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The associations between dietary minerals, obesity and hypertension in cold region

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Abstract

Objective: This study aimed to compare dietary patterns and nutrient intakes between cold and non-cold regions of China, and to assess the associations between dietary mineral intake and the risks of overweight, obesity, abdominal obesity and hypertension in residents of cold region. **Methods:** A total of 12,190 participants from the China Health and Nutrition Survey were included, of whom 1261 were residents of Heilongjiang province. Dietary intake was assessed using three consecutive 24 h individual dietary recalls. General linear models were applied to compare dietary differences between Heilongjiang and other provinces, and Cox proportional hazard models were used to evaluate the associations between mineral intake and the aforementioned health outcomes among Heilongjiang residents. **Results:** Significant differences were observed in the intake of fruits, vegetables, nuts, whole grains, processed meats, vitamin C, calcium, phosphorus, and magnesium between Heilongjiang and other provinces (all $P < 0.05$). In Heilongjiang residents, higher intakes of phosphorus, iron, and calcium were more strongly associated with lower risks of overweight, obesity, abdominal obesity, and hypertension than potassium or magnesium. The hazard ratios (HRs) and 95% confidence intervals (CIs) across tertiles of calcium, phosphorus and iron intake were as follows: 0.37 (0.28-0.50), 0.37 (0.28-0.49), 0.48 (0.36-0.64) for overweight; 0.53 (0.35-0.79), 0.50 (0.34-0.75), 0.45 (0.30-0.69) for obesity; 0.49 (0.38-0.64), 0.52 (0.40-0.66), 0.59 (0.46-0.77) for abdominal obesity; and 0.42 (0.32-0.54), 0.42 (0.33-0.53), 0.49 (0.38-0.63) for hypertension. **Conclusion:** Distinct dietary patterns exist between cold and other region of China. Adequate intake of phosphorus, iron, calcium, potassium and magnesium consumption may help protect against obesity and hypertension in populations living in cold environments.

Keywords

mineral; obesity; abdominal obesity; hypertension

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1 Introduction

Obesity has increased rapidly worldwide and has been identified by the WHO as a global epidemic. Over the past 50 years, its prevalence has nearly tripled and is projected to reach 18% of adults by 2030[1]. Obesity is a chronic, progressive disease that substantially increases the risk of multiple metabolic disorders, including hypertension[2]. According to the Global Burden of Disease, 3.71 million deaths and 129 million disability-adjusted life-years (DALYs) were attributable to overweight and obesity[3]. Cold exposure exerts various adverse effects on the health. The proportion of individuals with obesity is higher at northern latitudes of the Northern Hemisphere than in southern regions, with the highest proportions observed in the northeast. Hypertension—a globally recognized risk factor for cardiovascular disease and mortality—affects over 30% of adults worldwide[4]. In 2021, an estimated 226 million all-age DALYs were attributable to hypertension, with males accounting for 55.5% (125 million) of these DALYs[5]. In China, obesity and hypertension have become major public health concerns, the prevalences of overweight, obesity, and hypertension are 34.3%, 16.4% and 44.7%, respectively, imposing an enormous burden on the economy and public health systems[6].

Dietary minerals, although required in small amounts, are indispensable for maintaining life[7]. Clinical trials and reviews indicate that numerous minerals play important roles in the pathogenesis

and modulation of obesity and hypertension by inducing essential enzyme systems, regulating fluid and electrolyte balance, and influencing the activity of the renin-angiotensin system[8]. For example, 12 weeks of phosphorus supplementation reduced body weight, Body mass index (BMI), and waist circumference in overweight/obese participants[9]. In the Women's Health Study, higher dietary calcium intake was associated with a 13% reduction in hypertension risk[10]. A meta-analysis of seven randomized controlled trials (RCTs) found that magnesium supplementation reduced systolic blood pressure among patients with type 2 diabetes (T2D)[11].

Geographical differences contribute to distinct dietary habits and food consumption patterns between northern and southern China, which may lead to differential mineral intakes[12]. In northern China, dietary patterns are characterized by carbohydrate-rich and wheat-based staples, alcohol and Western-style foods, and convenience foods; in southern China, patterns are traditional southern, convenience food, wheat, and alcohol[13]. Moreover, residents in northern China are more susceptible to cold exposure, which has been identified as another principal factor influencing obesity and hypertension[14]. Consistent with Bergmann's rule, body size is inversely associated with the mean habitat temperature in polytypic warm-blooded species[15]. In China, the prevalences of overweight, obesity, and hypertension are higher in cold regions than in warmer regions[16]. However, few studies have comprehensively assessed mineral consumption and its associations with obesity and hypertension in cold region of China.

On this basis, the objective of this study was to compare mineral intakes between residents of Heilongjiang province and those of other provinces in China, and to assess the relationships of different minerals with overweight, obesity, abdominal obesity, and hypertension among Heilongjiang residents and those of other provinces in China, and to evaluate the relationships of different minerals with overweight, obesity, abdominal obesity, and hypertension among Heilongjiang residents. This study provides evidence to inform more precise preventive strategies and public health policies for populations.

2 Material and methods

2.1 Study population

The China Health and Nutrition Survey (CHNS) is a longitudinal household survey designed to investigate health and nutritional status in Chinese populations and to reflect how social, economic, and demographic transformations affect these outcomes[17]. The study used a multistage, random-cluster sampling process to select participants from 9 provinces that vary by geography, economic development, and health indicators, and conducted ten survey rounds from 1989 to 2015[18]. Based on the 2010 census, these provinces represented 47% of the Chinese population. Each survey maintained the desired range of sociological, economic, and demographic variables, and new participants were recruited to replenish losses of follow-up beginning in 1997.

The present analysis included adults aged ≥ 18 years who participated in seven survey waves from 1997 to 2015. By the end of 2015, 32,752 participants had completed the CHNS. We excluded 6817 participants who were < 18 years old at their first survey; 6817 participants who were less than 18 years old in the first survey; 8674 who took part in fewer than two waves; 4751 who lacked dietary information; 257 with implausible energy intake (< 500 kcal/day or > 5000 kcal/day); and 63 who were pregnant during follow-up. A total of 12,190 participants from across China were retained, of whom 1261 were residents of Heilongjiang province. For the four disease- specific cohorts among Heilongjiang residents, after excluding those with the respective baseline conditions (overweight, obesity, abdominal obesity, or hypertension), 895, 1173, 911, and 1047 participants were included in the final analytic samples, respectively.

The CHNS was conducted in accordance with the Declaration of Helsinki. Survey protocols, instruments, and informed-consent procedure were approved by the Institutional Review Committees of the University of North Carolina at Chapel Hill, NC, USA, and the China National Institute of Nutrition and Food Safety at the Chinese Center for Disease Control and Prevention (Beijing, China) (2015024). All participants provided written informed consent prior to the surveys.

2.2 Questionnaire survey

Trained interviewers administered structured, in-person questionnaires to collect demographic characteristics, dietary habits, lifestyle factors, medical history, and anthropometric information[19]. Dietary mineral intake was assessed using the combination of three consecutive 24 h individual dietary recalls and a household food-weighing inventory over the same three-day period. The three consecutive days were randomly allocated from Monday to Sunday and were approximately balanced across the week within each sampling unit. Individuals reported all foods and beverages consumed at and away from home during each 24 h period. At the household level, interviewers estimated consumption of cooking oils and condiments from the household inventory and apportioned amounts to individuals according to each family member's share, thereby improving individual-level estimates. The validity of the 24 h recall method for assessing energy and nutrient intakes has been documented, and combining individual- and household-level data further improves accuracy; this approach has been widely applied in previous studies[20-21]. Detailed dietary data collection procedures are described elsewhere[22].

Mineral intakes were expressed as energy density, defined as nutrient intake divided by total energy intake[23]. Current smoking was ascertained by the question, "Do you still smoke cigarettes or a pipe?" Alcohol consumption was assessed with the question, "During the past year, what was your consumption (frequency and quantity) of beer, liquor and wine?" Physical activity level (PAL) was defined as the combination of occupational and domestic activities, as previously reported, and total metabolic equivalents (METs) were calculated as MET-hours per week.

2.3 Anthropometric measurements and case ascertainment

At each survey, height was measured without shoes to the nearest 0.1 cm using a portable SECA stadiometer (SECA, Hamburg, Germany). Weight was measured without shoes and in light clothing to the nearest 0.1 kg using a calibrated beam scale. BMI was calculated as weight (kg) divided by the square of the height in meters (m^2). Waist circumference was measured at the midpoint between the lowest rib and the iliac crest in the horizontal plane using a non-elastic tape. Waist-to-hip ratio (WHR) was calculated as waist (cm) divided by hip (cm). All measurements were performed by trained examiners following World Health Organization (WHO) standard protocols, at the same locations and with the same procedures at each visit. Overweight, obesity, and abdominal obesity were defined according to the Working Group on Obesity in China (WGOC): overweight, BMI ≥ 25 kg/m^2; obesity, BMI ≥ 28 kg/m^2; abdominal obesity, waist ≥ 85 cm for men and ≥ 80 cm for women[24].

At each follow-up, trained staff measured blood pressure using a standard protocol. After a 10-minute seated rest, systolic blood pressures (SBP) and diastolic blood pressures (DBP) were measured three times on the right arm with a mercury sphygmomanometer; the mean of the three readings was used. Hypertension was defined as average SBP ≥ 140 mmHg or DBP ≥ 90 mmHg, self-reported physician-diagnosed hypertension, or current use of antihypertensive medication.

2.4 Statistical analysis

General linear models were used to compare differences in food and nutrient intakes between Heilongjiang and other provinces, adjusting for age, sex, WHR, smoking status, drinking status, physical activity, individual income, urban/rural residence, education level, urbanization index, and total energy intake.

Cox proportional hazards models were used to estimate associations between minerals intake and the risk of overweight, obesity, abdominal obesity, and hypertension, with age as the time scale. Time at entry was age at the beginning of follow-up; exit time was age at first diagnosis of the outcome of interest, loss to follow-up, or censoring at the end of follow-up, whichever occurred first. Model 1 adjusted for age; Model 2 additionally adjusted for sex, WHR, smoking status, drinking status, physical activity; Model 3 further adjusted for individual income, urban/rural residence, education level, urbanization index, and energy intake. Multiple imputation was used for missing covariate data.

All analyses were performed using IBM SPSS 25.0 Statistics (Chicago, USA), version 25.0. Statistical significance was set at two-sided $P < 0.05$.

3 Results

3.1 Baseline characteristics of participants

Table 1 presents baseline characteristics for participants with and without obesity and hypertension. At baseline in Heilongjiang Province, 14.1% had obesity and 46.1% had hypertension. In the obesity-related cohort, participants with obesity had lower income and lower proportions of women and urban residents than those without obesity. In the hypertension-related cohort, participants with hypertension were older; more likely to drink alcohol and smoke; and had higher BMI and waist circumference than normotensive participants.

3.2 Food and nutrients intake for in Heilongjiang and other provinces

Table 2 compares food and nutrient intakes between residents of Heilongjiang and other province of China. For food groups, residents of Heilongjiang consumed more eggs, rice, potatoes, beans, fruits, nuts, whole grains, and processed meats than residents of other provinces ($P < 0.05$). Conversely, intakes of fish, vegetable, red meat, and white meat were lower in Heilongjiang (all $P < 0.05$).

For macronutrient, the mean ± standard deviation (SD) of protein intake was 83.2 ± 19.8 g/day in Heilongjiang versus 87.3 ± 22.3 g/day f elsewhere; mean fat intake was 40.8 ± 17.5 g/day versus 47.6 ± 20.4 g/day; for other provinces. and mean carbohydrate intake was 406.5 ± 94.4 g/day versus 369.7 ± 90.5 g/day. Moreover, residents of Heilongjiang consumed more cholesterol and less saturated fatty acid, monounsaturated fatty acid, polyunsaturated fatty acids than those in other provinces.

For micronutrients, intakes of vitamin A, vitamin C, calcium, phosphorus, potassium, magnesium, and selenium were higher in Heilongjiang (all $P < 0.05$), whereas vitamin E, sodium, iron, zinc, and manganese intakes were lower (all $P < 0.05$). No significant differences were observed for vitamin D ($P = 0.34$) or copper ($P = 0.97$).

Table 1 Baseline characteristics of variables in obesity and hypertension patients and controls

Baseline variable	Obesity		Hypertension	
	No (*N* = 1008)	Yes (*N* = 165)	No (*N* = 564)	Yes (*N* = 483)
Age (years)	39.8 ± 13.7	38.2 ± 12.0	33.5 ± 11.9	39.7 ± 12.6
Female	549 (51.5)	82 (49.7)	333 (59.0)	224 (46.4)
BMI (kg/m^2)	22.3 ± 2.4	24.7 ± 2.2	22.1 ± 2.6	23.1 ± 2.8
Waist (cm)	77.8 ± 8.0)	84.1 ± 8.6	76.6 ± 7.8	79.7 ± 8.7
WHR	0.83 ± 0.07	0.86 ± 0.06	0.83 ± 0.07	0.84 ± 0.07
PAL (MET-h /week)	274.4 ± 189.6	277.9 ± 150.9	302.0 ± 309.9	256.4 ± 164.4
Systolic pressure (mmHg)	121.2 ± 16.0	121.1 ± 14.2	114.0 ± 9.5	117.2 ± 8.7
Diastolic pressure (mmHg)	80.4 ± 10.8	81.5 ± 11.5	75.6 ± 6.9	77.1 ± 6.8
Income (yuan)	7329.3 ± 10214.3	6969.2 ± 6998.9	7939.4 ± 11977.7	6909.6 ± 9803.4
Energy intake (kcal/day)	2187.6 ± 720.5	2362.4 ± 810.7	2267.4 ± 738.1	2182.5 ± 734.4
Calcium intake (mg/day)	628.7 ± 232.9	624.1 ± 280.9	641.3 ± 257.4	560.3 ± 229.1
Phosphorus intake (mg/day)	1147.1 ± 319.3	1152.5 ± 341.6	1159.2 ± 341.6	1038.5 ± 309.5
Potassium intake (mg/day)	2088.5 ± 592.2	2151.6 ± 739.0	2113.9 ± 626.5	1964.9 ± 630.5
Sodium intake (mg/day)	805.8 ± 601.4	808.2 ± 481.4	799.1 ± 387.7	714.5 ± 424.4
Magnesium intake (mg/day)	390.1 ± 109.0	393.9 ± 115.7	390.8 ± 118.5	361.1 ± 106.0
Iron intake (mg/day)	33.2 ± 10.2	33.6 ± 12.9	33.2 ± 10.9	29.7 ± 9.9
Zinc intake (mg/day)	14.5 ± 4.2	15.6 ± 5.3	14.7 ± 4.4	14.2 ± 4.7
Selenium intake (μg/day)	63.2 ± 21.8	70.0 ± 26.4	64.9 ± 23.6	65.9 ± 24.0
Copper intake (mg/day)	3.4 ± 1.2	3.6 ± 1.4	3.5 ± 1.4	3.2 ± 1.1
Manganese intake (mg/day)	8.9 ± 2.4	9.2 ± 2.8	8.9 ± 2.4	8.4 ± 2.4
Living in city	333 (33.3)	60 (36.4)	200 (35.5)	146 (30.2)
Urban index	52.7 ± 22.9	55.0 ± 23.5	55.1 ± 22.6	50.8 ± 20.1
Smoking	358 (35.5)	56 (33.9)	145 (25.7)	190 (39.3)
Drinking	408 (40.5)	67 (40.6)	180 (31.9)	209 (43.3)
High school education	265 (26.2)	45 (27.3)	180 (32.0)	111 (23.1)

BMI, body mass index; WHR, waist-hip ratio; PAL, physical activity level. Continuous variables were presented as mean ± standard deviation, category variables are presented as *N* (%).

3.3 Associations between dietary mineral intake, overweight and obesity

During follow-up, 399 incident cases of overweight were identified. As shown in Table 3, phosphorus and iron displayed the strongest inverse associations with overweight risk; the hazard ratios (HRs) for the highest versus lowest tertile were 0.37 (95% *CI* 0.28-0.50) and 0.37 (0.28-0.49), respectively. Calcium, potassium, and magnesium were also inversely associated with overweight, with corresponding HRs of 0.48 (0.36-0.64), 0.71 (0.55-0.92), and 0.57 (0.43-0.75). No significant associations were observed for zinc, sodium, copper, selenium, or manganese.

A total of incident 165 obesity cases occurred during follow-up. In the obesity-related cohort (Table 4), the inverse associations were strongest for calcium (HR across extreme tertiles: 0.45, 95% *CI* 0.30-0.69) and iron (HR 0.50, 95% *CI* 0.34-0.75), followed by phosphorus (HR 0.53, 95% *CI* 0.35-0.79), magnesium (HR 0.54, 95% *CI* 0.36-0.81), and potassium (HR 0.61, 95% *CI* 0.42-0.90).

3.4 Associations between dietary mineral intake and abdominal obesity

There were 471 incident cases of abdominal obesity during follow-up. Table 5 shows HRs (95% CIs) across tertiles of mineral intake. Phosphorus (0.49 [0.38-0.64]) and iron (0.52 [0.40-0.66]) were more strongly inversely associated with abdominal obesity than calcium (0.59 [0.46-0.77]), potassium (0.61 [0.48-0.78]), magnesium (0.60 [0.46-0.77]), and copper (0.67 [0.52-0.85]). No significant associations were detected for zinc, sodium, selenium, or manganese.

3.5 Associations between dietary mineral intake and hypertension

A total of 483 incident hypertension cases were identified. In the hypertension-related cohort (Table 6), calcium, phosphorus, potassium, magnesium, and iron each showed inverse associations of similar magnitude with hypertension risk; HRs (95% CIs) for the highest versus lowest tertiles were 0.49 (0.38-0.63), 0.42 (0.32-0.54), 0.51 (0.40-0.65), 0.49 (0.38-0.63), and 0.42 (0.33-0.53), respectively. In contrast, participants in the highest tertile of

Table 2 Food and nutrients intake of the participants in Heilongjiang and other provinces of China

Food and nutrients	Heilongjiang (*N* = 1261)	Others (*N* = 10929)	*P* value
Egg (g/day)	30.4 ± 21.2	22.1 ± 21.8	0.035
Rice (g/day)	204.8 ± 82.1	204.0 ± 135.4	< 0.001
Fish (g/day)	21.8 ± 26.0	32.0 ± 44.6	< 0.001
Potato (g/day)	79.2 ± 51.8	24.1 ± 34.7	< 0.001
Bean (g/day)	63.7 ± 41.2	24.2 ± 31.7	< 0.001
Fruit (g/day)	80.3 ± 88.5	32.6 ± 56.7	< 0.001
Vegetable (g/day)	237.7 ± 174.5	342.8 ± 193.8	< 0.001
Nut (g/day)	65.9 ± 41.2	27.3 ± 33.3	< 0.001
Whole grain (g/day)	25.5 ± 37.9	14.5 ± 31.1	< 0.001
Red meat (g/day)	49.4 ± 30.5	70.4 ± 65.5	< 0.001
White meat (g/day)	52.8 ± 24.0	60.0 ± 37.4	< 0.001
Poultry (g/day)	5.01 ± 11.9	10.9 ± 19.3	< 0.001
Processed meat (g/day)	4.6 ± 12.9	4.4 ± 11.5	< 0.001
Energy (kcal/day)	2310.0 ± 495.5	2251.4 ± 501.6	0.860
Protein (g/day)	83.2 ± 19.8	87.3 ± 22.3	< 0.001
Fat (g/day)	40.8 ± 17.5	47.6 ± 20.4	< 0.001
Carbohydrate (g/day)	406.5 ± 94.4	369.7 ± 90.5	< 0.001
Dietary fiber (g/day)	20.9 ± 8.5	19.5 ± 8.7	0.012
Saturated fatty acid (g/day)	13.3 ± 7.3	14.8 ± 8.0	< 0.001
Monounsaturated fatty acid (g/day)	16.1 ± 7.0	20.0 ± 8.5	< 0.001
Polyunsaturated fatty acids (g/day)	11.8 ± 4.4	12.1 ± 5.2	< 0.001
Cholesterol (mg/day)	430.9 ± 245.5	387.8 ± 309.6	< 0.001
Vitamin A (μg/day)	972.3 ± 318.2	934.1 ± 389.2	< 0.001
Vitamin C (mg/day)	137.2 ± 58.8	95.6 ± 48.9	< 0.001
Vitamin D (mg/day)	41.9 ± 109.5	38.8 ± 119.9	0.340
Vitamin E (mg/day)	16.4 ± 7.5	18.8 ± 9.6	< 0.001
Calcium (mg/day)	646.3 ± 186.4	636.9 ± 230.9	< 0.001
Phosphorus (mg/day)	1177.9 ± 261.6	1160.7 ± 293.4	< 0.001
Potassium (mg/day)	2140.4 ± 498.3	2061.3 ± 542.7	0.020
Sodium (mg/day)	811.9 ± 409.9	1052.0 ± 563.2	< 0.001
Magnesium (mg/day)	399.3 ± 88.2	378.1 ± 99.6	< 0.001
Iron (mg/day)	34.5 ± 8.6	35.6 ± 10.3	< 0.001
Zinc (mg/day)	14.6 ± 3.4	15.5 ± 4.1	< 0.001
Selenium (μg/day)	62.2 ± 17.0	61.4 ± 22.5	< 0.001
Copper (mg/day)	3.5 ± 0.9	3.2 ± 0.9	0.970
Manganese (mg/day)	9.1 ± 2.0	9.4 ± 4.4	< 0.001

Variables were presented as mean ± standard deviation (SD). General linear model was adjusted for age, sex, WHR, smoking status, drinking status, physical activity, individual income, urban or rural residence, education level, urbanization index and energy intake.

Table 3 Hazard ratio (95% CIs) for overweight risk by tertiles of mineral intake in participants from Heilongjiang province

Mineral	Tertiles of mineral consumption			*P* for trend
	T1	T2	T3	
Calcium				
Model 1	1	0.49 (0.38-0.64)	0.57 (0.44-0.73)	< 0.001
Model 2	1	0.49 (0.38-0.64)	0.57 (0.44-0.73)	< 0.001
Model 3	1	0.45 (0.35-0.59)	0.48 (0.36-0.64)	< 0.001
Phosphorus				
Model 1	1	0.48 (0.38-0.62)	0.48 (0.37-0.62)	< 0.001
Model 2	1	0.50 (0.38-0.64)	0.44 (0.34-0.58)	< 0.001
Model 3	1	0.47 (0.36-0.60)	0.37 (0.28-0.50)	< 0.001
Potassium				
Model 1	1	0.55 (0.42-0.71)	0.71 (0.56-0.91)	0.012
Model 2	1	0.55 (0.42-0.72)	0.72 (0.56-0.92)	0.016
Model 3	1	0.54 (0.41-0.71)	0.71 (0.55-0.92)	0.016
Sodium				
Model 1	1	0.79 (0.62-1.02)	0.86 (0.67-1.11)	0.250
Model 2	1	0.70 (0.54-0.90)	0.78 (0.60-1.00)	0.050
Model 3	1	0.68 (0.52-0.89)	0.79 (0.62-1.03)	0.050
Magnesium				
Model 1	1	0.65 (0.50-0.83)	0.55 (0.42-0.71)	< 0.001
Model 2	1	0.68 (0.53-0.87)	0.58 (0.44-0.75)	< 0.001
Model 3	1	0.66 (0.51-0.86)	0.57 (0.43-0.75)	< 0.001
Iron				
Model 1	1	0.45 (0.35-0.58)	0.42 (0.32-0.54)	< 0.001
Model 2	1	0.44 (0.34-0.56)	0.40 (0.31-0.52)	< 0.001
Model 3	1	0.40 (0.30-0.51)	0.37 (0.28-0.49)	< 0.001
Zinc				
Model 1	1	0.76 (0.59-0.99)	1.17 (0.91-1.50)	0.180
Model 2	1	0.73 (0.56-0.96)	1.06 (0.83-1.37)	0.550
Model 3	1	0.72 (0.55-0.94)	1.04 (0.79-1.36)	0.760
Selenium				
Model 1	1	0.82 (0.63-1.08)	1.48 (1.05-2.03)	0.008
Model 2	1	0.82 (0.62-1.08)	1.68 (1.00-1.87)	0.011
Model 3	1	0.83 (0.63-1.10)	1.53 (0.98-2.20)	0.021
Copper				
Model 1	1	0.77 (0.59-0.99)	0.84 (0.65-1.08)	0.190
Model 2	1	0.81 (0.62-1.04)	0.82 (0.63-1.06)	0.140
Model 3	1	0.80 (0.62-1.04)	0.80 (0.61-1.03)	0.090
Manganese				
Model 1	1	0.82 (0.64-1.05)	0.75 (0.58-0.97)	0.030
Model 2	1	0.85 (0.66-1.10)	0.78 (0.60-1.01)	0.060
Model 3	1	0.88 (0.68-1.15)	0.77 (0.58-1.02)	0.070

CI, confidence interval. Model 1 was adjusted for age. Model 2 was further adjusted for sex, waist-hip ratio, smoking status, drinking status, physical activity. Model 3 was additionally adjusted for individual income, urban or rural residence, education level, urbanization index and energy intake.

sodium intake had a higher risk of hypertension than those in the lowest tertile (HR 1.54 [95% *CI* 1.17-2.03]; *P* for trend = 0.002).

4 Discussion

In this study, we compared dietary intake between inhabitants of cold regions of China and those in other regions and investigated the associations between mineral intake and risks of overweight, obesity, abdominal obesity, and hyper-

Table 4 Hazard ratio (95% CIs) for obesity risk by tertiles of mineral intake in participants from Heilongjiang province

Mineral	Tertiles of mineral consumption			*P* for trend
	T1	T2	T3	
Calcium				
Model 1	1	0.38 (0.26-0.57)	0.57 (0.40-0.83)	< 0.001
Model 2	1	0.36 (0.24-0.53)	0.50 (0.34-0.73)	< 0.001
Model 3	1	0.35 (0.24-0.53)	0.45 (0.30-0.69)	< 0.001
Phosphorus				
Model 1	1	0.38 (0.25-0.57)	0.72 (0.50-1.03)	0.040
Model 2	1	0.33 (0.22-0.49)	0.55 (0.38-0.80)	0.001
Model 3	1	0.30 (0.20-0.46)	0.53 (0.35-0.79)	0.001
Potassium				
Model 1	1	0.46 (0.31-0.68)	0.61 (0.42-0.87)	0.007
Model 2	1	0.47 (0.32-0.70)	0.59 (0.41-0.85)	0.005
Model 3	1	0.49 (0.33-0.72)	0.61 (0.42-0.90)	0.011
Sodium				
Model 1	1	0.68 (0.47-0.98)	0.84 (0.58-1.22)	0.320
Model 2	1	0.56 (0.38-0.82)	0.71 (0.49-1.04)	0.070
Model 3	1	0.55 (0.37-0.81)	0.67 (0.46-1.02)	0.060
Magnesium				
Model 1	1	0.52 (0.35-0.75)	0.59 (0.40-0.85)	0.040
Model 2	1	0.49 (0.33-0.71)	0.50 (0.34-0.74)	< 0.001
Model 3	1	0.50 (0.34-0.74)	0.54 (0.36-0.81)	0.003
Iron				
Model 1	1	0.47 (0.32-0.70)	0.59 (0.41-0.86)	0.005
Model 2	1	0.45 (0.30-0.66)	0.49 (0.34-0.72)	< 0.001
Model 3	1	0.44 (0.30-0.66)	0.50 (0.34-0.75)	0.001
Zinc				
Model 1	1	0.95 (0.65-1.40)	1.27 (0.87-1.85)	0.190
Model 2	1	0.84 (0.57-1.24)	1.13 (0.77-1.66)	0.480
Model 3	1	0.81 (0.54-1.21)	1.06 (0.70-1.61)	0.730
Selenium				
Model 1	1	0.83 (0.56-1.24)	1.46 (1.01-2.11)	0.035
Model 2	1	0.82 (0.55-1.23)	1.43 (0.99-2.08)	0.043
Model 3	1	0.87 (0.57-1.31)	1.40 (0.95-2.06)	0.070
Copper				
Model 1	1	0.60 (0.41-0.89)	0.87 (0.60-1.25)	0.480
Model 2	1	0.55 (0.37-0.81)	0.74 (0.51-1.07)	0.130
Model 3	1	0.56 (0.38-0.83)	0.71 (0.48-1.04)	0.100
Manganese				
Model 1	1	0.96 (0.67-1.39)	0.84 (0.57-1.24)	0.380
Model 2	1	0.92 (0.63-1.33)	0.75 (0.51-1.12)	0.170
Model 3	1	0.97 (0.66-1.42)	0.82 (0.54-1.26)	0.380

CI, confidence interval. Model 1 was adjusted for age. Model 2 was further adjusted for sex, waist-hip ratio, smoking status, drinking status, physical activity. Model 3 was additionally adjusted for individual income, urban or rural residence, education level, urbanization index and energy intake.

Table 5 Hazard ratio (95% CIs) for abdominal obesity risk by tertiles of mineral intake in participants from Heilongjiang province

Mineral	Tertiles of mineral consumption			*P* for trend
	T1	T2	T3	
Calcium				
Model 1	1	0.64 (0.51-0.81)	0.74 (0.58-0.94)	0.013
Model 2	1	0.61 (0.48-0.78)	0.69 (0.54-0.87)	0.002
Model 3	1	0.57 (0.45-0.73)	0.59 (0.46-0.77)	< 0.001
Phosphorus				
Model 1	1	0.54 (0.43-0.69)	0.61 (0.48-0.78)	< 0.001
Model 2	1	0.55 (0.43-0.70)	0.57 (0.44-0.72)	< 0.001
Model 3	1	0.52 (0.40-0.66)	0.49 (0.38-0.64)	< 0.001
Potassium				
Model 1	1	0.66 (0.52-0.83)	0.64 (0.51-0.82)	< 0.001
Model 2	1	0.65 (0.51-0.82)	0.61 (0.48-0.77)	< 0.001
Model 3	1	0.65 (0.51-0.83)	0.61 (0.48-0.78)	< 0.001
Sodium				
Model 1	1	0.94 (0.74-1.19)	0.98 (0.77-1.25)	0.900
Model 2	1	0.87 (0.68-1.10)	0.86 (0.67-1.10)	0.200
Model 3	1	0.77 (0.60-0.99)	0.67 (0.51-0.88)	0.005
Magnesium				
Model 1	1	0.59 (0.47-0.75)	0.55 (0.43-0.70)	< 0.001
Model 2	1	0.60 (0.48-0.77)	0.55 (0.43-0.70)	< 0.001
Model 3	1	0.63 (0.49-0.81)	0.60 (0.46-0.77)	< 0.001
Iron				
Model 1	1	0.56 (0.44-0.71)	0.57 (0.45-0.72)	< 0.001
Model 2	1	0.53 (0.42-0.68)	0.54 (0.42-0.68)	< 0.001
Model 3	1	0.51 (0.40-0.66)	0.52 (0.40-0.66)	< 0.001
Zinc				
Model 1	1	0.84 (0.66-1.07)	1.18 (0.93-1.49)	0.180
Model 2	1	0.80 (0.63-1.02)	1.05 (0.82-1.33)	0.680
Model 3	1	0.71 (0.55-0.92)	0.89 (0.69-1.16)	0.440
Selenium				
Model 1	1	0.83 (0.65-1.07)	1.55 (1.22-1.96)	< 0.001
Model 2	1	0.82 (0.64-1.06)	1.41 (1.11-1.79)	0.005
Model 3	1	0.80 (0.62-1.04)	1.28 (0.93-1.68)	0.060
Copper				
Model 1	1	0.85 (0.67-1.08)	0.73 (0.57-0.92)	0.009
Model 2	1	0.83 (0.66-1.06)	0.69 (0.55-0.88)	0.003
Model 3	1	0.83 (0.65-1.05)	0.67 (0.52-0.85)	0.001
Manganese				
Model 1	1	0.70 (0.55-0.89)	0.70 (0.55-0.89)	0.004
Model 2	1	0.71 (0.56-0.90)	0.70 (0.55-0.89)	0.004
Model 3	1	0.80 (0.62-1.04)	0.82 (0.63-1.06)	0.150

CI, confidence interval. Model 1 was adjusted for age. Model 2 was further adjusted for sex, waist-hip ratio, smoking status, drinking status, physical activity. Model 3 was additionally adjusted for individual income, urban or rural residence, education level, urbanization index and energy intake.

Table 6 Hazard ratio (95% CIs) for hypertension risk by tertiles of mineral intake in participants from Heilongjiang province

Mineral	Tertiles of mineral consumption			*P* for trend
	T1	T2	T3	
Calcium				
Model 1	1	0.54 (0.43-0.68)	0.51 (0.40-0.66)	< 0.001
Model 2	1	0.58 (0.46-0.73)	0.50 (0.39-0.64)	< 0.001
Model 3	1	0.57 (0.45-0.72)	0.49 (0.38-0.63)	< 0.001
Phosphorus				
Model 1	1	0.60 (0.48-0.75)	0.46 (0.36-0.59)	< 0.001
Model 2	1	0.58 (0.46-0.72)	0.45 (0.35-0.57)	< 0.001
Model 3	1	0.56 (0.44-0.70)	0.42 (0.32-0.54)	< 0.001
Potassium				
Model 1	1	0.69 (0.55-0.87)	0.54 (0.43-0.69)	< 0.001
Model 2	1	0.68 (0.54-0.86)	0.51 (0.40-0.66)	< 0.001
Model 3	1	0.67 (0.53-0.84)	0.51 (0.40-0.65)	< 0.001
Sodium				
Model 1	1	1.01 (0.80-1.29)	1.33 (1.05-1.68)	0.012
Model 2	1	1.05 (0.83-1.34)	1.41 (1.11-1.80)	0.003
Model 3	1	1.15 (0.89-1.49)	1.54 (1.17-2.03)	0.002
Magnesium				
Model 1	1	0.58 (0.46-0.72)	0.52 (0.41-0.66)	< 0.001
Model 2	1	0.56 (0.44-0.70)	0.51 (0.40-0.65)	< 0.001
Model 3	1	0.52 (0.41-0.66)	0.49 (0.38-0.63)	< 0.001
Iron				
Model 1	1	0.48 (0.38-0.60)	0.43 (0.34-0.54)	< 0.001
Model 2	1	0.49 (0.38-0.61)	0.42 (0.33-0.53)	< 0.001
Model 3	1	0.47 (0.37-0.60)	0.42 (0.33-0.53)	< 0.001
Zinc				
Model 1	1	0.71 (0.56-0.90)	1.02 (0.81-1.27)	0.820
Model 2	1	0.68 (0.53-0.86)	0.94 (0.74-1.18)	0.620
Model 3	1	0.70 (0.55-0.89)	0.95 (0.74-1.22)	0.710
Selenium				
Model 1	1	0.82 (0.64-1.05)	1.42 (1.07-1.86)	< 0.001
Model 2	1	0.79 (0.61-1.01)	1.25 (0.93-1.66)	0.480
Model 3	1	0.78 (0.61-1.00)	1.21 (0.89-1.61)	0.600
Copper				
Model 1	1	0.69 (0.55-0.88)	0.74 (0.58-0.93)	0.012
Model 2	1	0.67 (0.53-0.85)	0.70 (0.55-0.89)	0.004
Model 3	1	0.67 (0.53-0.85)	0.72 (0.57-0.92)	0.010
Manganese				
Model 1	1	0.81 (0.64-1.02)	0.87 (0.69-1.09)	0.270
Model 2	1	0.79 (0.62-1.00)	0.84 (0.67-1.06)	0.190
Model 3	1	0.74 (0.57-0.94)	0.79 (0.62-1.02)	0.110

CI, confidence interval. Model 1 was adjusted for age. Model 2 was further adjusted for sex, waist-hip ratio, smoking status, drinking status, physical activity. Model 3 was additionally adjusted for individual income, urban or rural residence, education level, urbanization index and energy intake.

tension. Participants in cold regions consumed more eggs, rice, potatoes, beans, nuts, whole grains, processed meats, carbohydrates, cholesterol, vitamin A, calcium, phosphorus, potassium, magnesium, and selenium, but less vegetables, white meat, vitamin E, sodium, zinc, manganese than participants from other regions. Furthermore, in cold regions, phosphorus and iron exhibited stronger inverse associations with overweight, abdominal obesity, and hypertension than did calcium, potassium, and magnesium.

China spans five geographical time zones and encompasses diverse climates and terrains[25]. Owing to long-standing geographical and cultural differences, regional dietary discrepancies have been documented across China[13]. In the Chinese Health and Nutrition Survey, geographical distribution significantly influenced dietary characteristics. Delimited by the Qinling Mountains-Huaihe River line, distinct dietary patterns have been observed between northern and southern China: residents in the north consume more wheat, tubers, eggs, and liquor, whereas those in the south consume more rice, vegetables, meat, poultry, and fish[26]. Our study extends this literature by focusing on differences between cold and non-cold regions, using Heilongjiang Province as a representative cold region. The findings are partially consistent with prior work and reinforce the notion that climate and culture contribute to dietary variation.

Obesity and hypertension remain major public health challenges in China, particularly in northern regions[27]. Diet is a well-established determinant of both conditions. As key dietary components, minerals participate in molecular pathways governing cellular growth, development, and signaling networks that are closely related to obesity and hypertension[28]. In our analysis, phosphorus, iron, and calcium displayed stronger protective associations with overweight, obesity, and abdominal obesity than potassium, magnesium, and copper. Phosphorus is essential for the utilization of carbohydrates, proteins, and lipids and may aid weight management. In C57BL/6J mice, a high-phosphorus diet (1.20% phosphorus) for 6 weeks improved skeletal muscle lipid metabolism and reduced body and liver weights compared with an adequate-phosphorus diet (0.30% phosphorus), consistent with other studies[26,29-30]. In overweight/obese adults, a randomized controlled trial showed that 12 weeks of phosphorus supplementation improved weight outcomes and subjective appetite scores[9]. Mechanistically, low dietary phosphorus can reduce hepatic ATP production and increase appetite; phosphorus deficiency may also lower hemoglobin oxygen affinity, potentially reducing capacity for physical activity and thus increasing obesity risk[31]. Observational data suggest that low iron intake is associated with higher obesity risk in children, independent of energy intake. In C57BL/6 mice, dietary iron deficiency disrupts iron balance in inguinal adipose tissue, impairs adaptive thermogenesis, and exacerbates diet-in-

duced weight gain[32]. Regarding calcium, animal experiments indicate that low-calcium diets are associated with higher body weight, greater fat pad mass, and larger adipocytes, effects that can be mitigated by calcium supplementation[33]. Population-based studies have reported lower prevalences of overweight/obesity with higher calcium intake; low-calcium diets inhibit lipolysis, stimulate lipogenesis, and promote lipid accumulation, whereas higher calcium intake may reverse these processes[34].

For hypertension, we observed inverse associations of dietary calcium, phosphorus, potassium, magnesium, and iron with hypertension risk in cold regions. A meta-analysis of 42 clinical trials found that increasing calcium intake significantly reduced blood pressure[35-36]. Calcium may modulate 1,25-dihydroxyvitamin D, thereby influencing intracellular calcium in vascular smooth muscles cells and adipocytes; calcium intake has also been shown to attenuate salt sensitivity, particularly in hypertensive individuals[37]. Modest increases in phosphorus intake have been linked to lower hypertension risk[38]. Phosphorus contributes to plasma membrane structure, energy production and storage, enzyme activation, and second-messenger systems, all of which may influence blood pressure regulation[38]. Numerous epidemiological studies have reported inverse associations between dietary magnesium and blood pressure; magnesium may compete with sodium at vascular smooth muscle binding sites and increase precursors of prostaglandin E, promoting vasodilation and blood pressure reduction[28]. Prospective cohort data indicate that highest iron quartile intake is associated with a 26% (95% *CI* 13%-33%) reduction in hypertension risk in men and a 15% (95% *CI* 3%-26%) decrease women[39]. Experimental evidence suggests that maternal iron deficiency adversely affects offspring blood pressure regulation, potentially *via* upregulation of the vasoconstrictor endothelin-1 in vascular smooth muscle[40-41]. Additionally, a meta-analysis of 22 randomized controlled trials and 11 cohort studies reported that higher dietary potassium consumption benefits blood pressure control[42].

This study has several strengths, including its prospective design and reasonably long follow-up. Nonetheless, limitations should be acknowledged. First, self-reported dietary assessments are subject to measurement error. Second, detailed information on mineral supplement use was unavailable, potentially biasing intake estimates. Third, as an observational study, reverse causality cannot be fully excluded; well-designed intervention trials are needed. Finally, our participants were drawn from the CHNS in China; generalizability to other ethnicities and populations requires further study.

5 Conclusion

In conclusion, we identified differences in food and nutrients intake between residents of cold and other regions of China and found that higher intakes of phosphorus, iron, calcium, potassium, and magnesium were associated with lower risks of overweight, obesity, abdominal obesity, and hypertension in cold regions. These findings support the development of region-specific dietary recommendations to prevent obesity, abdominal obesity, and hypertension among populations living in cold climates.

Acknowledgements

Not applicable.

Research ethics

This study was approved by the Institutional Review Committees of the University of North Carolina at Chapel Hill and the China National Institute of Nutrition and Food Safety at the Chinese Center for Disease Control and Prevention (2015024).

Informed consent

Written informed consent was obtained from all participants.

Author contributions

Wang C and Wang W Q conceived and designed the study. Sun H Y and Zhou R performed the statistical analyses. Wang W Q and Li L drafted the initial version of the manuscript, and all authors contributed to revising and refining the content. All authors had full access to the data, approved the final version of the manuscript, and agreed to its submission for publication.

Use of large language models, AI and machine learning tools

No large language models, AI or machine learning tool was used for any part of the present study.

Conflicts of Interests

All authors did not have any competing interest to declare.

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Data availability

Data described in the manuscript will be made publicly and freely available at https://www.cpc.unc.edu/projects/china/.

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