Food Security
https://doi.org/10.1007/s12571-024-01514-4

ORIGINAL PAPER

Food consumption away from home had divergent impacts on diet nutrition quality across urban and rural China

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Received: 16 May 2024 / Accepted: 29 November 2024

Abstract

China's rapid economic growth has led to a significant increase in the number of people who are eating away from home. However, some studies show that increased meat consumption poses a health burden while others show dietary diversity promoted by away from home enhances health. As a result, the effects of away from home on dietary nutritional quality remain inconclusive. Moreover, estimates of total food consumption are underestimated without considering away from home. Herein, we constructed away from home models ($R^2 = 0.59$) to assess its impacts on the quantity and quality of food consumption. By 2020, away from home accounted for 18% (233.37 g) of total consumption in urban areas and 8% (81.80 g) in rural areas. Although, at the national scale, away from home consumption of meat, poultry, and aquatic products led to decreased dietary nutritional quality in urban areas from 2000 to 2020 and in rural areas since 2015, by 2020, three urban provinces and 12 rural provinces still showed improvements in dietary nutritional quality from such consumption. Additionally, overall dietary nutritional quality of away from home impact in urban areas improved from 2000 to 2015 but decreased in 2020, whereas rural areas saw consistent improvement across all years, suggesting the divergent impacts on diet nutrition quality across urban and rural China. Our findings underscore the urgency and necessity of extensively strengthening national nutritional education and developing specific nutrition-health policies tailored to economic conditions. This study also provides critical data for accurate food consumption and life cycle evaluations, promoting sustainability in the food system.

Keywords Food consumption · Eating away from home · Nutritional quality · Dietary transition

1 Introduction

Over the past two decades, as a result of remarkable economic growth (Liu et al., 2015), the diet of Chinese residents has undergone a rapid transition (Xin, 2021). Moreover, the behavior of eating away from home (AFH) has increased significantly, and this trend is expected to continue (Orfanos et al., 2007; Zhou et al., 2012; Huang et al., 2021). According to the 2020 Report on Chinese Nutrition and Chronic Disease (National Bureau of Disease Control & Prevention, 2022), nearly half (46.3%) of Chinese residents ate AFH at least once a week, with a notable increase of 10.8% compared to 2015. AFH has become a substantial component of dietary consumption (Zang et al., 2018). While the dietary consumption records from the National Bureau of Statistics of China (NBSC) dataset are long-term and nationally representative, the records on AFH consumption are lacking. This gap results in an underestimation of Chinese food consumption and impacts studies related to the sustainability of the food system, environmental health, food security and lifecycle assessment (Wang & Tao, 2023; Yu & Abler, 2014), which has been criticized by numerous studies (Bai et al., 2020; Seale Jr et al. 2012; Xiao et al., 2015; Xin & Li, 2018).

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Published online: 30 December 2024

In addition to offering a similar sense of satiety as eating at home (AH), AFH often serves social and entertainment purposes, such as hosting guests, gathering with friends, and tasting delicious cuisine (Jin et al., 2022; Tian et al., 2016). These preferences lead to variations in dietary structure. Compared with AH, AFH typically includes greater meat consumption (Bai et al., 2020; Mao et al., 2016; Song et al., 2019; Xiao et al., 2015; Zang et al., 2018). As a result, some studies have linked this AFH consumption preference to dietary imbalances and an increased health burden (Bu et al., 2021; Huang et al., 2021). However, these conclusions lack comprehensiveness (Anfinson et al., 2016; Yuan et al., 2018; Zeng & Zeng, 2018). Animal products account for only 20% to 30% of total AFH consumption (Li et al., 2019). Moreover, AFH supports a healthier and more balanced diet by enhancing dietary diversity, particularly by increasing the consumption of vegetables, fruits, and dairy products.(H. Wang et al., 2019). Currently, it remains unclear whether AFH contributes to an improvement or deterioration in dietary nutritional quality (DNQ) (Zang et al., 2018), underscoring the urgent need for a thorough evaluation of how various food types consumed in AFH specifically affect DNQ.

Although some cross-sectional studies have concentrated on AFH (Bai et al., 2016; Chen et al., 2021; Wang Bingya, 2021; Zang et al., 2018), the results lack representativeness due to regional limitations and sample size constraints (Batis et al., 2014). Currently, the China Health and Nutrition Survey (CHNS) database, a longitudinal survey covering 9 provinces and 3 municipalities (Shu Zhang et al., 2019), is the most extensively used database for AFH research (P. He et al., 2018; Wang et al., 2020; Xu et al., 2015) and is generally regarded as representative of the whole of China (Batis et al., 2014; Su et al., 2017; Zhen et al., 2018). For example, He et al. (2018) explored the Chinese DNQ of urban and rural food intake across different income levels based on the CHNS database. However, most studies have only supplemented with AFH data to analyze total food consumption (L. Wang et al., 2020), neglecting focused research on AFH. Only a few scholars, such as Song et al. (2017) and Li et al. (2019), have explored the spatiotemporal differences in AFH across various food types. More importantly, most AFH studies covered data only up to 2011 (M. Li & Shi, 2017; Zhen et al., 2018) because of the limited public availability of the CHNS database.

As a developing country with considerable geographical diversity, China has significant regional disparities in dietary structure between urban and rural areas (Rui et al., 2022; Yin et al., 2020). Considering the consumption quantity, dietary structure, and DNQ of AFH at the national scale alone is inappropriate (Hu et al., 2022). Moreover, these dietary structures change over time. Consequently, evaluating the situation and variation in AFH among residents from various provinces, encompassing both urban and rural areas, is essential. To address these gaps, we aimed to 1) develop AFH models to estimate their consumption quantities and trends from 2000 to 2020 2) compare food consumption structures of AFH with those of AH; and 3) assess the contribution of AFH to DNQ. These findings will provide insights for enhancing national nutrition and advancing food system sustainability in China.

2 Materials and methods

2.1 Study design

Over the past two decades, China has undergone a rapid diet transition. Since 1998, researchers have highlighted the underestimation of NBSC data due to the lack of AFH consumption records (Huang & Rozelle, 1998; Lu, 1998). As urbanization progresses, AFH has become increasingly difficult to avoid (Bai et al., 2016; Lachat et al., 2012; Xiao et al., 2015). In response, several studies have estimated consumption by incorporating AFH survey data (He et al., 2018; Wang et al., 2020), although these estimates are based on limited field studies. CHNS data is known to be comprehensive and continuous (Xin & Li, 2018) therefore, those data have widely been used. However, CHNS data on AFH consumption among urban and rural residents have not been available since 2011, creating a significant gap in accurately quantifying consumption (Hu et al., 2022). Overall, incorporating detailed AFH data into consumption estimates, with extensive temporal and spatial coverage, will greatly improve related studies, such as those on diet and nutrition, climate impact, and food loss and waste (Fig. 1).

Drawing on two widely used databases (CHNS and NBSC), for the first time, we attempted to develop an AFH model covering eight food types and extrapolated AFH quantities up to 2020 at a subnational scale. We analyzed the variations in AFH consumption and their impacts on DNQ separately by urban and rural residents in China from 2000 to 2020. The consumption records in the NBSC database (for only AH) are generally consistent with those in the CHNS database (Fig. S1a). In this study, we identified the variables affecting AFH that were recorded in both databases and validated their consistency. First, we constructed AFH estimation models for various food types and validated their accuracy (Table 2 and Fig. S4). Next, we input variables from the NBSC database into these models to estimate the AFH quantities for each food type (Fig. 2a-b) and the total (Fig. 3a-b and Table S5) at five-year intervals from 2000 to 2020. We then explored two decades of AFH variation by assessing its proportion relative to AFH + AH consumption (Fig. 2c) and examined AFH trends (Fig. 3c-e) via the Mann–Kendall test and Sen's slope analysis. Additionally, we assessed the dietary structure of AFH in terms of the proportion of food types

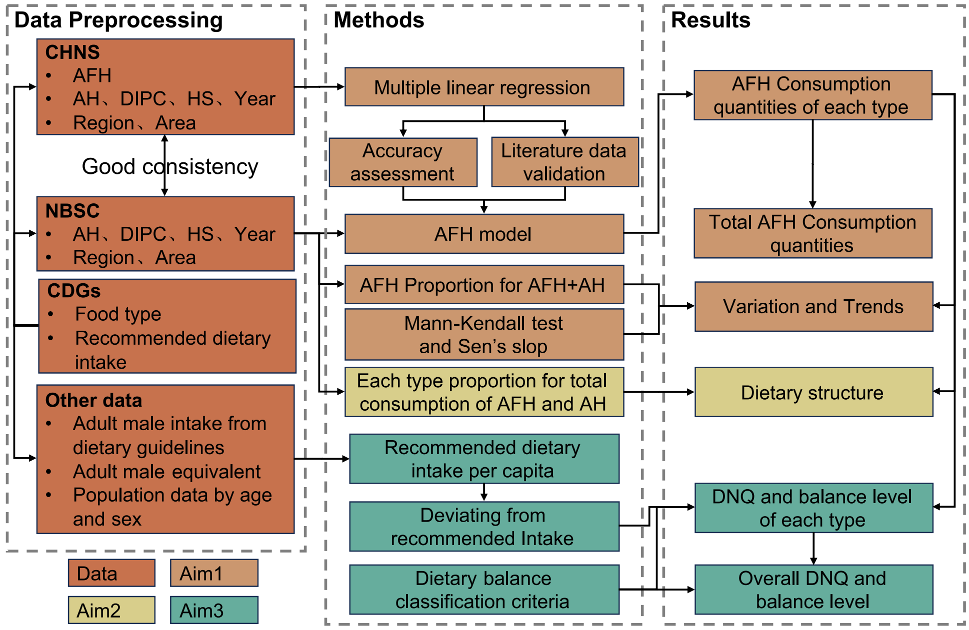

Fig. 1 Framework of this study. Abbreviations: CHNS, China Health and Nutrition Survey; NBSC, National Bureau of Statistics of China; CDGs, Chinese Dietary Guidelines; AFH, away from home; AH, at home; DIPC, disposable income per capita; HS, household size; DNQ, dietary nutritional quality

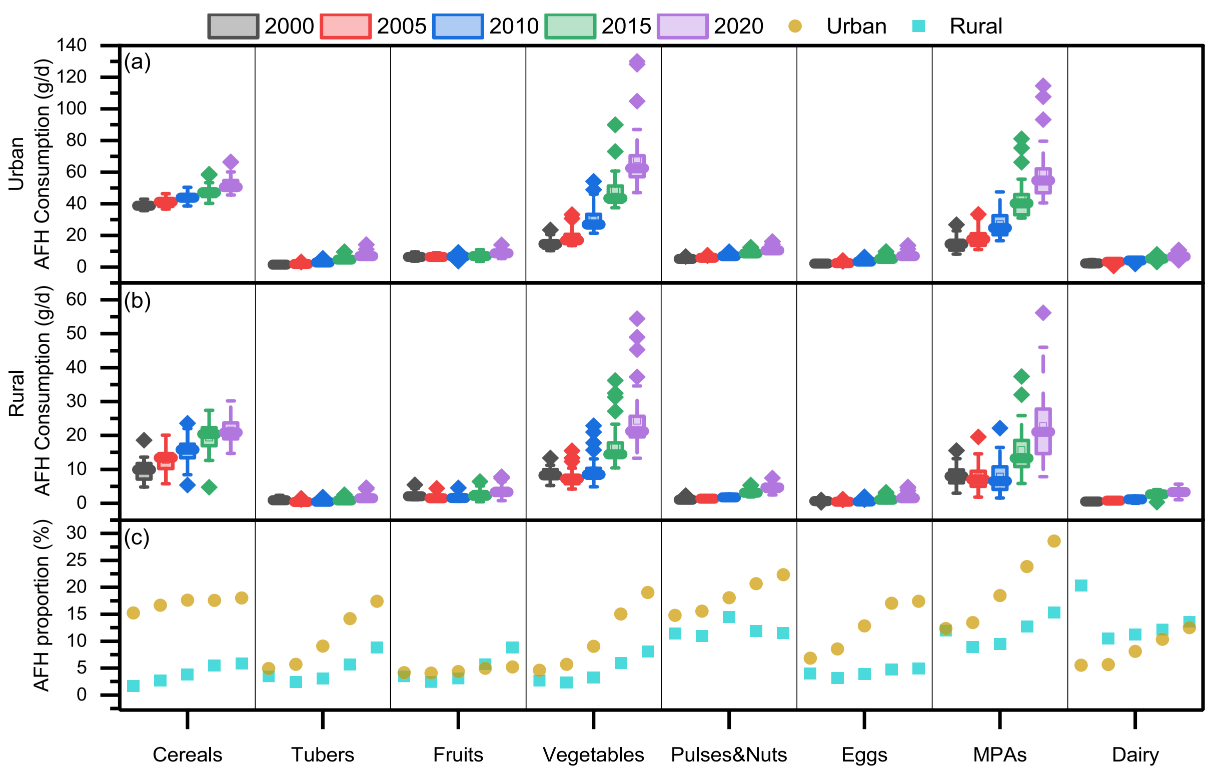

Fig. 2 Changes in food consumption quantities with box plots for all provinces. (**a**) urban areas, (**b**) rural areas, and (**c**) per capita AFH proportions every five years from 2000 to 2020

(Fig. 4a-d and Fig. S6) and compared it with that of AH (Fig. 4e-f). Finally, we evaluated the impact of AFH on DNQ and the balance level of each food type (Fig. 5a-d), as well as overall DNQ and balance levels (Fig. 5e-f). This was accomplished by examining deviations from the recommended dietary intake per capita (RDIPC) for each food type via an improved DNQ evaluation method that accounts for sex and age differences within provincial populations.

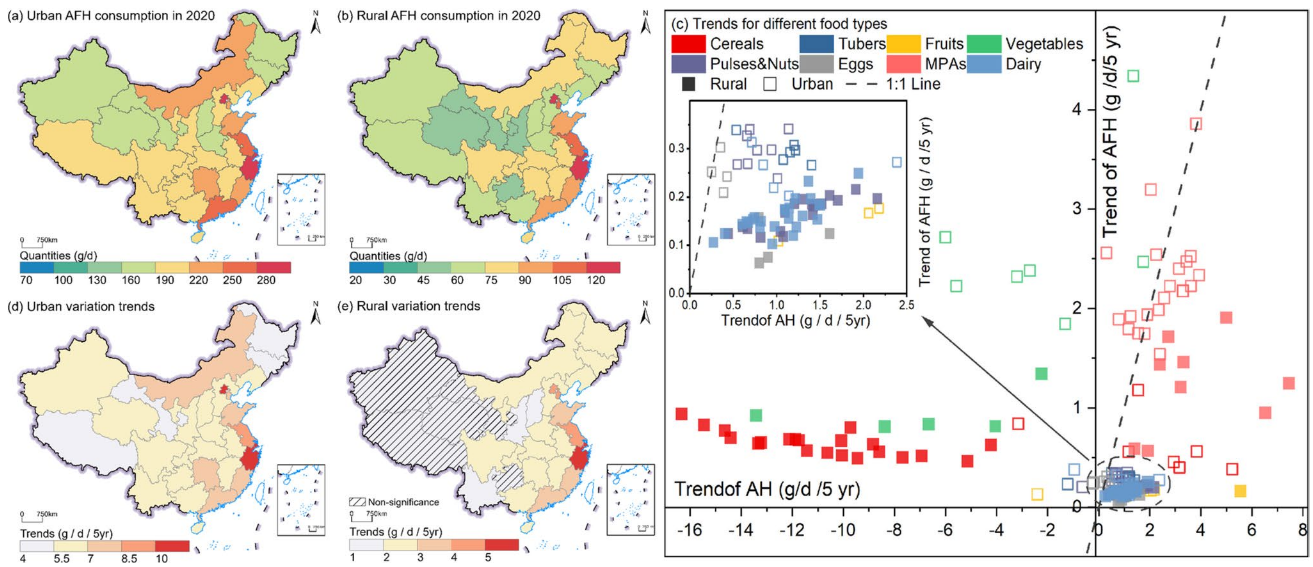

Fig. 3 Comparisons of food consumption quantities and trends in urban and rural areas. (**a-b**) Total AFH consumption in urban and rural areas for each province in 2020 (**c**) AFH and AH trends from 2000 to 2020 by food type, with all points significant at $p < 0.1$, and (**d-e**) AFH trends for urban and rural areas in each province from 2000 to 2020

2.2 Data preprocessing

(1) Chinese Dietary Guidelines

The Chinese dietary guidelines, available at https://www.cnsoc.org/tool/, provide recommended daily dietary intake ranges for various food types from the perspective of a balanced diet (Fig. S3). We considered eight food types according to Chinese dietary guidelines, including plant-based foods (cereals (200–300 g), tubers (50–100 g), fruits (200–350 g), vegetables (300–500 g), and pulses and nuts (25–35 g)) and animal-based foods (eggs (40–50 g); meat, poultry and aquatic products (MPAs) (70–160 g); and dairy (300–350 g)). The total daily intake, ranging from 1195 to 1835 g, aligns with the requirement of 1600 to 2400 kcal/d.

(2) China Health and Nutrition Survey and National Bureau of Statistics of China datasets

The China Health and Nutrition Survey (CHNS, https://www.cpc.unc.edu/projects/china) is an ongoing longitudinal household survey that utilizes a robust sampling method (B. Zhang et al., 2014). It is conducted across 12 provinces in China, covering 3 to 5 provinces for each region from east to west (Fig. S2). It is the only large-scale and long-term survey that collects representative socioeconomic data. Food consumption records were separately collected on the basis of eating behavior (AH and AFH) for both urban and rural areas (Su et al., 2017). The National Bureau of Statistics of China (NBSC) publishes various statistical yearbooks that provide comprehensive, long-term, and nationally representative data on socioeconomic factors for each province in China (Yuan et al., 2018), but they do not include records of AFH consumption.

AFH consumption is influenced by various factors, such as AH consumption (J. Li et al., 2019), disposable income per capita (DIPC) (Claro et al., 2014; Lund et al., 2017), occupation (Mills et al., 2018), educational level (Thornton et al., 2011), region (J. Li et al., 2019; Orfanos et al., 2007), household size (HS) (Ma et al., 2006) and area (Yin et al., 2020). Considering the variables recorded in both the two datasets, except category (different regions and areas) and time (year), three variables, AH consumption, DIPC and HS, were selected from the two datasets. We extracted 2.15 million AFH and AH food intake records from 27,887 residents across 8,009 households with DIPC and HS information for the years 1997, 2000, 2004, 2006, 2009 and 2011 from the CHNS database. AFH records encompassed all categories from the V41 MEAL LOCATION variable in the CHNS Individual Daily Meals (nutr3_00) dataset, including 'at school or work,' 'restaurant or food stand,' 'relative's or friend's house,' 'nursery school,' 'festival/celebration,' and 'other'. To ensure data quality, outliers beyond the average of ± 2 standard deviations (SDs) were removed (J. Wu et al., 2023; Zhang et al., 2022a, b). Moreover, zero consumption records were retained, but they were deleted if household consumption for all food types, both AFH and AH, was zero during the survey period. The remaining data were further analyzed at the provincial scale. In the NBSC dataset, records of AH consumption for different food types were collected

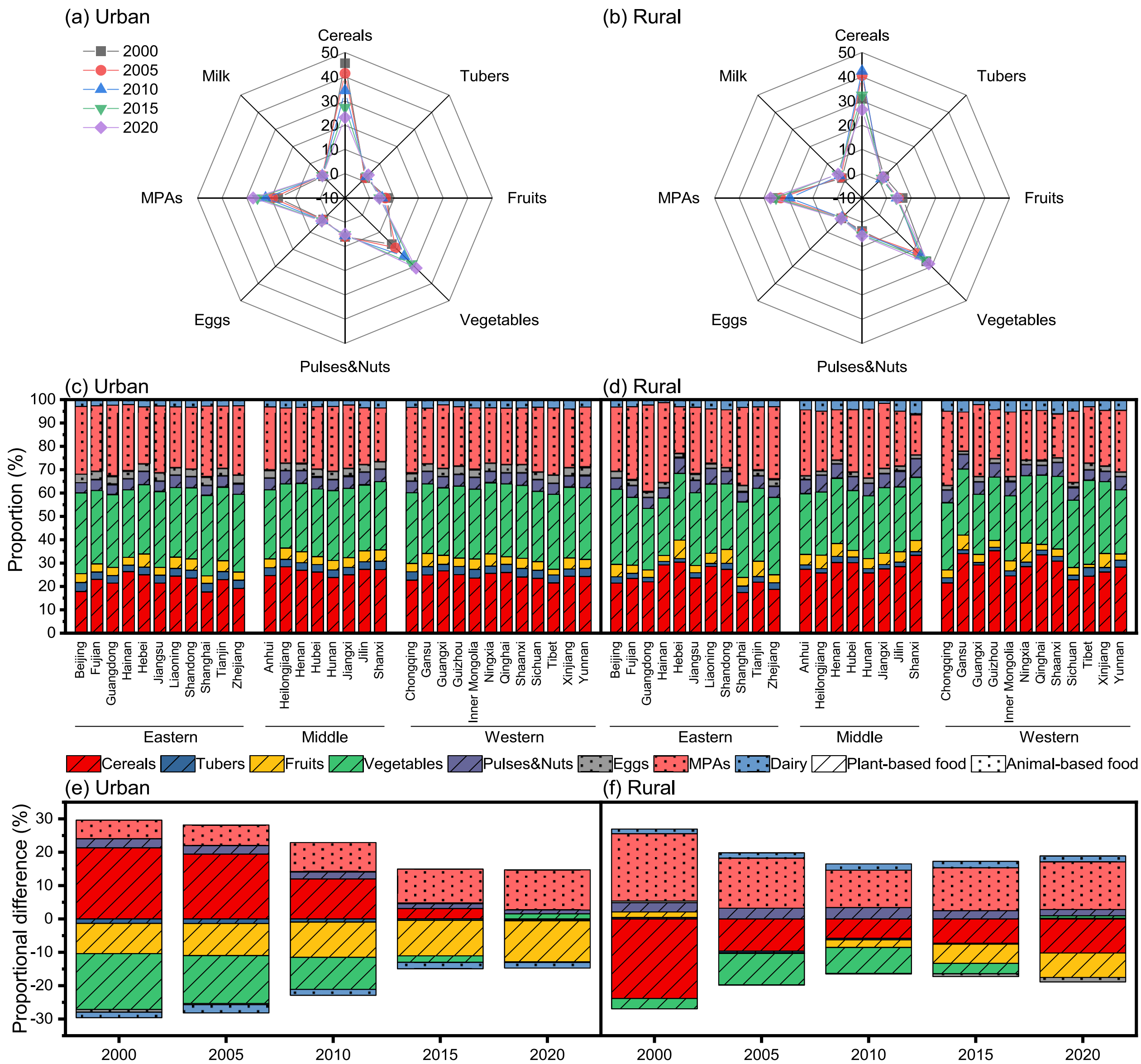

Fig. 4 Food structure variation and comparison between urban and rural areas. Urban and rural AFH dietary variation at (**a**-**b**) national and (**c**-**d**) provincial scales in 2020 and (**e**–**f**) proportional differences between AFH and AH

separately for urban and rural areas, along with DIPC and HS information for each province, every five years from 2000 to 2020. Cereal and tuber consumption was reported as raw grains, whereas urban residents' cereal and tuber consumption was reported as processed grains before 2013 (Wang et al., 2020). Therefore, we converted raw grains to processed grains via a conversion coefficient of 0.82 for cereals and 0.94 for tubers, on the basis of averages from other studies (X. He et al., 2004; Y. Zhang et al., 2012). All AFH and AH daily consumption quantities (g/d) were initially collected and calculated at the provincial level and then aggregated to the national level based on the provincial population data (Supplement Sect. 1.4).

(3) Other data

Additional data were gathered to calculate RDIPC as follows: The upper dietary recommendation, represented as the dietary standard for adult males (2400 kcal/d) according to the Chinese dietary guidelines, was established as the baseline. Adult male equivalent data (Table S4) were obtained from Zhong et al. (2012) and were calculated on the basis of the Food and Agricultural Organization (2001). Urban and rural population distribution data by age and sex were collected from the fifth, sixth, and seventh National Population Censuses of China, as well as sample surveys in 2005 and 2015.

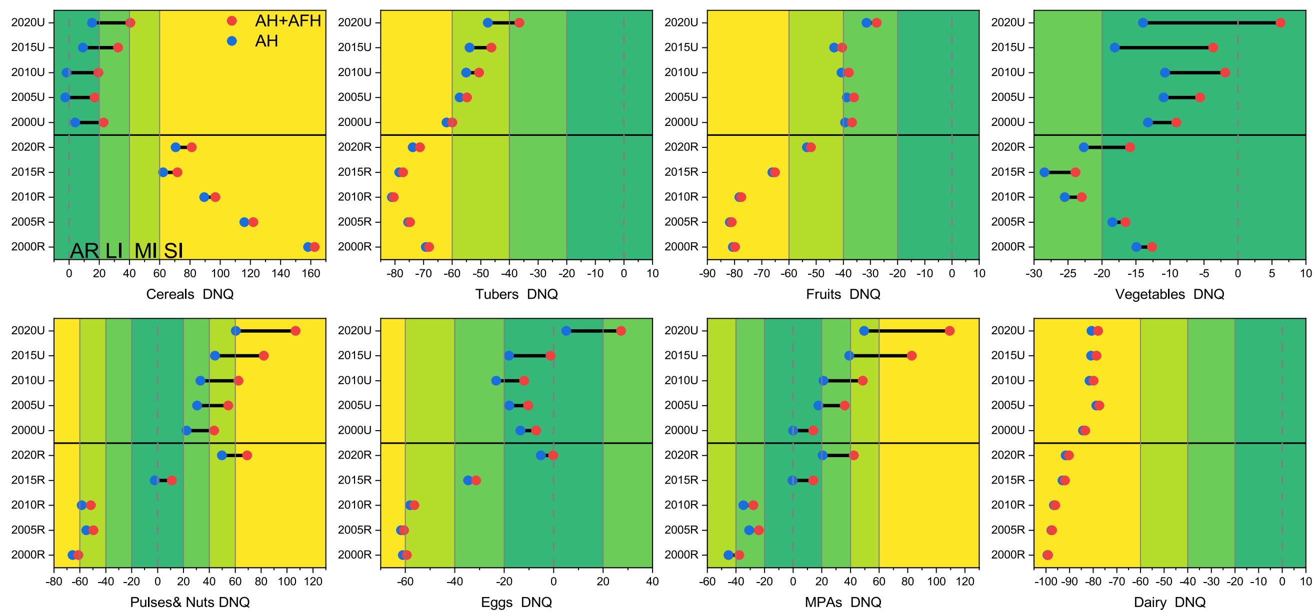

Fig. 5 Urban (U) and rural (R) DNQ and balance levels for each food type from 2000 to 2020, with or without the inclusion of AFH. The four dietary balance levels, appropriate range (AR), low imbalance (LI), moderate imbalance (MI), and severe imbalance (SI), are defined in Table 1

2.3 Model development

(1) Model construction

Multiple linear regression is commonly used to establish a relationship between a dependent variable and two or more independent variables (Aiken et al., 2003). Owing to the comparative consistency of the three numerical variables (C_{AH}, *DCPI* and *HS*) observed in the two datasets (Fig. S1b-d), we employed variables from the CHNS (1997–2011) to construct AFH models for each food type via multiple linear regression with backward stepwise selection in SPSS 27 (data details are presented in Table S1). We subsequently input variables from the NBSC into the AFH models through the scoring wizard in SPSS, and extrapolated these AFH data to 2020 (Crona et al., 2020). The AFH model was defined as follows:

$$C_{AFH,t} = \alpha_0 + \alpha_1 C_{AH,t} + \alpha_2 HS + \alpha_4 Year + \alpha_5 Urban + \alpha_6 Rural + \alpha_7 East + \alpha_8 Middle + \alpha_9 West \quad (1)$$

where $C_{AFH,t}$ represents AFH consumption for food type t, and $C_{AH,t}$ represents that of AH. *HS* refers to the number of households, *DIPC* represents disposable income per capita, and *Year* indicates the year surveyed. *Urban* is a binary variable, with 1 representing an urban area and 0 representing other areas. Similar coding was used for other binary variables (*Rural*, *East*, *Middle*, *West*). α_0 is an unknown fixed coefficient and α_1-α_9 are the unknown coefficients of the eight variables. All coefficients were estimated via the least squares method (Ciulla & D'Amico, 2019).

(2) Model accuracy assessment

To evaluate the model accuracy, we used the root mean square error (*RMSE*) and coefficient of determination (R^2).

$$RMSE = \sqrt{\sum_{i=1}^{n} \left(V_{NBSC,ij} - V_{CHNS,ij}\right)^2 / n} \quad (2)$$

$$R^2 = 1 - \sum_{i=1}^{n} \left(V_{NBSC,ij} - V_{CHNS,ij}\right)^2 / \sum_{i=1}^{n} \left(V_{NBSC,ij} - \overline{V}_{NBSC,ij}\right)^2 \quad (3)$$

where $V_{NBSC,ij}$ represents the variable j in province i from the NBSC database, $V_{CHNS,ij}$ represents the corresponding variable from the CHNS database, $\overline{V}_{NBSC,j}$ represents the average of variable j from the NBSC database, n is the number of provinces, and k is the number of independent variables.

In addition, to assess whether there is a collinearity problem among variables, we used the variance inflation factor (*VIF*) for detection (Dormann et al., 2013). Typically, if the computed *VIF* values were less than 5, we considered that no significant collinearity problem existed among the variables (James et al., 2021). The formula for calculating the *VIF* is as follows:

$$VIF = \frac{1}{1 - R^2} \quad (4)$$

(3) Literature data validation

To further validate our model's accuracy, we searched survey data from other literatures. We conducted a literature search on the China National Knowledge Infrastructure (CNKI, https://www.cnki.net/) and Web of Science (https://www.webofscience.com/) databases with keywords including "eating away from home", "eating out of home", "food consumption outside", "take away", and "dining out". These searches were limited to China and covered the period from 2000 to 2020, excluding studies focused solely on children and those specifically related to the COVID-19 period.

2.4 Consumption quantities analysis

(1) Quantities variation and trends

Based on AFH models, we estimated AFH consumption from 2000 to 2020. Additionally, we analyzed the trends in AFH consumption over these two decades by dividing the period into two distinct phases. First, we calculated the proportion of AFH consumption quantity ($Pqu_{AFH,t}$), relative to that of the total AFH + AH consumption (Eq. 5). Next, we applied two nonparametric methods to assess variation trends: Sen's slope estimator (Sen, 1968) was used to quantify trend magnitude, and the Mann–Kendall test (Kendall, 1948; Mann, 1945) was used to test the significance of the observed trends. These methods were utilized to examine the variation trends of AFH consumption for each food type and the total among different provinces, which are widely used in time series analysis (Hamed, 2008; Harka et al., 2021; J. Han et al., 2022). To provide a comprehensive view, we also calculated AH trends for each food type for comparison with those of AFH. Only standard normal test statistic (Z_S) values greater than 1.645 (considered significant, $p < 0.1$) were further analyzed. Detailed information and equations for the Sen's slope estimator and the Mann–Kendall test are provided in Supplement Sect. 1.4.

$$Pqu_{AFH,t} = C_{AFH,t} / \left(C_{AFH,t} + C_{AH,t} \right) \tag{5}$$

(2) Dietary structure

For dietary structure, we calculated the proportions of eight food types among total consumption (Eq. 6). Additionally, to compare the differences between AFH and AH dietary structures (Dif_t), we calculated the difference between the proportion of each food type consumed AFH ($Pat_{AFH,t}$) and AH ($Pat_{AH,t}$).

$$Pat_{AFH,t} = C_{AFH,t} / \sum_{t=1}^{8} C_{AFH,t} \tag{6}$$

$$Pat_{AH,t} = C_{AH,t} / \sum_{t=1}^{8} C_{AH,t} \tag{7}$$

$$Dif_t = Pat_{AFH,t} - Pat_{AH,t} \tag{8}$$

2.5 Improved dietary nutrition quality evaluation

We proposed an improved method for evaluating DNQ, drawing on relevant studies (A. Han et al., 2023; P. He et al., 2018; Liang et al., 2023). Previous methods were primarily based on deviations from Chinese dietary guidelines (P. He et al., 2018), which often overlook variations in recommended dietary intake across different age groups and sexes, both important factors given the demographic differences among provinces. Here, we calculated the RDIPC for each province on basis of adult male equivalents (Table S4). This method allows for a more accurate evaluation of DNQ per capita for various food types, which aligns closely with the actual demographic profiles of each province. Finally, we aggregated the overall DNQ across all food types. Additionally, we categorized the DNQ level according to dietary balance standards (Table 1). The improved method for evaluating DNQ is as follows:

(1) Recommended dietary intake per capita calculation

Owing to varying energy requirements across different age groups and sexes, dietary intake standards differ accordingly (Liang et al., 2023). It is not feasible to determine the specific standards for a healthy, balanced diet required by each province solely based on the dietary guidelines. To calculate the RDIPC, we adopted the dietary standard for adult males as the baseline and multiplied it by the urban and rural population distribution data of various ages and sexes for each province, along with the corresponding adult male equivalent.

(2) Dietary nutrition quality calculation

Table 1 Dietary balance level classification criteria

Absolute Deviation	Dietary balance level
[0%, 20%]	Appropriate range (AR)
(20%, 40%]	Low imbalance (LI)
(40%, 60%]	Moderate imbalance (MI)
(60%, ∞)	Severe imbalance (SI)

We characterized DNQ by assessing deviations from consumption quantities via the RDIPC. To assess the contribution of AFH to DNQ, we separately calculated the DNQ for AH and AH + AFH via the following equations:

$$Deviation_{AH,t} = \left(C_{AH,t} - RDIPC_t\right)/RDIPC_t \tag{9}$$

$$Deviation_{AH,t+AFH,t} = \left(C_{AH,t} + C_{AFH,t} - RDIPC_t\right)/RDIPC_t \tag{10}$$

where $Deviation_{AH,t}$ and $Deviation_{AH+AFH,t}$ represent the extent of deviation between AH consumption ($C_{AH,t}$) and total consumption ($C_{AH,t+}C_{AFH,t}$) of food type t from the RDIPC ($RDIPC_{,t}$), respectively.

(3) Overall dietary nutrition quality

We assessed the overall DNQ in two scenarios: one without considering AFH (Eq. 11) and one with AFH included (Eq. 12), to investigate the impact of AFH on diet quality (Eq. 13).

$$OD_{AH} = \frac{1}{8}\sum_{t=1}^{8} Deviation_{AH,t} \tag{11}$$

$$OD_{AH+AFH} = \frac{1}{8}\sum_{t=1}^{8} Deviation_{AH,t+AFH,t} \tag{12}$$

$$OD_{AFH} = \begin{cases} \left|OD_{AH}\right| - \left|OD_{AH+AFH}\right| & OD_{AH+AFH} \le 0 \\ \left|OD_{AH}\right| - OD_{AH+AFH} & OD_{AH+AFH} \ge 0 \end{cases} \tag{13}$$

where OD_{AH}, OD_{AH+AFH} and OD_{AFH} represent the overall DNQ of AH, AH + AFH, and AFH.

(4) Dietary balance level

We evaluated the level of dietary balance on the basis of absolute DNQ value for various food types and the total, following the criteria proposed by Han et al. (2023).

3 Results

3.1 Away from home models for eight food types

We developed the AFH models based on the CHNS database and subsequently validated their accuracy separately for urban and rural areas (Table 2, Table S2, Fig. S4). In total, all eight models passed the F test ($p < 0.001$) and demonstrated good accuracy ($R^2 = 0.59$ and $RMSE = 4.60$ g/day). All the VIF values were less than 5, suggesting an insignificant collinearity issue among the independent variables. Among these models, the accuracy for cereals and tubers was relatively lower. This may be attributed primarily to the opposing AFH and AH cereal consumption trends, as well as frequent changes in the status of tubers (Supplement Sect. 1.7), which lowered the accuracy of the AFH model simulation.

Additionally, we compiled an AFH validation dataset from previous publications, including 8 food types and nearly 40,000 households (Table S3), to further validate our model simulations. The results demonstrated good consistency between our simulations and other survey data, with an R^2 of 0.53 and $RMSE$ of 15.61 g/d (Fig. S4). It has been observed that AFH consumption is lower than that of previous studies. This discrepancy may stem from the inclusion of zero consumption records in our AFH model. We believe that recording zero consumption accurately reflects the actual consumption behavior of residents, as suggested by Bai et al. (2016). Moreover, our research encompasses provinces in the western region, which were often excluded from prior studies. These areas exhibit lower AFH frequencies, and including consumption data from these provinces naturally results in lower AFH consumption.

3.2 Away from home consumption quantity variation and trends

The per capita AFH consumption varied significantly by food type and year (Fig. 2a-b). AFH quantities were consistently greater in urban areas than in rural areas. Cereals,

Table 2 AFH models and accuracy

Food Type	Regression equation	R^2	$RMSE$
Cereals	$C_{AFH} = 26.76 – 0.03 * C_{AH} + 40 * DIPC + 17.96 * Urban + 0.90 * Middle – 2.66 * West$	0.53	11.33
Tubers	$C_{AFH} = 189.13 + 0.02 * C_{AH} + 0.34 * HS + 2.17 * DIPC—0.10 * Year + 0.63 * Middle + 0.74 * West$	0.50	2.21
Fruits	$C_{AFH} = 177.90 + 0.04 * C_{AH} + 0.50 * HS + 1.06 * DIPC—0.09 * Year—0.97 * Rural—0.42 * Middle$	0.65	1.43
Vegetables	$C_{AFH} = 1302.97—0.01 * C_{AH} + 18.48 * DIPC—0.65 * Year—0.98 * Urban + 0.80 * Middle + 3.57 * West$	0.55	8.33
Pulses & Nuts	$C_{AFH} = 2.85 + 0.05 * C_{AH} + 1.50 * DIPC—2.50 * Rural$	0.59	2.74
Eggs	$C_{AFH} = 128.21—0.02 * C_{AH} + 1.85 * DIPC –0.06 * Year + 1.22 * Urban$	0.65	1.07
MPAs	$C_{AFH} = 1469.91 + 0.09 * C_{AH} + 15.59 * DIPC—0.74 * Year + 3.47 * Rural + 2.91 * Middle + 4.31 * West$	0.64	7.83

vegetables, and MPAs were the dominant AFH food types consumed in both areas. Urban vegetable and MPA consumption increased the most significantly, with increases of 53.51 g and 45.07 g in the two decades, respectively. The consumption averages were less than 11 g in urban areas and less than 5 g in rural areas for other food types. In terms of the proportion of AFH consumption relative to the total (Fig. 2c), we observed fluctuating upward trends for most food types in both areas. Overall, urban areas represented a greater proportion of AFH consumption than rural areas, except for dairy. MPA proportions reached 28.6% and 15.3%, the highest recorded values, in 2020 for urban and rural areas, respectively.

From 2000 to 2020, AFH consumption quantities (Fig. 3a-b and Table S5) increased for both urban (89.37 g to 233.77 g) and rural residents (30.46 g to 81.80 g), reaching 18% and 8% of total consumption by 2020, with a widening gap. Similarly, AFH quantities varied across provinces, ranging from 43.92 g to 207.4 g in urban areas, and 27.79 g to 121.61 g in rural areas. Notably, Shanghai, Zhejiang, and Beijing presented significantly higher AFH consumption quantities than other provinces did, with Beijing and Shanghai exceeding 370 g in 2020 because of their higher daily AFH frequency (Zang et al., 2018). AFH consumption increased rapidly as time progressed from 2000 to 2020, especially in urban areas, where the increase exceeded 4 g/d/5 yr (Fig. 3d-e). The spatial pattern of consumption trends was similar to that of the AFH quantity distribution.

We further compared the trends between AFH and AH for each of the eight food types separately (Fig. 3c). All data points were found to lie above the X-axis, confirming positive trends in AFH for all food types and both urban and rural areas. Moreover, most points fell below the 1:1 line in the first quadrant, indicating that the AFH growth rates (0.74 g/d/5 yr) were lower than those of AH (1.70 g/d/5 yr excluding negative values). Additionally, the growth rate of AFH in urban areas (1.17 g/d/5 yr) surpassed that in rural areas (0.44 g/d/5 yr). MPAs (2.61 g/d/5 yr) and vegetables (2.25/d/5 yr) in the urban area experienced the fastest growth in AFH consumption.

3.3 Away from home dietary structure

To better understand AFH dietary habits, we further analyzed AFH dietary structure. Overall, cereals, vegetables, and MPAs were the main food items consumed AFH, accounting for approximately 80% of the total AFH consumption (Fig. 4a-b). The variation in urban areas was more pronounced than that in rural areas. Cereals proportion of AFH decreased by 22.4% in urban areas, whereas in rural areas, an initial increase was followed by a decline. The consumption proportions of vegetables and MPAs in urban areas increased by 13.9% and 10.2%, respectively, whereas the increases were relatively smaller in rural areas (only approximately 1.4% and 1.2%, respectively).

Across different regions (Fig. 4c-d and Fig. S5), the proportion of plant-based foods consistently ranked highest in the middle region, followed by the western and eastern regions. This is primarily because the middle region, a traditional agricultural area, strongly prefers cereals (Wang et al., 2023b), in contrast to the eastern region where rapid economic growth has led to reduced cereal demand (Ma et al., 2006). The opposite trends were observed for animal-based food consumption. The highest proportions were recorded in the urban areas of the eastern region, followed by the western and middle regions. In rural areas, the proportion of animal-based foods in the eastern region increased from the lowest to the highest, while the western region consistently had higher proportions than the middle region. MPA consumption was notably higher in the eastern region because of the continuously increasing demand driven by rapid economic development and enhanced supply capabilities from improved transportation and logistics (Wang and Tao, 2023). Moreover, the western region, known for its long history of pastoralism (Yin et al., 2020), also exhibited increased consumption of animal-based foods. From 2000 to 2020, the differences in food proportions between rural and urban areas decreased from 7.3% to 0.4%. Additionally, the disparity in food type proportions among provinces narrowed, reaching only 4.2% in urban and 8.8% in rural areas in 2020.

We further investigated the differences between AFH and AH separately in urban and rural areas (Fig. 4e-f) and detected decreases by 29.7% and 16.1%, respectively, from 2000 to 2020. The proportion of AFH MPAs consumption was significantly greater than the proportion of AH. The gap in vegetable intake gradually narrowed, as indicated by positive values in 2020. This is primarily because MPAs are generally considered more delicious, suitable for celebrations and hospitality, and technically challenging to cook than vegetables are, which leads to greater MPA choices in AFH settings (Xue et al., 2021; Yuan et al., 2018). Distinct values were observed for cereal consumption, with mostly positive values in urban areas (indicating a higher AFH than AH cereal proportion) and negative values in rural areas, with narrowing gaps in both areas. In urban areas, AH cereal consumption has stabilized since 2000, whereas AFH cereal consumption initially accounted for a greater proportion (45.6%) due to limited food variety, but gradually decreased to 23.1% by 2020 as more food types became available. In rural areas, the change was caused mainly by the rapid decrease in the cereal proportion of AH. The consumption trend of vegetables in both urban and rural areas has shifted from primarily AH to predominantly AFH by 2020. For fruit consumption, mostly negative values were observed in both areas, especially in urban areas. This is mainly because fruits are rarely included, or only provided in small amounts, in Chinese restaurant menus (Qian et al., 2021). The variation in the proportions of vegetable and cereal consumption also reflects China's dietary transition toward more diversified diets (Xin, 2021). The differences in the AFH and AH consumption ratios were not significant for other food types and were generally within ± 3%.

3.4 Impact of away from home on dietary nutritional quality

Using the improved DNQ assessment method, we calculated the DNQ values and balance levels (Fig. 5). For AH, there was considerable variation in DNQ across different food types. In addition to cereal consumption, which presented significantly greater deviation values in rural areas, all other food types presented lower DNQ values in rural areas than urban areas. The consumption proportions of certain food types, including tubers, fruits, vegetables, eggs, and dairy, generally indicated a more balanced diet. However, by 2020, except for vegetables and eggs, which aligned with the dietary levels of fruits in urban areas within the AR and LI levels, all other food types mentioned above still fell into the MI and SI levels. For the consumption of MPAs and pulses & nuts, they enhanced DNQ and promoted dietary balance from 2000 to 2010 in rural areas, but as their consumption continuously increased over time, they contributed to dietary imbalance. For cereals, rural areas exhibited rapid improvements in DNQ, yet the DNQ was still > 60, indicating an SI level, whereas urban areas showed only slight changes, remaining within the AR level.

When considering AFH, the consumption of MPAs and pulses & nuts has been found to truly lower the DNQ and exacerbate dietary imbalances in both urban and rural areas since 2015. In 2020, the DNQ of MPAs decreased by 59.8% in urban areas (from MI to SI) and by 21.8% in rural areas (from LI to MI). For pulses & nuts, the DNQ fell by 46.1% in urban areas (remaining in SI) and 19.5% in rural areas (from MI to SI). However, the impacts on DNQ varied by food type. Regarding foods that were under consumed, AFH consumption helped compensate for these deficiencies, enhancing DNQ to some extent, particularly in rural areas. For example, AFH vegetable intake in rural areas in 2020 improved DNQ from LI to AR. This highlights the importance of a detailed assessment of specific foods and their intake quantities. The impacts of AFH on DNQ have changed over the past two decades. The impacts of vegetables, eggs, and MPAs on urban residents and those of pulses & nuts and MPAs on rural residents have shifted improvement to deterioration in terms of DNQ. Although AH consumption has a fundamental effect on DNQ and dietary balance levels, the impact of AFH on DNQ has continuously increased, particularly in urban areas.

We calculated the deviations in total consumption from the RDIPC after considering AFH from 2000 to 2020 at the provincial scale (Fig. 6). In 2000, the overall DNQ was negative in both urban (Fig. 6a) and rural areas (Fig. 6b). The balance level of DNQ in urban areas was better than that in rural areas, with LI level mainly observed in the provinces of western and southern of China. After considering the impacts of AFH, it is evident that the inclusion of AFH improved DNQ, as shown by the red dots. Additionally, the chord diagram distinctly illustrates the balance level improving from MI to LI in one province and from LI to AR in ten provinces, with more than 58% of the provinces achieving AR level. This demonstrates a significant average DNQ improvement of 8.1% attributable to AFH. In rural areas, due to the lower quantities of AFH at that time, the improvement impact on DNQ was weaker, averaging only 2.9%. The MI level was 26%, with an LI level of 68%, and only two provinces reached AR level. By 2020, the impact of AFH on DNQ (Fig. 6c and d) had changed. In urban areas, the overall DNQ values of most provinces were positive indicating a decrease in DNQ for AFH. Nine provinces experienced a decline in their dietary balance level, shifting from AR to LI levels, but AR levels remained predominant (68%). In rural areas, the overall DNQ was still negative for most provinces. Nevertheless, AFH improved their DNQ values, although the improvement was weak according to the dietary balance level. From a national perspective (Fig. 6e and f), between 2000 and 2020, the overall AH DNQ for both urban and rural areas showed an increasing trend reaching AR level by 2020 due to the negative values. Notably, when the impact of AFH was considered, the influence on DNQ varied over time and between urban and rural areas. We found that AFH significantly improved DNQ in urban areas from 2000 to 2010 (Fig. 6e). However, this improvement declined in 2015 and shifted to deterioration in 2020. In rural areas, AFH has a consistently positive effect on DNQ (from 2.8% to 8.6%). However, with the rapid increase in overall DNQ, the impact of AFH on DNQ could shift from improvement to deterioration in the future.

4 Discussion

4.1 Does increased away for home meat, poultry, and aquatic products consumption decrease dietary nutrition quality?

From a quantity perspective, previous studies have criticized that consuming more MPAs in AFH contributes to a greater health burden for Chinese residents (Bu et al., 2021; L. Huang et al., 2021). However, we found that AFH MPA consumption was slightly lower than that of vegetables, with average deficits of 2.97 g/d in urban areas and 0.63 g/d in

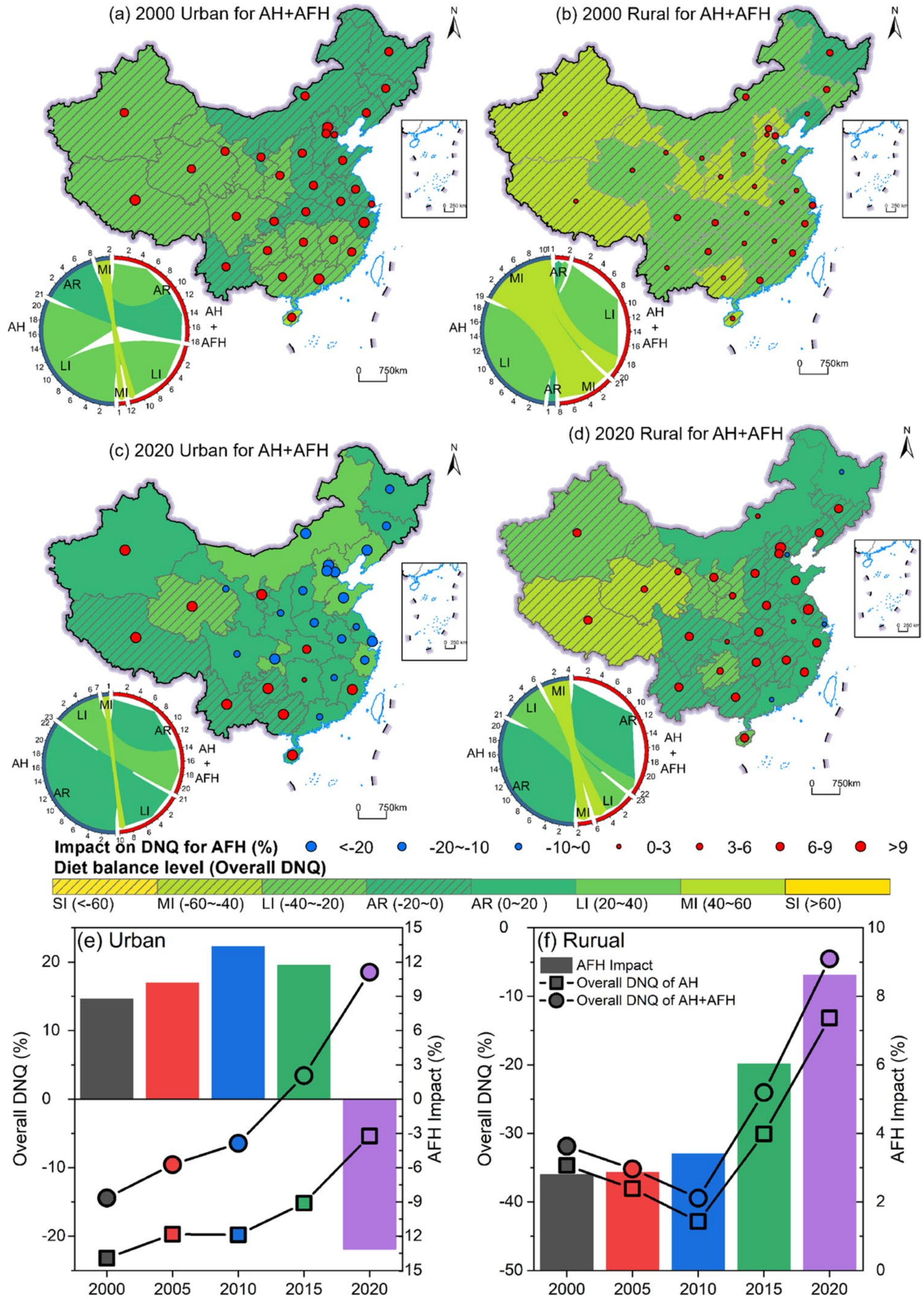

Fig. 6 Overall DNQ and the impact of AFH at the (**a**-**d**) provincial scale and (**e**–**f**) national scale in urban and rural areas. The background color in (**a**-**d**) represents different DNQ-based dietary balance levels. The diagonal lines indicate negative DNQ values. The blue and red dots represent the impacts of AFH on DNQ, with the blue dots representing deterioration and the red dots representing improvement. The chord diagram shows the dietary balance level shifts before and after considering AFH

rural areas over the 20-year period. Bai et al. (2016) also noted that in 2010, AFH MPA consumption was approximately 10 g/d less than that of vegetables. The growth rates of the two types are also similar (Fig. 3c). MPAs significantly exceeded other food types in terms of the proportion of AFH consumption, accounting for 28.56% in urban areas and 15.28% in rural areas (Fig. 2c).

From a quality perspective, we found AFH had a negative impact on DNQ in urban areas only in 2020 (Fig. 6e). Specifically, regarding MPAs, AFH consistently had a negative nutritional impact in urban areas. However, analysis at the provincial scale further revealed that even in urban areas (Fig. S7a), AFH MPAs improved DNQ for more than half of the provinces. Even in 2020, MPAs consumption in the urban areas of Shanxi, Shaanxi, Ningxia, Qinghai, Gansu, and Henan still did not meet the RDIPC. AFH compensated for these deficiencies and improved DNQ in Shanxi, Shaanxi, and Ningxia, but it decreased DNQ in Qinghai and Gansu due to high AFH consumption quantities (Fig. S7a). In rural areas, between 2000 and 2010, AFH MPAs acted as a beneficial supplement to diets where AH intake did not meet the RDIPC. From 2015 to 2020, the influence of AFH shifted toward a negative effect due to the increase of MPA AH intake. Although the median trend aligns with the overall pattern, a significant number of provinces still display opposing trends. This divergence confirms that the effects of increased AFH MPAs intake on DNQ for Chinese residents need reconsideration. Additionally, while AH MPAs consumption remains the dominant factor influencing DNQ, the impact of AFH is becoming increasingly important.

4.2 Strategies for transitioning to a more nutritious diet

The dynamic patterns of consumption in the present study revealed that AFH is becoming less beneficial over time and increasingly associated with the deterioration of nutritional health. In this situation, timely dietary interventions for both urban and rural residents in China are highly necessary for improving DNQ and reducing the nutritional burden. Dietary guidelines have been developed by numerous countries to promote healthy eating habits and enhance DNQ (Herforth et al., 2019; Springmann et al., 2016). These guidelines aim to inform individuals about balanced food intake according to scientific nutritional principles (Herforth et al., 2019). In the United States, adherence to dietary guidelines was shown to be associated with a lower risk of developing cardiovascular diseases, cancer, and other diseases (D. Yu et al., 2014). Chinese residents have severe deficiencies in dairy consumption, resulting in over 97% of the population facing the risk of inadequate calcium intake (National Bureau of Disease Control & Prevention, 2022).

Thus, we emphasize the importance and urgency of enhancing nutritional education (Hou et al., 2024) to improve public dietary knowledge, particularly by promoting awareness of Chinese dietary guidelines. This includes encouraging increased consumption of fruits and dairy products, reducing red meat intake, and shifting toward greater consumption of aquatic products. These measures collectively aim to enhance the DNQ of both urban and rural Chinese residents and promote food system sustainability.

4.3 Limitations

First, we developed AFH models based on the CHNS and NBSC databases. For the CHNS, investigators collected three-day consumption data in autumn, which failed to capture seasonal influence (Y. Huang et al., 2017) but minimized seasonal variability to some extent (Kim et al., 2003). Second, expanding the results to the regional scale and extrapolating the data to 2020 (Crona et al., 2020) might introduce some errors due to differences in dietary habits and transitions (Wang et al., 2023a). Third, we developed AFH models with several variables rather than all factors potentially associated with AFH estimates after comprehensively considering the consistency and availability between both databases. Additionally, to align with the dietary guidelines, we only constructed one model for MPAs, which did not account for the internal nutritional quality differences within MPAs, particularly for aquatic products. Aquatic products, known for their abundant micronutrients, are associated with a lower risk of developing cardiovascular diseases and have more positive health effects than red and processed meats (Kaljonen et al., 2019; Rimm et al., 2018; Zhang et al., 2022b). In the future, it will be necessary to conduct more comprehensive field surveys on consumption. Additionally, there is a need to refine the types of MPAs and conduct detailed assessments of the differences in AFH consumption among these types and their impacts on DNQ.

5 Conclusions

Based on refined AFH estimations ($R^2 = 0.59$ and $RMSE = 4.60$ g/d), we analyzed dynamic patterns of consumption and assessed their effects on DNQ and dietary balance levels. We observed significant differences in the quantity and growth rate of AFH between urban and rural areas, leading to an expanding gap. By 2020, AFH accounted for 18% (234 g) of total consumption in urban areas and 8% (82 g) in rural areas. Cereals, vegetables, and MPAs are the main food types consumed in AFH settings, accounting for approximately 80% of total AFH consumption. MPAs and vegetables in urban areas experienced the fastest growth, at rates of 2.61 g/d/5 yr and 2.25 g/d/5 yr respectively. Additionally, the dietary differences between AH and AFH consumption decreased by 29.7% in urban areas and 16.1% in rural areas from 2000 to 2020. The impacts of AFH on DNQ varied by area, food type, and time. In urban areas, AFH consumption of MPAs and pulses & nuts consistently had negative effects on DNQ. Conversely, in rural areas, these food types had positive impacts on DNQ from 2000 to 2010, but negative effects from 2015 to 2020. Other food types also exhibited varied trends. In terms of total consumption, AFH initially improved urban DNQ from 2000 to 2015 but subsequently showed deteriorating effects. In contrast, AFH consistently had a positive effect on DNQ in rural areas. Although AH consumption has a fundamental impact on DNQ and dietary balance levels, the impact of AFH on DNQ has continuously increased, particularly in urban areas. We emphasize the importance of enhancing nutritional education for Chinese residents to develop healthy dietary habits. This study deepens our understanding of consumption patterns among urban and rural residents, particularly the relationship between AFH and DNQ. The insights provided can support AFH-related research concerning environmental impacts, policy-making, and lifecycle assessments, thus contributing to the objectives of the "Healthy China 2030" initiative and enhancing food system sustainability.

Supplementary information The online version contains supplementary material available at https://doi.org/10.1007/s12571-024-01514-4.

Acknowledgements This work was supported by the National Natural Science Foundation of China (grant no. 42061144003 and 42301187).

Author contribution **Huaqing Wu**: Conceptualization, Methodology, Formal analysis, Writing—review & editing. **Zhao Zhang**: Conceptualization, Project administration, Writing -review & editing. **Jialu Xu**: Conceptualization, Writing -review & editing. **Jie Song**: Data curation. **Jichong Han**: Data curation, Visualization. **Jing Zhang**: Conceptualization. **Qinghang Mei**: Writing—review & editing. **Fei Cheng**: Methodology. **Huimin Zhuang**: Methodology. **Shaokun Li**: Methodology.

Data availability Data will be made available on request.

Declarations

Competing interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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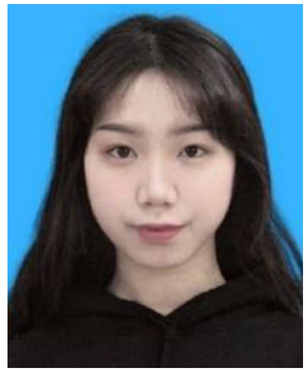

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