For hypertension, estimates were stable in women (32.4%) and rural residents (31.6%), but numerically unstable in men because of a very small total regional difference. For obesity, explained proportions were predominantly negative across strata (ranging from −35.9% to +1.1%).

DISCUSSION

This study provides a systematic comparison of food and nutrient intakes between the Lingnan and Northwest regions, quantifying the contribution of specific nutrient gaps to divergent cardiometabolic risk profiles. The main finding was that lower intakes of carotenoids, vitamin C, and niacin in the Northwest jointly explained 81.6% of the regional hypertension gap and 40.7% of the hypertriglyceridemia gap. Together, these three nutrients emerge as important protective factors

Table 2. Comparison of food intake between Lingnan and Northwest China (g/(person·day), mean ± SD)

Food Group	Lingnan Region(n = 6,701)	Northwest Region(n = 7,140)	t	P
Rice	249.68 ± 102.32	53.96 ± 57.82	127.21	< 0.001
Wheat	26.74 ± 40.17	243.26 ± 120.91	−127.37	< 0.001
Soybeans	6.46 ± 14.22	4.85 ± 11.59	6.81	< 0.001
Vegetables	287.01 ± 141.77	182.51 ± 123.24	43.21	< 0.001
Fruit	31.74 ± 61.38	35.66 ± 73.22	−3.2	0.001
Red meat	101.14 ± 64.30	23.73 ± 34.40	80.61	< 0.001
Poultry	30.27 ± 42.02	5.88 ± 21.99	39.37	< 0.001
Milk products	10.47 ± 65.84	30.93 ± 81.32	−15.33	< 0.001
Eggs	14.54 ± 22.24	15.06 ± 23.73	−1.24	0.216
Seafood	50.80 ± 69.55	2.71 ± 13.00	52.08	< 0.001

Note. Values are presented as mean ± SD. P values were derived from two-sample t tests. Given the large sample sizes (n > 6,000 per region), t tests are robust to deviations from normality.

whose deficiency in the Northwest substantially accounts for its excess cardiometabolic burden relative to Lingnan.

This finding must be interpreted within the broader context of the Lingnan Dietary Pattern, formally codified in 2023 by the Guangdong Nutrition Society[4]. The pattern's eight defining features—including abundant vegetables and fruits, adequate aquatic products, light and fresh flavors with minimal oil and salt, and predominant use of steaming and quick stir-frying—collectively create a nutrient environment rich in antioxidants and B vitamins. **While this pattern recommends abundant fruit intake, our observed data showed that actual fruit consumption was slightly higher in the Northwest (35.66 *vs.* 31.74 g/d). Nevertheless**, Lingnan participants consumed significantly more vegetables (+104.5 g/d), seafood (+48.1 g/d), which translatedinto markedly higher intakes of carotenoids (+1,166.1 μg/d), vitamin C (+27.9 mg/d), and niacin (+5.9 mg NE/d). These micronutrients, concentrated in the plant foods and aquatic products emblematic of the Lingnan dietary tradition, are precisely those our decomposition analysis identified as statistically explaining the majority of the hypertension disparity.

Table 3. Comparison of crude nutrient intakes and energy-adjusted differences between the Lingnan and Northwest regions (mean ± SD)

Nutrients	Lingnan Region (*n* = 6,701)	Northwest Region (*n* = 7,140)	Energy-adjusted Difference (95% *CI*)
Energy (kcal/d)	1,902.1 ± 581.9	1,862.4 ± 631.8	59.061 (40.214, 77.908)* †
Carbohydrate (g/d)	230.2 ± 72.4	271.7 ± 84.5	−44.023 (−45.769, −42.276)*
Dietary fiber (g/d)	8.7 ± 3.0	10.0 ± 3.4	−1.495 (−1.591, −1.399)*
Protein (g/d)	61.6 ± 17.2	53.9 ± 16.3	6.938 (6.490, 7.386)*
Total fat (g/d)	74.2 ±26.2	60.1 ± 24.7	13.143 (12.418, 13.869)*
Calcium (mg/d)	333.4 ± 134.1	264.2 ± 115.3	61.137 (57.362, 64.913)*
Copper (mg/d)	1.4 ± 0.6	1.6 ± 0.6	−0.193 (−0.208, −0.178)*
Iron (mg/d)	18.7 ± 5.9	18.9 ± 6.1	−0.512 (−0.660, −0.365)*
Magnesium (mg/d)	237.0 ± 70.5	253.0 ± 79.7	−19.791 (−21.669, −17.914)*
Manganese (mg/d)	5.0 ± 1.7	5.3 ± 1.9	−0.352 (−0.399, −0.305)*
Phosphorus (mg/d)	851.0 ± 236.2	832.7 ± 256.8	5.043 (−0.544, 10.629)
Potassium (mg/d)	1,441.0 ± 463.0	1,422.2 ± 463.2	−8.984 (−21.356, 3.387)
Selenium (μg/d)	43.0 ± 19.8	38.4 ± 16.9	3.913 (3.375, 4.452)*
Sodium (mg/d)	5,802.9 ± 2,616.6	5,640.2 ± 2,934.7	179.485 (86.787, 272.183)*
Zinc (mg/d)	10.5 ± 2.8	8.5 ± 3.0	1.825 (1.758, 1.892)*
Carotenoids (μg/d)	2,221.6 ± 1,687.8	1,019.9 ± 1,157.7	1,166.122 (1,118.393, 1,213.851)*
Niacin (mg NE/d)	17.0 ± 5.4	10.8 ± 4.9	5.903 (5.760, 6.047)*
Retinol (μg/d)	85.1 ± 61.1	50.8 ± 58.0	31.415 (29.492, 33.339)*
Riboflavin (mg/d)	0.7 ± 0.2	0.6 ± 0.2	0.147 (0.141, 0.154)*
Thiamin (mg/d)	0.8 ± 0.3	0.9 ± 0.3	−0.085 (−0.094, −0.077)*
Vitamin C (mg/d)	87.9 ± 43.6	58.8 ± 34.2	27.872 (26.601, 29.144)*
Vitamin E (mg/d)	21.4 ± 14.3	50.1 ± 41.7	−29.007 (−30.009, −28.006)*

Note. Values in the first two columns are crude (unadjusted) mean ± SD. The last column presents energy-adjusted differences (Lingnan − Northwest) for all nutrients except energy. Nutrient intakes were adjusted for total energy intake using the residual method, and differences were further adjusted for age, sex, ethnicity, education, physical activity level (PAL), smoking, and drinking status. †For energy intake, no energy adjustment was applied; the value represents the covariate-adjusted difference in crude energy intake. NE, niacin equivalent; *CI*, confidence interval; SD, standard deviation; PAL, physical activity level. *Indicates statistical significance at $p < 0.001$.

The biological plausibility of carotenoids, vitamin C, and niacin as protective agents is well established, with each nutrient exerting distinct yet complementary effects on cardiometabolic health. The stratified decomposition results suggest that the protective associations of carotenoids, vitamin C, and niacin may be particularly pronounced for hypertriglyceridemia among **men and urban residents** in the Northwest. This pattern may reflect the greater relative importance of antioxidant and B-vitamin inadequacy in this subgroup, where dietary patterns may otherwise be more varied. **The predominantly negative explained proportions for obesity across strata indicate that the micronutrient triad does not account for the obesity disparity; other unmeasured dietary or lifestyle factors may contribute.** Future studies with larger subgroup samples and formal interaction decomposition methods are needed to confirm and extend these exploratory stratified findings.

A supplementary decomposition analysis using total carbohydrate intake in place of the three micronutrients provides further insight into this interpretation. Total carbohydrate intake explained only −3.1% of the obesity gap (95% *CI* of the explained component: −0.0053 to 0.0012, crossing zero; Supplementary Table S3), indicating that the absolute quantity of dietary carbohydrate, as captured by 24-hour dietary recall, does not independently account for the regional obesity disparity. This null finding suggests that the quality of carbohydrates (e.g., refined versus whole grains, glycemic index), rather than their absolute amount, along with other dietary factors such as total energy intake and dietary fat composition, may be more relevant determinants of obesity. The 95% *CI* crossing zero further confirms the absence of a statistically significant contribution of total carbohydrate quantity to the obesity gap. Future studies using more detailed dietary assessment tools that distinguish refined from whole-grain carbohydrates are needed to identify the specific dietary drivers of obesity disparities across Chinese regions.

Carotenoids, including β-carotene, lycopene, and lutein, are lipid-soluble antioxidants that preferentially accumulate in cell membranes and lipoproteins, where they quench singlet oxygen and terminate lipid peroxidation chain reactions[21]. This membrane-stabilizing function is particularly relevant to endothelial health: by reducing oxidative modification of LDL particles and preserving endothelial nitric oxide synthase (eNOS) activity, carotenoids enhance nitric oxide bioavailability and promote vasodilation[21]. Epidemiological evidence supports these mechanistic observations. A 2023 meta-analysis of 13 studies including 26,349 participants reported that higher dietary total antioxidant capacity (TAC)—to which carotenoids are major contributors—was associated with significant reductions in systolic blood pressure (**weighted mean difference [WMD]** : −1.08 mmHg)

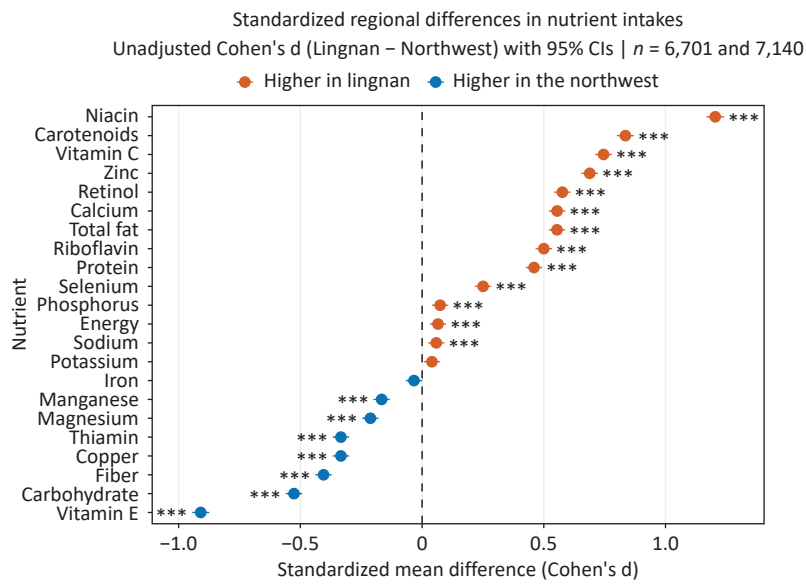

Figure 1. Forest plot of nutrient intake differences between the Lingnan and Northwest regions. *CI*, confidence interval.

and diastolic blood pressure (WMD: −0.85 mmHg)[22]. In our decomposition analysis, **the carotenoid deficit (1,166.1 μg/d lower than in Lingnan), together with the vitamin C and niacin deficits, contributed to the jointly explained hypertension disparity.**

Vitamin C (ascorbic acid) is the predominant water-soluble antioxidant in human plasma, functioning as the first line of defense against aqueous free radicals. Beyond its direct radical-scavenging activity, vitamin C regenerates membrane-bound α-tocopherol (vitamin E) from its oxidized form, thereby maintaining the integrity of the entire antioxidant network[23]. In the vasculature, vitamin C preserves endothelial function by preventing the oxidative inactivation of tetrahydrobiopterin (BH4), an essential eNOS cofactor, and by reducing NADPH oxidase-derived superoxide production[24]. A 2025 cross-sectional study of 12,046 Chinese adults found that individuals in the highest quartile of dietary total antioxidant capacity (DTAC) had a 62% lower risk of hypertension (*OR* = 0.38, 95% *CI*: 0.32–0.46) compared with those in the lowest quartile, with vitamin C identified as a principal contributor to this

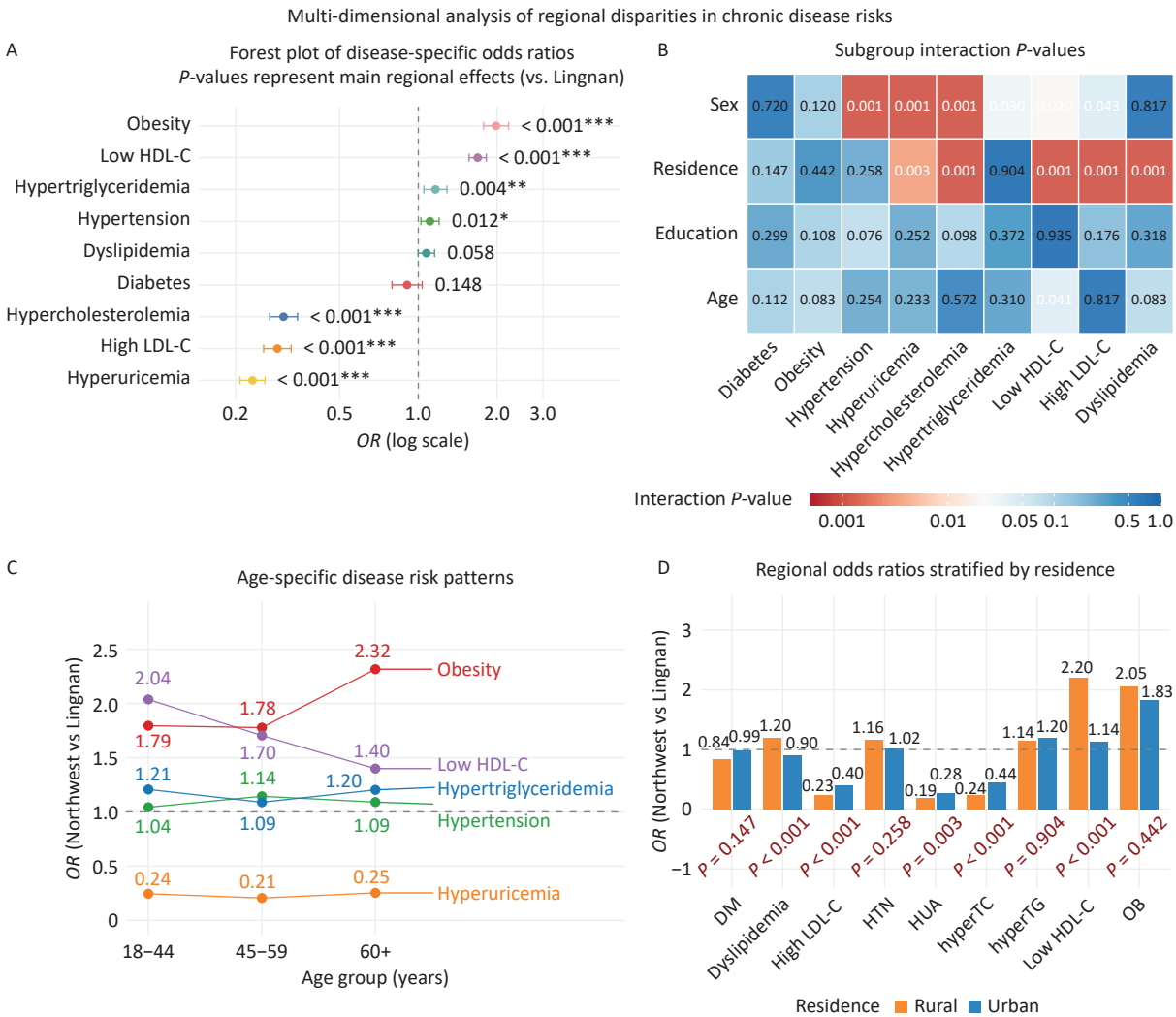

Figure 2. Multi-dimensional analysis of regional disparities in chronic disease risks between Northwest and Lingnan China. (A) Forest plot of disease-specific odds ratios (main regional effects). (B) Subgroup interaction P values. (C) Age-specific disease risk patterns. (D) Regional odds ratios stratified by residence. *OR*, odds ratio; *CI*, confidence interval; DM, diabetes; OB, obesity; HTN, hypertension; HUA, hyperuricemia; hyperTC, hypercholesterolemia; hyperTG, hypertriglyceridemia; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol. *OR* > 1 indicates higher risk in the Northwest; *OR* < 1 indicates higher risk in Lingnan.

protective association[25]. The Northwest's 27.9 mg/d deficit in vitamin C intake relative to Lingnan thus represents a substantial loss of this primary aqueous antioxidant defense.

Niacin (vitamin B3) exerts unique lipid-modulating and vasodilatory effects distinct from the antioxidant actions of carotenoids and vitamin C. At pharmacological doses, niacin inhibits hormone-sensitive lipase in adipose tissue via activation of the GPR109A receptor, reducing free fatty acid flux to the liver and consequently lowering hepatic triglyceride synthesis and **very-low-density lipoprotein (VLDL)** secretion[26]. This mechanism directly accounts for niacin's well-established triglyceride-lowering and HDL-cholesterol-raising effects. A 2024 systematic review and meta-analysis of 12 randomized controlled trials confirmed that niacin intervention significantly reduced apolipoprotein B levels (WMD: −24.37 mg/dL, P = 0.01) and increased apolipoprotein A1 levels (WMD: 8.23 mg/dL, P < 0.001), with the most pronounced effects at dosages > 1,500 mg/d and with extended-release formulations[27]. **These pharmacological findings provide mechanistic context but do not establish equivalent effects at dietary intake levels.** Beyond its lipid-modulating properties, niacin serves

Table 4. Regional risk of cardiometabolic diseases: Northwest region compared with the Lingnan region

Risk Direction	Cardiometabolic Outcome	Northwest *vs.* Lingnan Region *OR* (95% *CI*)	*P*
Higher Risk in the Northwest			
	Obesity	1.984 (1.778, 2.214)	**< 0.001***
	Hypertension	1.108 (1.023, 1.201)	**0.012***
	Hypertriglyceridemia	1.163 (1.050, 1.287)	**0.004***
	Low HDL-C	1.687 (1.564, 1.820)	**< 0.001***
Lower Risk in the Northwest			
	Hyperuricemia	0.232 (0.208, 0.259)	**< 0.001***
	Hypercholesterolemia	0.305 (0.270, 0.345)	**< 0.001***
	High LDL-C	0.289 (0.256, 0.326)	**< 0.001***
No Significant Difference			
	Diabetes Mellitus	0.906 (0.793, 1.035)	0.148
	Dyslipidemia	1.073 (0.998, 1.154)	0.058

Note. *OR*, odds ratio; *CI*, confidence interval; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; BMI, body mass index. The Lingnan region served as the reference group. All models were adjusted for age, sex, ethnicity, education, physical activity, smoking, alcohol consumption, area of residence, and BMI (except for obesity).

Table 5. Decomposition of regional disparities in cardiometabolic diseases associated with carotenoid, vitamin C, and niacin intake

Disease Outcome	Total Difference (95% *CI*)	Explained Component (95% *CI*)	Explained Proportion (%)
Hypertriglyceridemia	0.0341 (0.0168, 0.0515)	0.0139 (0.0047, 0.0231)	40.7*
Low HDL-C	0.1367 (0.1129, 0.1604)	0.0081 (−0.0046, 0.0209)	6.0
Obesity	0.0650 (0.0495, 0.0804)	−0.0140 (−0.0224, −0.0056)	−21.5*
Hypertension	0.0379 (0.0161, 0.0597)	0.0309 (0.0187, 0.0432)	81.6*

Note. Values are presented as point estimates with 95% *CIs* in parentheses. The explained component represents the portion of the regional disparity associated with differences in carotenoid, vitamin C, and niacin intake. All models were adjusted for age, sex, education, physical activity, smoking, and alcohol consumption; Models were additionally adjusted for BMI for all outcomes except obesity. * Indicates statistical significance at P < 0.05, indicated by a 95% *CI* for the explained component that does not include zero. HDL-C, high-density lipoprotein cholesterol; *CI*, confidence interval; BMI, body mass index.

as a precursor for nicotinamide adenine dinucleotide (NAD+), a critical coenzyme in cellular redox reactions and energy metabolism. Emerging evidence from clinical trials indicates that strategies to increase NAD+ using vitamin B3 derivatives can reduce blood pressure and improve cardiometabolic parameters[28]. Additionally, niacin enhances nitric oxide bioavailability and stimulates prostaglandin-mediated vasodilation, mechanisms directly relevant to blood pressure regulation[28]. In our decomposition analysis, the Northwest's 5.9 mg NE/d **dietary** niacin deficit—reflecting lower intakes of niacin-rich foods such as seafood, lean meats, and whole grains—together with carotenoid and vitamin C deficits, explained 40.7% of the hypertriglyceridemia disparity and 81.6% of the hypertension disparity. Notably, a recent nationwide cohort study in China demonstrated that higher dietary riboflavin intake—another B vitamin with vasodilatory properties—was associated with a significantly reduced risk of new-onset hypertension among Chinese adults[29], providing direct domestic evidence that B vitamins contribute to blood pressure regulation in Chinese populations.

Importantly, the Lingnan Dietary Pattern's eight defining features create a nutrient environment uniquely enriched in all three protective factors[4]. The emphasis on "abundant vegetables and fruits" ensures high carotenoid and vitamin C intakes; the recommendation for "adequate aquatic products" provides preformed niacin from seafood; and the preference for "steaming and quick stir-frying" minimizes thermal degradation of these heat-labile vitamins. A 2022 clinical trial of the Guangxi longevity dietary pattern—a regional diet sharing core features with the Lingnan pattern, including high vegetable, fruit, and aquatic product consumption—demonstrated that just two weeks of dietary intervention significantly reduced SBP, DBP, TC, and LDL-C while increasing HDL-C in volunteers with cardiovascular risk[30]. This interventional evidence, derived from a population geographically and culturally similar to our study population, provides strong corroboration that the nutrient triad identified in our decomposition analysis exerts measurable and clinically meaningful cardiometabolic protection when consumed as part of a coherent regional dietary pattern.

A second notable finding concerns the hypertension paradox: despite a **higher energy-adjusted sodium intake** in Lingnan (+179.5 mg/d), the Northwest exhibited a significantly greater hypertension burden (*OR* = 1.11). This paradox is partially resolved by the antioxidant triad identified above—which explained 81.6% of the hypertension gap Additionally, it is plausible that the Lingnan pattern's emphasis on "light and fresh flavors" and "minimal oil and salt" plays a role. **Although the energy-adjusted difference in potassium intake between the two regions was not statistically significant (Table 3), we hypothesize that the higher sodium intake in Lingnan might contribute to a more unfavorable sodium-to-potassium ratio.** Potassium antagonizes sodium's hypertensive effects at the vascular level[31], and a higher ratio could theoretically mitigate what would otherwise be an even larger blood pressure differential[32]. This interpretation aligns with the Lingnan pattern's explicit advocacy for "minimal oil and salt" and "adequate vegetables and fruits" as core principles; **however, direct measurements of the sodium-to-potassium ratio are needed in future studies to test this hypothesis.**

The regional disparity in hyperuricemia—markedly higher in Lingnan (23.8% *vs.* 7.9%)—merits brief acknowledgment, as it represents an area where the Lingnan pattern's benefits are tempered by specific risks. **Our data confirmed** that the pattern's emphasis on "adequate aquatic products" translates into substantially higher seafood intake in Lingnan (Table 2), thereby entailing higher purine exposure. **Although sugar-sweetened beverage intake was not measured in our study, and observed fruit intake was not higher in Lingnan (Table 2), previous literature suggests that** the subtropical climate and regional dietary habits in Lingnan may involve high consumption of sugar-sweetened beverages and fructose-rich sources[33].. Fructose metabolism is known to contribute to uric acid (UA) production through ATP depletion and purine nucleotide degradation pathways. **Therefore, it is plausible that** the combination of measured high purine exposure from seafood and potential high fructose intake—as reported in other regional studies—creates a hyperuricemic milieu that may partially offset the cardiometabolic advantages conferred by the antioxidant-rich diet. We acknowledge that a formal dose-response analysis linking seafood intake to serum UA concentrations was beyond the scope of the current analysis, as our primary focus was on the cardiometabolic protective triad. Future studies with detailed dietary purine and fructose assessment are needed to quantify these relationships. From a public health perspective, these observations suggest that dietary guidance in Lingnan should not advocate unrestricted seafood

consumption but rather encourage the selection of lower-purine aquatic products (e.g., fish with lower purine content) and subtropical fruits, while preserving the pattern's core protective features—abundant vegetables, light cooking methods, and antioxidant-rich foods. Such nuanced guidance would maintain the cardioprotective benefits of the Lingnan Dietary Pattern while mitigating its hyperuricemic risks.

The contrasting regional patterns of dyslipidemia components also warrant discussion. Hypertriglyceridemia was more prevalent in the Northwest, consistent with its high-carbohydrate diet, which promotes hepatic de novo lipogenesis and VLDL secretion[34]. Conversely, hypercholesterolemia and elevated LDL-C were more common in Lingnan, despite its higher intake of vegetables and antioxidants. This seemingly paradoxical finding likely reflects the Lingnan pattern's higher consumption of seafood and organ meats, which are rich in dietary cholesterol. A meta-analysis of controlled feeding studies has shown that dietary cholesterol increases both serum TC and LDL-C in a dose-dependent manner, independent of saturated fat intake[35,36]. In the Lingnan region, frequent intake of shrimp, crab, shellfish, and animal viscera may contribute to elevated serum cholesterol levels, partially offsetting the benefits of its antioxidant-rich diet. Furthermore, genetic factors such as ApoE polymorphisms, which influence cholesterol absorption and metabolism, **are known to modify cardiovascular risk in the Chinese population**[37], **and could** modify individual responses to dietary cholesterol. This differential dietary etiology—where Northwest dyslipidemia is driven primarily by carbohydrate-induced hypertriglyceridemia, while Lingnan dyslipidemia partly reflects cholesterol-induced hypercholesterolemia—underscores the need for region-specific lipid management strategies. This mutual attenuation of opposing lipid trends likely accounts for the borderline *P* value for the composite dyslipidemia outcome (*P* = 0.058).

The comparable diabetes prevalence (*OR* = 0.91, *P* = 0.148) may reflect competing dietary influences: high refined carbohydrate intake in the Northwest versus potential sugar-sweetened beverage consumption in subtropical Lingnan, resulting in similar glycemic outcomes despite divergent overall diets.

These findings have practical implications for region-specific dietary improvement strategies in Northwest China. Rather than simply recommending increased vegetable and aquatic product consumption—which may be constrained by local availability and cultural preferences—our results point to several modifications achievable using local foods:

First, carotenoid intake in the Northwest could be enhanced by promoting locally cultivated carotenoid-rich foods, including carrots, pumpkins, tomatoes, goji berries (wolfberries), and sea buckthorn. Goji berries, in particular, are a traditional food in Ningxia and Xinjiang with exceptionally high zeaxanthin and β-carotene content, and their regular consumption has been associated with improved antioxidant status in Chinese populations.

Second, vitamin C intake could be increased through locally available fruits such as jujube (red dates, widely grown in Shaanxi and Gansu), kiwifruit, and sea buckthorn, all of which contain vitamin C at concentrations several times those in common fruits such as apples. A handful of fresh jujubes (approximately 100 g) can provide over 200 mg of vitamin C, substantially exceeding the daily recommended intake.

Third, niacin intake could be improved by replacing a portion of refined wheat products with buckwheat and oats—traditional coarse grains in Northwest China that are naturally rich in niacin and also provide soluble fiber with established lipid-lowering benefits. Additionally, moderate consumption of lean lamb and dairy products, which are culturally accepted protein sources in the region, can further contribute to niacin intake. These recommendations draw on the existing food resources and culinary traditions of Northwest China, making them more feasible and culturally acceptable than generic advice to increase seafood consumption—a food category with limited availability in this arid region.

The decomposition approach used in this study aligns with a growing body of public health research that applies this methodology to quantify drivers of geographic health disparities. Decomposition analyses have been used to examine rural–urban disparities in healthcare utilization in India, revealing that socioeconomic factors explained approximately 41% of observed differentials[38]; while similar applications have quantified sociodemographic contributions to depression prevalence disparities in southern India[39]. The Blinder–Oaxaca framework has been endorsed as a practical tool for identifying policy levers to reduce health inequalities, given its capacity to partition observed gaps into explained

and unexplained components. Our application extends this analytical tradition to nutritional epidemiology—linking specific nutrient deficits to cardiometabolic risk disparities—and demonstrates the utility of decomposition analysis for identifying actionable targets for dietary intervention across China's diverse regional dietary patterns. Reassuringly, sensitivity analyses using logit models yielded **virtually** identical decomposition results, confirming the robustness of our linear probability model approach in this large sample.

Several limitations should be acknowledged. The cross-sectional design precludes causal inference, and the associations identified through decomposition analysis should be interpreted as quantitative descriptions rather than causal relationships. Dietary assessment *via* 24-hour recalls may not fully capture habitual intake, although three consecutive days help account for day-to-day variation. Regional classifications may obscure within-region variations, as the Northwest grouping covers five provincial-level regions and the Lingnan grouping three, each with internal dietary heterogeneity. However, this macro-regional grouping was based on shared geographic and dietary and cultural characteristics and provides a necessary framework for identifying broad disparities. Data on added salt and cooking oil intake were not separately available, which may limit our ability to characterize fully dietary sodium and fat sources associated with regional cardiometabolic risk differences. Additionally, other dietary confounders such as refined carbohydrates (as distinct from total carbohydrate, which we tested in sensitivity analyses), saturated fat, and added sugars were not incorporated into the decomposition models, which may introduce residual confounding in the estimated attributable fractions. Nutrient intakes were estimated from dietary recall data without validation against blood-based biomarkers, which may introduce measurement error. The Oaxaca–Blinder decomposition assumes additive and independent effects of explanatory variables; potential synergistic interactions among carotenoids, vitamin C, and niacin could not be formally tested within this framework. Future studies integrating both dietary assessment and nutritional biomarkers are warranted to confirm these findings.

Despite these limitations, this study has notable strengths. The large sample size (13,841 participants) provides adequate statistical power. The use of energy-adjusted nutrient residuals accounts for total energy intake. The Oaxaca–Blinder decomposition approach offers a rigorous framework for quantifying the contribution of nutrient differences to regional health disparities, with bootstrap-estimated standard errors and confidence intervals. Importantly, our findings are derived directly from the 2015–2017 CNHS, representing one of China's most nationally representative datasets, and thus constitute direct evidence from Chinese populations, including residents of Northwest China. Methodologically, this study demonstrates the utility of decomposition analysis as a tool for examining the nutritional underpinnings of health disparities across China's diverse regional dietary patterns.

Future randomized controlled trials specifically testing the combined effects of carotenoids, vitamin C, and niacin supplementation on blood pressure and triglyceride levels in Northwest Chinese populations are warranted to confirm the protective triad identified in this observational study.

CONCLUSION

Lower intakes of vegetables, seafood, and their associated micronutrients—particularly carotenoids, vitamin C, and niacin—in the Northwest contribute to its excess burden of hypertension and hypertriglyceridemia relative to Lingnan. More broadly, this study demonstrates how a systematic comparison of food and nutrient intakes across China's regional diets can identify actionable nutritional targets for cardiometabolic risk reduction.

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Authors' Contributions Study design and supervision: Lichen Yang and Gangqiang Ding. Material preparation and data collection: Wenxuan Wu, Yanyang Han, Jie Feng, Xiaoli Xu, Lahong Ju, Ping Gan, Panpan Huang, Jiaqi Li and Rongzhen Li. Data analysis and manuscript writing: Jingxin Yang and Jian Wen. All the authors have read and agreed to the published version of the manuscript.

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