

Time trends in dietary Zn intake and occurrence of dietary Zn inadequacy among Chinese adults: data from the China Health and Nutrition Surveys between 2004 and 2011

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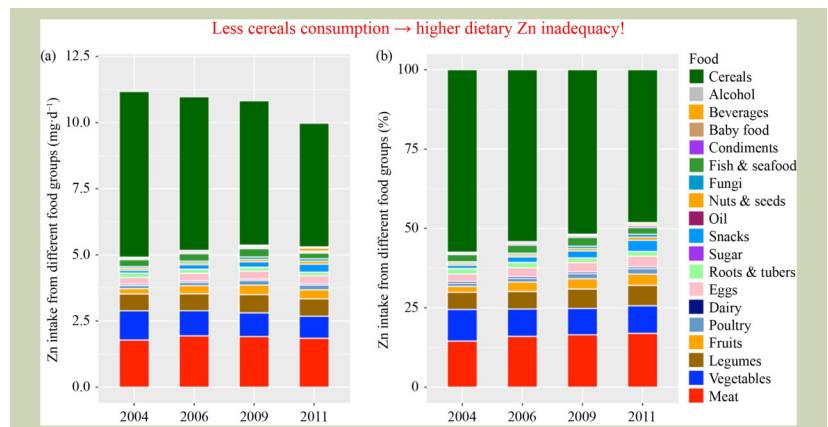
KEYWORDS

Cereals, food consumption pattern, sociodemographic characteristics, time trend, zinc intake inadequacy

HIGHLIGHTS

- The percentage of the surveyed adults with inadequate Zn intake increased from 2004 to 2011.
- The decrease of dietary Zn intake related to reduced cereal consumption.
- Dietary Zn intake is related to income but not different between rural and urban.
- Reverting current trend require region specific policies considering diet patterns.

GRAPHICAL ABSTRACT



ABSTRACT

Adequate dietary zinc intake remains a public health challenge in China. Also, there is a lack of information on the relationship between Zn intake and food consumption patterns across provinces and over time. In this study, data from the China Health and Nutrition Survey 2004–2011 (21,266 individuals) was used to explore associations between dietary Zn intake and sociodemographic factors. Zn intake per person declined from 11.1 mg·d⁻¹ in 2004 to 9.89 mg·d⁻¹ in 2011, with reduction in cereal consumption the greatest contributor to this. However, the reduction resulting from the lower cereal consumption was only partly compensated by an increase in consumption of Zn-rich foods. The percentage of the study population with inadequate Zn intake increased from 23% in 2004 to 37% in 2011. While Zn intake was positively associated with income levels in each survey year, the time trend for all income levels was a gradually reducing Zn intake. In all years, males had an average higher dietary

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Zn intake, whereas no significant difference was found between living areas. In conclusion, this study shows that dietary Zn inadequacy was high and has increased over the studied period. Remediation could be sought by shifting dietary patterns toward more Zn-dense food or by enhancing Zn concentration through biofortification.

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1 Introduction

Zinc (Zn) is an essential nutrient for humans as for other organisms, and occurs in more than 300 enzymes in living organisms^[1,2]. Adequate Zn nutrition is necessary for child growth, for a healthy immune system and neurobehavioral development^[3,4]. Zn deficiency is one of the most widespread human micronutrient deficiencies, also known as hidden hunger^[5,6]. The prevalence of dietary Zn deficiency is decreasing globally due to higher income and a better food supply system, but the risk remains large. In 2011, 16% of the world population (1.1 billion people) was at risk of Zn deficiency due to inadequate dietary supply, where it had been 22% in 1992^[7]. In 2020, an estimated 22% of children under 5 years old were affected by stunting globally because of multiple factors including Zn deficiency^[8–10]. The disruptive effects of the COVID-19 pandemic on the economy and food systems threaten to exacerbate undernutrition in low- and middle-income countries^[11].

Insufficient Zn intake is a public health concern in China as well. High risk groups comprise infants, preschoolers, pregnant and breast feeding women, and the elderly^[3]. Earlier studies in 2003 found a high prevalence (38%) of low serum Zn in Chinese children 3–5 years old^[12]. Another study showed 45% of people 60 or more years old had a dietary Zn intake below the estimated average requirement (EAR)^[13]. Nutrient intake is related to dietary patterns and is determined by cultural and other sociodemographic factors^[14,15]. Main dietary sources of Zn include meat, fish, shellfish, nuts, legumes, and whole-grain cereals^[16,17]. Over the last 4 decades, China has experienced tremendous economic and societal development, in parallel with a vast change in food consumption^[18–20], for example, a surge in consumption of animal protein from 4.2 g·d⁻¹ per person in 1961 to 37.2 g·d⁻¹ per person in 2011^[21]. However, the effect of such shifts on dietary Zn intake of the Chinese population as a whole and differences across provinces within the country have not been analyzed.

While the Zn requirement is essentially similar between humans living in different locations, regions differ in their

environments and agricultural resources to meet the dietary needs of the inhabitants, especially from cereal production^[22–25]. Inadequate intake of Zn is especially common in regions where diets are dominated by cereals, and where access to food from plant and animal sources that are richer in Zn is limited^[26,27]. To date, it is not known which regions in China are most affected by dietary Zn intake inadequacy, or how shifts in food consumption patterns have affected dietary Zn intake over time.

The aim of this study was to characterize differences between provinces across China in the occurrence of dietary Zn intake inadequacy and identify how such differences are related to changes in food consumption patterns. The analysis was based on the China Health and Nutrition Survey (CHNS) of 2004, 2006, 2009, and 2011. We evaluated the dietary Zn intake of surveyed adults to find subpopulations with a high percentage of inadequate Zn intake using the EAR (mg·d⁻¹) cut-point method^[28]. We further looked for explanatory sociodemographic variables of dietary Zn intake, including gender, income level, food consumption patterns and whether people were living in urban or rural areas.

2 Materials and methods

2.1 Data

The data of this study were derived from the CHNS which is an ongoing longitudinal survey that has been conducted every few years since 1989. This periodic survey has always been conducted between August and December, collecting information on sociodemographic characteristics, nutrition, physical activity and health status, to provide information on a representative sample of households and individuals across a large part of China. For the present analysis, we extracted data for adults 18–50 years old from the CHNS of 2004, 2006, 2009, and 2011. The earlier surveys were not included as codes for food items could not be matched with the food composition table used (see below). Data were available for nine regions in the four survey years: Heilongjiang, Liaoning, Shandong,

Jiangsu, Henan, Hubei, Hunan, Guizhou, and Guangxi, as well as for three cities only in 2011 (Beijing, Chongqing, and Shanghai; Table S1). For the analyses, the explanatory variables included: gender (male vs female), living area (rural vs urban) and income level (low, middle and high classified by year-specific quantiles). For these latter year-specific quantiles were: < 2400 yuan as low income, 2400–5450 yuan as middle income, and > 5450 yuan as high income in 2004; < 2620 yuan as low income, 2620–6440 yuan as middle income, and > 6440 yuan as high income in 2006; < 4720 yuan as low income, 4720–10,600 yuan as middle income, and > 10,600 yuan as high income in 2009; and < 7140 yuan as low income, 7140–16,415 yuan as middle income, and > 16,415 yuan as high income in 2011. Table 1 lists the sociodemographic characteristics of the population included in this study (for more detail see Table S2).

2.2 CHNS dietary measurement methods

The CHNS monitors how the social and economic transformation of the Chinese society affects the nutritional status of its population. For this, in all selected households those older than 12 years old were asked to report all food consumed at home and away from home in the 24 h prior to the interview. Each person was interviewed on three consecutive days where the start day was randomized uniformly over the 7 days of the week. Trained interviewers recorded the type of food, the amount, and type of meal and place of consumption of all food items during the 24 h prior to the interview. Consumption of edible oils, sugar and salt in the households were determined by measuring the household disappearance rate that is by weighing these foods on a daily basis and then calculating household consumption averaged over the number of household members. To calculate average

daily Zn and energy intake, food recall data were then matched with food items in the Chinese Food Composition Tables^[29]. After this step data from three consecutive days per person were averaged to assess intake per person.

2.3 Inadequacy of dietary Zn intake

We estimated the proportion of individuals with a daily dietary Zn intake below their age- and gender-specific EAR, also known as the EAR cut-point method, which is a simplification of the full probability approach for calculating the prevalence of dietary intake inadequacy^[28,30,31]. The EAR cut-point method assumes that the dietary intake and requirement distributions are independent. Table S3 provides the EAR for Zn by age and gender as set by the People's Republic of China National Health Commission^[32].

2.4 Food consumption pattern calculation

The foods and drinks in the database were classified into 19 food groups, similar to the classification in the 2009 Chinese Food Composition Table: cereals, meat, vegetables, legumes, fruits, dairy, poultry, eggs, roots and tubers, sugar, snacks, oil, nuts and seeds, fungi, fish and seafood, condiments, baby food, beverages, and alcohol^[29]. For each individual, Zn intake as reported in the survey from each food item was summed per food group, and then converted into a proportion of the total Zn intake per day based on the values in the Food Composition Table. While consumption changes with survey, the food composition is considered to remain stable over time. The food consumption and Zn intake in the three megacities in 2011 were analyzed separately (Fig. S1). Differences in Zn and energy content, and in Zn density between food groups, as

Table 1 Sociodemographic characteristics of the included study population from the China Health and Nutrition Surveys conducted in 2004–2011

| Number of observations (%) | | 2004 | 2006 | 2009 | 2011 |
|----------------------------|--------|--------------|--------------|--------------|--------------|
| Gender | Male | 2600 (48.1%) | 2332 (47.6%) | 2356 (48.3%) | 2831 (46.6%) |
| | Female | 2804 (51.9%) | 2572 (52.4%) | 2524 (51.7%) | 3247 (53.4%) |
| Living area | Urban | 1799 (33.3%) | 1624 (33.1%) | 1567 (32.1%) | 2426 (39.9%) |
| | Rural | 3605 (66.7%) | 3280 (66.9%) | 3313 (67.9%) | 3652 (60.1%) |
| Income level | Low | 1722 (31.9%) | 1467 (29.9%) | 1520 (31.1%) | 1823 (30.0%) |
| | Middle | 1876 (34.7%) | 1713 (34.9%) | 1711 (35.1%) | 2222 (36.6%) |
| | High | 1806 (33.4%) | 1724 (35.2%) | 1649 (33.8%) | 2033 (33.4%) |
| Total | | 5404 | 4904 | 4880 | 6078 |

Note: Nine regions (Heilongjiang, Liaoning, Shandong, Jiangsu, Henan, Hubei, Hunan, Guizhou, and Guangxi) were included in all years, and three cities (Beijing, Chongqing, and Shanghai) only in 2011.

derived from the Chinese Food Composition Table, are presented in Fig. S2.

2.5 Statistical analysis

Eight records were excluded from all analyses because of an extremely high dietary Zn intake ($> 100 \text{ mg}\cdot\text{d}^{-1}$ per person). All analyses were conducted using linear mixed effects models in R (version 1.1.463). The relationship between dietary Zn intake ($\text{mg}\cdot\text{d}^{-1}$) and explanatory variables (i.e., survey year (as classes, years 1–4), gender (female vs male), living area (rural vs urban), and income level (as classes low, middle, or high)) was explored using the following linear mixed effects model:

$$\begin{aligned} \text{Zn intake} = & \beta_0 + \beta_1 \times \text{Year}_{ij}^{(2)} + \beta_2 \times \text{Year}_{ij}^{(3)} + \beta_3 \times \text{Year}_{ij}^{(4)} \\ & + \beta_4 \times \text{Male}_{ij} + \beta_5 \times \text{Urban}_{ij} + \beta_6 \times \text{Middle}_{ij}^{(2)} \\ & + \beta_7 \times \text{High}_{ij}^{(3)} + a_i + \varepsilon_{ij} \end{aligned}$$

where, indices i and j were the community and individual IDs, with community being a government-designated administrative district. In all mixed effects models, β_0 was the intercept, and β_{1-7} were the slope of each explanatory variables. a_i was a random community effect, and ε_{ij} was a residual random error, both assumed to be independent and normally distributed with constant variance. Mixed effects models were fitted using the *lme* function in the R package “nlme”^[33,34]. Model selection was based on the lowest Akaike’s information criterion in R. The assumptions of normality and homogeneity of variance were checked graphically^[35].

3 Results

3.1 Inadequacy of dietary Zn intake in the nine regions

The average percentage of inadequate Zn intake in the total adult population increased from 23% in 2004 to 37% in 2011. These percentages varied strongly between provinces. Henan Province, had the highest occurrence of inadequate dietary Zn intake of all regions across all survey years, with the inadequacy in this region increasing from 37% in 2004 to 65% in 2011 (Table 2). The regions with the lowest occurrence of inadequate dietary Zn intake were Jiangsu (9%) in 2004 and Guangxi (19%) in 2011. For the three cities (Beijing, Chongqing, and Shanghai) in 2011, the percentages of inadequate Zn intake were 54%, 55%, and 35%, respectively.

3.2 Associations between sociodemographic factors and dietary Zn intake

Over the years studied, there was a decreasing trend in average dietary Zn intake (Table 3 and Table S4; $P < 0.001$). In all years, males ($11.5 \text{ mg}\cdot\text{d}^{-1}$) had on average a higher ($P < 0.001$) dietary Zn intake than females ($9.67 \text{ mg}\cdot\text{d}^{-1}$) whereas there was no significant difference found between people living in urban ($10.7 \text{ mg}\cdot\text{d}^{-1}$) and rural areas ($10.4 \text{ mg}\cdot\text{d}^{-1}$, $P = 0.54$). People in the highest income level households had higher dietary Zn intake than people in the lowest income level households in all survey years ($P < 0.001$). To explain these differences in dietary

Table 2 Percentages of people with Zn intake inadequacy in the surveyed regions for four selected years

| Region | 2004 | 2006 | 2009 | 2011 |
|--------------|------|------|------|------|
| Guangxi | 18.0 | 23.5 | 18.9 | 18.7 |
| Guizhou | 14.2 | 19.3 | 19.5 | 23.0 |
| Heilongjiang | 36.9 | 33.1 | 30.4 | 34.4 |
| Henan | 36.8 | 42.0 | 44.5 | 65.2 |
| Hubei | 15.2 | 11.8 | 18.3 | 27.3 |
| Hunan | 11.0 | 20.8 | 22.4 | 24.5 |
| Jiangsu | 9.4 | 14.7 | 12.9 | 25.2 |
| Liaoning | 29.5 | 22.6 | 23.2 | 37.8 |
| Shandong | 32.7 | 31.2 | 31.6 | 44.4 |
| Shanghai | | | | 37.0 |
| Beijing | | | | 54.9 |
| Chongqing | | | | 54.8 |

Note: Zn intake inadequacy was defined as Zn intake below the estimated average requirement (EAR) of Zn. Nine regions (Heilongjiang, Liaoning, Shandong, Jiangsu, Henan, Hubei, Hunan, Guizhou, and Guangxi) were included in 2004, 2006, 2009, and 2011, and three cities (Beijing, Chongqing, and Shanghai) only in 2011.

Table 3 Mean dietary Zn intake ($\text{mg}\cdot\text{d}^{-1}$) differences between years and according to gender, living area, and income level as estimated using mixed-effect regression of dietary Zn intake ($\text{mg}\cdot\text{d}^{-1}$)

| Variable | Mean dietary Zn intake ($\text{mg}\cdot\text{d}^{-1}$) with 95% CI | Standard error | P value |
|--------------------|--|----------------|---------|
| Survey year | | | |
| 2004 (reference) | 11.1 [10.8, 11.5] | 0.183 | |
| 2006 | 10.9 [10.6, 11.3] | 0.185 | < 0.001 |
| 2009 | 10.8 [10.4, 11.1] | 0.185 | < 0.001 |
| 2011 | 9.89 [9.54, 10.2] | 0.178 | < 0.001 |
| Gender | | | |
| Female (reference) | 9.67 [9.34, 10.0] | 0.175 | |
| Male | 11.5 [11.2, 11.9] | 0.176 | < 0.001 |
| Living area | | | |
| Rural (reference) | 10.4 [10.0, 10.9] | 0.222 | |
| Urban | 10.7 [10.6, 11.2] | 0.270 | 0.54 |
| Income level | | | |
| Low (reference) | 10.2 [9.82, 10.5] | 0.184 | |
| Middle | 10.6 [10.2, 10.9] | 0.180 | < 0.001 |
| High | 10.8 [10.4, 11.1] | 0.181 | < 0.001 |

Note: Nine regions (Heilongjiang, Liaoning, Shandong, Jiangsu, Henan, Hubei, Hunan, Guizhou, and Guangxi) were included in 2004, 2006, 2009, and 2011. Community was added to the model as a random effect.

Zn intake, we further compared the food consumption patterns of some subgroups.

3.3 Zn intake and food consumption patterns

Daily Zn intake derived from the 19 food groups was calculated for all adults (21,266 individuals, 18–50 years old) and Zn intake patterns according to food group were visualized separately by survey year, gender, living area (urban vs rural), income level, and region. Cereals and meat were the two most important food sources for Zn intake. Over the survey years, there was a clear downward trend in the amount of dietary Zn intake from cereals (from $6.27 \text{ mg}\cdot\text{d}^{-1}$ in 2004 to $4.68 \text{ mg}\cdot\text{d}^{-1}$ in 2011, from 58% in 2004 to 48% in 2011), while there was a possible but not significant increase in Zn intake from meat (from $1.78 \text{ mg}\cdot\text{d}^{-1}$ in 2004 to $1.85 \text{ mg}\cdot\text{d}^{-1}$ in 2011, from 15% in 2004 to 17% in 2011). These trends were similar in absolute and in relative terms (Fig. 1).

These trends were similar for rural and urban populations (Fig. 2(a,b)), although rural populations had higher Zn intake from cereals and lower Zn intake from meat compared to urban populations (Fig. S3(a,b)). Trends were also similar for males and females (Fig. 2(c,d)), but males had higher Zn intake from cereals and meat than females. Also, there was a

decreasing trend in the amount of dietary Zn intake from cereals for people at all income levels. Dietary Zn intake from meat increased slightly over time for persons in the low- and middle-income groups (Figs. 2(e–g) and S2). Dietary Zn intake from meat in the high-income group slightly decreased over time, although this did not lead to an obvious change in the proportion of Zn intake from meat (Fig. S3).

Lastly, we compared the time trends in dietary Zn intake between the nine regions from 2004 to 2011, which showed an interaction between survey year and region that is time trends differed between regions (Fig. 3). For regions with a high occurrence of dietary Zn inadequacy like Henan Province (Table 2), the average dietary Zn intake was low and more than half of it was from cereals in all survey years (66% in 2004 to 57% in 2011; Fig. 3(d)), while the contribution from meat was quite low (8% in 2004 to 9% in 2011; Fig. S4). In regions with a lower occurrence of dietary Zn inadequacy, including Jiangsu (Fig. 3(g)), Liaoning (Fig. 3(h)), and Shandong (Fig. 3(i)), average Zn intake increased from 2004 to 2009, but decreased again in 2011, with a relatively smaller contribution of cereals and larger contribution of meat (Fig. S4). Guangxi (Fig. 3(a)), Guizhou (Fig. 3(b)), and Hunan (Fig. 3(f)) had the highest intake of Zn from meat and lower occurrence of dietary Zn inadequacy (Table 2) than the other regions.

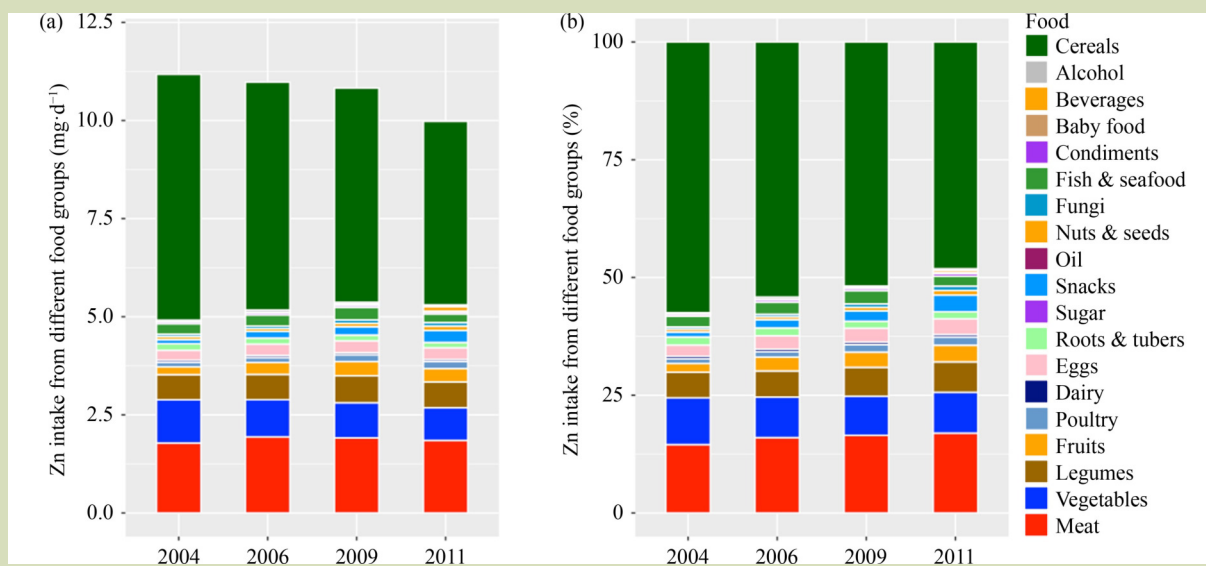


Fig. 1 Time trend of dietary Zn intake from 19 food groups for adults in four surveys by amount (a) and proportion of total daily intake (b).

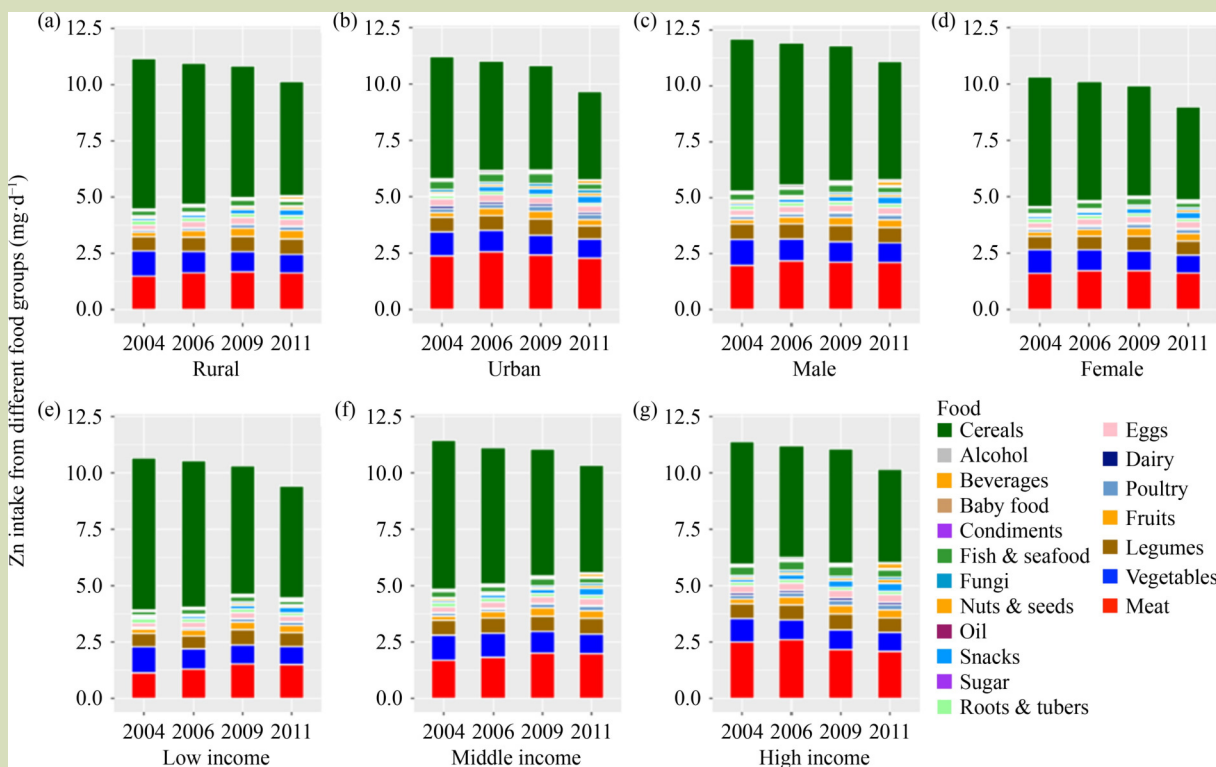


Fig. 2 Time trend of dietary Zn intake (mg·d⁻¹) from 19 food groups for adults living in rural area (a), living in urban area (b), for males (c), for females (d), and for three income levels ((e) low, (f) middle, (g) high). For proportions, see Fig. S4.

4 Discussion

Modern China has and continues to undergo a dramatic

transition in disease and dietary patterns, accompanied by rapid economic growth, lifestyle changes, and population aging^[36,37]. A growing number of studies have shown that the

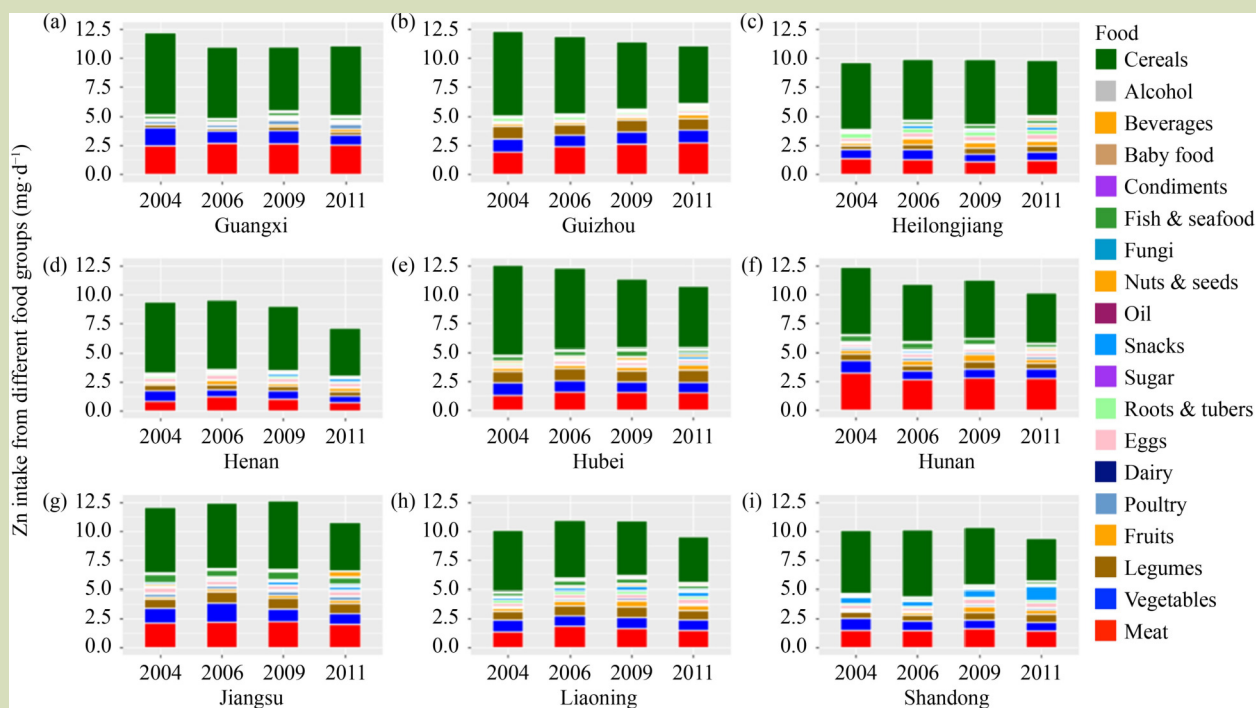


Fig. 3 Time trend of dietary Zn intake ($\text{mg}\cdot\text{d}^{-1}$) from 19 food groups for nine regions. For proportions, see Fig. S4.

shift in dietary patterns has contributed to a large disease burden^[38,39]. We found that inadequacy of dietary Zn intake increased from 23% in 2004 to 37% in 2011 on average over 10 Chinese regions (Table 2) and the average dietary Zn intake of surveyed adults decreased from $11.1 \text{ mg}\cdot\text{d}^{-1}$ in 2004 to $9.89 \text{ mg}\cdot\text{d}^{-1}$ in 2011 on average, based on data from CHNS 2004–2011. It has been reported previously that daily consumption of dietary Zn was relatively low in the Chinese population as shown by the large number of individuals that did not reach the EAR for Zn intake from food (27%–45.6% of surveyed children in 2011 and 45.8% of surveyed elderly people in 2015)^[13,40,41]. Previous studies have also evaluated that the average energy intake per reference person per day decreased by 78 kcal for Chinese people from 2002 to 2010–2012, while the dominant dietary pattern shifted from one high in carbohydrate, to one high in fat^[37,42]. Also in our study, a reduction in cereal consumption and in dietary Zn intake was found using the same data sets. The earlier reported shift in energy intake from carbohydrates (from cereals) to fat (other sources) and the here reported drop in Zn intake from cereals thus are related to a same dietary shift.

In a recent analysis, 15% of adults (> 19 years) in the USA were found to have an inadequate intake of Zn based on the 2005–2016 National Health and Nutrition Examination

Surveys^[43] whereas an earlier analysis found that 35%–45% of adults in the USA (> 60 years) had zinc intakes below the EAR^[44]. When comparing recent nationally representative dietary survey data for adults 18–60 years old from Europe, including Belgium, Denmark, France, Germany, the Netherlands, Poland, Spain and the UK, the percentages of Zn intake below the EAR ranged from 1.8% in Germany to 20.8% in the UK for males, and from 2.2% in Spain to 20.4% in the UK for females^[45]. These figures show that, although differences between countries exist, inadequate dietary Zn intake remains a global challenge and should receive more attention. For China, the data indicate substantial differences between provinces, with inadequacy in Zn intake ranging from 37% in 2004 and 65% in 2011 in Henan to 18% in 2004 and 19% in 2011 in Guangxi, which suggests that province-specific policies rather than nationwide policies may need to be considered to improve Zn nutrition. The problem of inadequate dietary Zn intake can be expected to change with time. Based on the blood samples of 3903 people (18–60 years old) from 31 regions, Zn deficiency rate of Chinese adults in 2015 was 6.04%. There were significant differences in gender, regions, smoking status, and drinking status^[46]. A meta-analysis of 55 studies from 2005 to 2021, including 292,877 healthy children and adolescents, found that Zn deficiency rate in Chinese children under 14 years old was as high as 27%^[47]. The results of these two studies indicated that the situation of

Zn deficiency among children and adolescents in China remains severe, while the issue of inadequate Zn intake among adults has shown some improvement compared to the findings from our study. Though differences in studied populations make exact comparisons difficult.

Zn intake was, in the four selected years, positively correlated with income level in our regression analysis: people in middle- and high-income groups had, on average, 0.39 and 0.57 mg·d⁻¹ higher dietary Zn intake than people in the low-income group, mainly related to higher meat consumption (Table 3 and Fig. 2(e–g)). Previous studies showed that income was one of the factors related to dietary Zn intake due to the cost of food items, as well as awareness and knowledge about the nutritional value of different food items^[7,13]. Many studies suggest that micronutrients are more likely to be deficient in low and middle-income countries or areas because of lower diet quality and affordability of foods^[48,49]. However, China has developed from a low- to a middle-income country, regional differences in income have become larger and may thus partly explain observed regional differences in inadequacy of Zn intake, though also region-specific dietary shifts away from cereals like in Henan seem to contribute. Thus, there is room for a more in-depth analysis of drivers given the large differences in Zn intake differences and trends found. Also, the observation that while within years a higher income is associated with higher Zn intake, the observed reduction in Zn intake with time is contrary to the average income increase over the same period. Therefore, more research is needed on the actual food expenditure of households over the same period, for which we did not have the data.

There were some differences in dietary patterns and related Zn intake between southern and northern China (Table 2), which might be related to agroclimatic conditions, food supply or dietary habits, or combinations of these. The diet in southern China (including Jiangsu, Hubei, Hunan, Guangxi, and Guizhou) is on the whole more diverse, with a great variety of vegetables, fruits, eggs, fish, and meat along with rice^[50,51], than the diet in the northern provinces, which is mainly composed of wheat noodles, dumplings, steamed buns, and flat cakes^[52]. This may explain the lower intake of Zn and the higher occurrence of inadequacy in Heilongjiang, Liaoning, Henan, and Shandong (Fig. S4) located in north China^[40].

In general, plant-based foods were the most important sources of dietary Zn, although their consumption decreased over time (Fig. 1). The decline in Zn intake from cereals was only partly compensated by an increase in Zn intake from meat or other food items. While there is an overall increasing trend in meat

consumption in the study population and over the study period this trend is not consistent among provinces with some showing reduction or no change, in all leading to a rather small positive overall effect on Zn. It should be noted, though, that we did not take into account any differences in bioavailability of Zn between food sources. Plant-based foods often contain high levels of phytate, which is a potent inhibitor of Zn absorption in the human gut^[53,54]. The Chinese Food Composition Table does not contain information on phytate content, and therefore we could not establish changes in phytate content of diets over time quantitatively. Nevertheless, with the declining intake of Zn from cereals and the increasing intake from meat and other food items, which tend to be lower in phytate than cereals, bioavailability of Zn may have increased over time. It is uncertain whether such an increase in bioavailability could have fully compensated for the decline in total Zn intake. In addition to a lack of phytate data in the food composition tables, also region-specific information on Zn content of foods is missing. This is relevant, as in regions with soils that are low in available Zn, the Zn levels in food may be below what is reported in the national food composition tables. In China, about 40% of the soils are estimated to have marginal plant-available Zn^[55,56]. For these regions, a region-specific food composition correction based on major food items, including cereals that are often locally sourced, might give additional information.

The current study had some limitations. First, all analyses were based on 24-h recall data for food consumption over 3 days, which might be affected by under- and overreporting because of memory lapses^[57], but also because people may report what they consider desirable to the interviewer. It is therefore not certain whether the observed trends were partially due to differences in self-reporting bias of the participants or represent true differences in intake. Also, because consumption data were recorded for three consecutive days, rather than with larger time intervals, we decided to use the mean of the 3 days of Zn intake to account for within person variation in food intake. This method estimates the means, and thus the time trends and between group differences in Zn intake well, but could overestimate the prevalence of inadequacy compared to separation of within and between person variation for recall data at sufficient time differences^[58]. Secondly, all surveys were conducted from August to December, and therefore the data reflect food consumption patterns for only part of the year.

If the observed trend in increased consumption of animal source food is maintained, it may continue to improve dietary Zn intake in the Chinese population. Yet, while meat is a desirable source of highly bioavailable Zn and several other

nutrients, studies indicate that an increasing consumption of, often fat-rich, meat also increases the risk of obesity, cardiovascular disease and some forms of cancer. In addition, and not of least importance, it increases the environmental burden of the food system, particularly consumption of red meat and processed meat^[59,60]. As an alternative to meat, there are other food items that are both high in Zn and protein without the above issues, such as legumes. Although legumes are also potentially rich in phytate, if eaten unprocessed, which may reduce Zn absorption, there is a wealth of phytate degrading food technologies available that are culturally acceptable to Chinese consumers^[54]. Also, a promising way to overcome dietary Zn inadequacy is to increase Zn concentration in major consumed plant-based food items, such as cereals, vegetables and legumes, by means of biofortification technologies, like breeding or fertilization^[61–64]. So, while the present study shows that Zn intake diminished between 2004 and 2011, there are clearly options for policy to support the production, processing and consumption of a wider range of (biofortified) foods to enhance Zn intake, while steering toward a more sustainable and healthier diet^[65].

5 Conclusions

Using data from CHNS 2004–2011, this study identified an increasing time trend of dietary Zn inadequacy of Chinese adults, which was associated with sociodemographic characteristics and shifts in food consumption patterns. The percentage of the population studied with inadequate Zn intake increased from 23% in 2004 to 37% in 2011, and the average dietary Zn intake decreased from 11.1 mg·d⁻¹ in 2004 to 9.89 mg·d⁻¹ in 2011. This decline was attributable to a reduction in dietary Zn intake from cereals, which was not sufficiently compensated by increased Zn intake from meat and other Zn-rich food items. This decline in Zn intake due to changing food consumption patterns should be addressed by appropriate public health policies to warrant optimal nutrition and health of the Chinese population. The vast differences between provinces indicate that such policies should consider region-specific approaches that take local food culture and food availability into account.

Supplementary materials

The online version of this article at <https://doi.org/10.15302/J-FASE-2024584> contains supplementary materials (Tables S1–S4; Figs. S1–S4)

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Compliance with ethics guidelines

Lu Liu, Alida Melse-Boonstra, Wen-Feng Cong, Mo Li, Fusuo Zhang, Wopke van der Werf, and Tjeerd Jan Stomph declare that they have no conflicts of interest or financial conflicts to disclose. This article does not contain any studies with human or animal subjects performed by any of the authors.

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