Eating away from home promotes diet nutrition quality for both urban and rural residents in China

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Abstract:

With China's rapid economic growth, eating away from home (EAFH) has surged. The absence of EAFH data leads to significant underestimation of household food consumption. We utilized the China Health and Nutrition Survey (CHNS), a comprehensive survey to construct EAFH models (R^2 = 0.67) for major food types and estimate consumption from 2000 to 2020. By 2020, daily EAFH consumption averaged 214g in urban and 84g in rural areas, accounting for 17.6% and 7.8% of the total, respectively. EAFH consumption grew in both urban and rural areas, the rate was slower than eating at home (EAH). Food's positive EAFH effects on nutritional quality balanced out negative impacts for urban and rural areas. Moreover, the total nutrition quality had been noticeably improved in urban (-18.0% to -6.3%) and rural (-24.3% to -19.1%) areas after considering EAFH. Our study can provide references for dietary transformation and the Healthy China 2030 Action.

Key words: Eating away from home, food consumption, dietary nutrition, diet transition

1. Introduction

Over the past two decades, China's economy has increased remarkably, significantly improves people's lives. Meanwhile, their eating behaviors (eating at home, EAH and eating away from home, EAFH) have greatly changed (Huang et al., 2021). The food consumption of EAFH has been increasing and will keep the trend in near future (Ma et al., 2006; Orfanos et al., 2007; Zhou et al., 2012; Liu et al., 2015). According to the 2020 Report on Chinese Nutrition and Chronic Disease (National Bureau of

Disease Control and Prevention, 2022), nearly half (46.3%) of Chinese residents were EAFH at least once a week (+10.8% after 5 years), with 22.3% ones over nine times a week. Such distinct increases in EAFH indicate an nutrition transition in China (Huang et al., 2021), implying a systematic study on EAFH is highly urgent.

EAFH has a different food structure that leads to more health and environment issues, as highlighted by numerous prior studies primarily focused on developed countries, including the increasing risk from non-communicable diseases (Afshin et al., 2019; Gesteiro et al., 2022; Lachat et al., 2012) due to excessive caloric intake and poor diet quality (Todd et al., 2010; Todd and Mancino, 2010), a huger food loss and waste (EAFH: 13%; EAH: 4%) (Talwar et al., 2023) and a larger carbon footprint due to the high-intensity methane emissions from increased meat consumption (Horgan et al., 2019; Biermann and Rau, 2020).

Many studies on EAFH conducted in China were mainly focused on the frequency (Zhai et al., 2014; Yao et al., 2019) and its drivers (Liu et al., 2015; Zheng and Wang, 2016; Li et al., 2019). However the amount and structure of EAFH, closely related to environment and health, are still unclear(Zhai et al., 2014). The related studies were very limited due to the lack in EAFH data even a long-term annual food consumption records available from National Bureau of Statistics of China (NBSC) (XIAO et al., 2015; Yuan et al., 2018). Several studies have examined dietary structure through field surveys (Bai et al., 2016; Wang et al., 2017; Chen et al., 2018), but some limitations existed there because of their representativeness and comparability due to small sizes sampled, restricted areas and periods surveyed (Xin and Li, 2018). Therefore, developing a EAFH consumption model is crucial to accurately dialogize the spatio-temporal characteristics of residents' dietary, finally realize the aims of the Healthy China 2030 and Sustainable Development Goals in China (Xin and Li, 2018). Moreover, we are sure the EAFH model will benefit to monitor nutritional status more accurately and reliably, consequently improve residents' health and ensure national food security (Yu and Abler, 2014).

For informing individuals on making balanced food choices, many countries have promulgated dietary guidelines to promote healthy eating habits and enhance nutrition quality (Herforth et al., 2019). Adhering to the national guideline did lower the risk of cardiovascular diseases, cancer, and other diseases in America. (Yu et al. (2014). Although previous studies have emphasized the negative impacts of EAFH from excessive meat intake (Lachat et al., 2012; Gesteiro et al., 2022), the disparity between consumption and dietary guidelines and comprehensive nutrient quality assessment beyond meat are untacked in China.

To address the above issues on EAFH among Chinese residents, we aim to 1) develop an EAFH model and improve food consumption estimation; 2) analyze EAFH features and dynamic food structures; 3) comprehensively assess the nutrition quality of residents. The potential findings will provide insights for promoting diet transition and nutrition health in China.

2. Materials and methods

2.1 Data collection

(1) Dietary guideline

The recommended daily dietary intake ranges and food types are based on the latest 5th edition of the Chinese Dietary Guidelines (https://www.cnsoc.org/tool/), released in 2022, comprising eight types with specified amounts: cereals (200-300g), tubers (50-100g), fruits (200-350g), vegetables (300-500g), eggs (40-50g), meat (70-160g), pulses & nuts (25-35g), and milk (300-350g). The total daily intake per person ranges from 1195 to 1835g. Detailed information was provided in the supplementary materials (Fig. S1).

(2) CHNS datasets

The China Health and Nutrition Survey (CHNS) is an ongoing longitudinal household survey conducted in 12 provinces of China and since 1989, utilizing a robust sampling method (Zhang et al., 2014). It is the only large-scale and long-term survey that collected representative data on socio-economic and food consumption separately recorded by eating behaviors (EAH and EAFH, definitions presented in the supplement) for both rural and urban areas (Su et al., 2017), As a result, the CHNS datasets have been extensively employed (Song et al., 2015; He et al., 2018; Li et al., 2019; Wang et al., 2020).

For this study, we extracted 2.15 million food intake records from a total of 27,887 residents in 8,009 households, with information on per capita disposable income, household size and eating behavior for the years 1997, 2000, 2004, 2006, 2009, and 2011. To ensure data quality, outliers beyond the average of ±2SD (standard deviation) were removed following previous studies (Zhang et al., 2022; Wu et al., 2023), and the remaining data were further analyzed at the provincial scale. Data details were presented in Table S1.

(3) NBSC datasets

The National Bureau of Statistics of China (NBSC) provides various statistical yearbooks offering comprehensive, long-term and nationally representative data on socio-economic factors for each province in China (Yuan et al., 2018) while excluding information on food consumption of EAFH. Data on per capita disposable income, household size and food consumption of EAH for different food types were separately collected for urban and rural areas of each province every five years from 2000 to 2020. The consumption of cereals and tubers was reported as raw grains, while urban residents' consumption was reported as processed grain before 2013 (Wang et al., 2020). Hence, we converted the raw grains to processed grain using a conversion coefficient of 0.82 for cereals and 0.94 for tubers based on the averages of previous studies (He et al., 2004; Zhang et al., 2012).

(4) EAFH data collected from literatures

We conducted a literature search on China National Knowledge Infrastructure (CNKI, https://www.cnki.net/) and Web of Science (https://www.webofscience.com/) databases using 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 1997 to 2023, excluding studies solely focused on children and those specifically related the COVID-19 period. All data details were summarized in the supplement (Table S2).

2.2 EAFH model development

The food consumption of EAFH is impacted by various factors, such as food consumption of EAH, per capita disposable income, occupation, educational level, region, household size, and area (Li et al., 2019). Considering variables recorded in the two datasets, eight variables were selected as predictor variables. Before the model development, we performed a consistency test on numerical variables (food consumption of EAH, per capita disposable income and household size) from CHNS and NBSC databases, using the Pearson correlation coefficient (Lavelle et al., 2017; Gibbs et al., 2018; Reedy et al., 2018).

Multiple linear regression (MLR) is commonly employed to establish a relationship between a dependent variable and two or more independent variables (Aiken et al., 2003). After the consistency test, we utilized data from the CHNS dataset to construct the EAFH model by MLR with backward stepwise selection in SPSS 27. Subsequently, NBSC dataset was used to estimate food consumption of EAFH. The EAFH model was defined as follows:

$$C_{EAFH,t} = \alpha_0 + \alpha_1 C_{EAH,t} + \alpha_2 Householdsize + \alpha_3 Income + \alpha_4 Year + \alpha_5 Urban + \alpha_6 Rural + \alpha_7 East + \alpha_8 Middle + \alpha_9 West \quad (1)$$

where $C_{EAFH,t}$ represents the food consumption of EAFH for food type t, and $C_{EAH,t}$ for those of EAH. *Householdsize* refers to the number of households, *Income* represents per capita disposable income, and *Year* indicates the year surveyed. *Urban* is a binary variable where 1 indicates an urban area while another area was labeled as 0, and similar rules were 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 by the least square method (Ciulla and D'Amico, 2019).

To evaluate the model accuracy, we utilized the root mean square error (*RMSE*) and adjusted coefficient of determination (R^2), which prevented overfitting and provided a more robust result when compared with R^2 (Kaytez et al., 2015).

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

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

$$\text{Adjusted } R^2 = 1 - \frac{(1-R^2)\times(n-1)}{n-k-1} \quad (4)$$

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

2.3 EFAH and EAH trend analysis

We employed two non-parametric methods, the Mann-Kendall test (Kendall, 1948; Mann, 1945) and Sen's slope estimator (Sen, 1968), to examine the trends of EAFH and EAH. The Mann-Kendall test, which is insensitivity to outliers (Hamed, 2008), was used to test the significance of the observed trends. Only the standard normal test statistic Z_S values greater than 1.96 (thought as significant, $p<0.05$) were further analyzed. Sen's slope estimator provided a non-parametric approach for estimating the slope of the EAFH and EAH trends. These two methods are widely used in time series analysis (Hamed, 2008; Harka et al., 2021; Han et al., 2022). The supplement provided more detailed information and equations for the Mann-Kendall test and Sen's slope estimator.

2.4 Dietary nutrition quality assessment

We assess the nutrition quality gap whether considering EAFH based on the deviation from dietary guidelines proposed by He et al. (2018) and Yin et al. (2021).

$$Deviation_{EAH+EAFH,t} = \begin{cases} (C_{EAH,t} + C_{EAFH,t} - C_{DG\,min,t}) / C_{DG\,min,t} & C_{EAH,t} + C_{EAFH,t} > C_{DG\,min,t} \\ 0 & C_{DG\,min,t} \le C_{EAH,t} + C_{EAFH,t} \le C_{DG\,min,t} \\ (C_{EAH,t} + C_{EAFH,t} - C_{DG\,max,t}) / C_{DG\,max,t} & C_{EAH,t} + C_{EAFH,t} > C_{DG\,max,t} \end{cases} \quad (5)$$

$$Deviation_{EAH,t} = \begin{cases} (C_{EAH,t} - C_{DG\,min,t}) / C_{DG\,min,t} & C_{EAH,t} > C_{DG\,min,t} \\ 0 & C_{DG\,min,t} \le C_{EAH,t} \le C_{DG\,min,t} \\ (C_{EAH,t} - C_{DG\,max,t}) / C_{DG\,max,t} & C_{EAH,t} > C_{DG\,max,t} \end{cases} \quad (6)$$

$$Deviation_{EAFH,t} = Deviation_{EAH+EAFH,t} - Deviation_{EAH,t} \quad (7)$$

where $Deviation_{EAH,t}$, $Deviation_{EAH+EAFH,t}$, and $Deviation_{EAFH,t}$ represent the extent of deviation between the consumption of EAH ($C_{EAH,t}$), total consumption ($C_{EAH+EAFH,t}$) and consumption of EAFH ($C_{EAFH,t}$) of food type t and the recommended intake range specified in the dietary guidelines, respectively. $C_{DGmin,t}$ and $C_{DGmax,t}$ represent the lower and upper limits of the recommended intake range, respectively, recommended by the dietary guidelines.

Additionally, we assessed the overall nutrition quality under two scenarios: one considering the impact of EAFH (Eq. 8) and the other not considering EAFH (Eq. 9), aiming to investigate the impact on diet quality. Furthermore, we evaluated the level of diet balance based on the absolute deviation from the dietary guidelines (Table S3) according to the criteria proposed by Han et al. (2023) .

$$\mathrm{TD}_{EAH+EAFH} = \frac{1}{8}\sum_{t=1}^{8} Devation_{EAH+EAFH,t} \quad (8)$$

$$\mathrm{TD}_{EAH} = \frac{1}{8}\sum_{t=1}^{8} Devation_{EAH,t} \quad (9)$$

where $TD_{EAH+EAFH}$ and TD_{EAH} represent the total deviation of total consumption and consumption of EAH.

3.Results and Discussion

3.1 EAFH Model Accuracy

Firstly, the three numerical variables, including , from the NBSC database are strong consistency with those of CHNS database, with Pearson correlation coefficient values of 0.93, 0.90, and 0.62, respectively. Thus, we constructed the EAFH models using the CHNS data, and can apply them into those of NBSC for further predicting food consumptions (Table 1) in each province.

Table 1 EAFH models and the accuracy

Food Type	Regression equation	Adjusted R^2	*RMSE* (g/day)
Cereals	C_{EAFH} = 95.94 - 0.12 * C_{EAH} -10.95 * *Householdsize* + 0.49 * *Income* - 5.59 * *Rural* + 14.05 * *Middle* + 12.39 * *West*	0.54	11.54
Tubers	C_{EAFH} = 189.13 + 0.02 * C_{EAH} + 0.34 * *Householdsize* + 2.17 * *Income* - 0.10 * *Year* + 0.63 * *Middle* + 0.74 * *West*	0.51	2.21
Fruits	C_{EAFH} = 177.90 + 0.04 * C_{EAH} +0.50 * *Householdsize* + 1.06 * *Income* - 0.09 * *Year* - 0.97 * *Rural* - 0.42 * *Middle*	0.55	1.43
Vegetables	C_{EAFH} = 1302.97 - 0.01 * C_{EAH} + 18.48 * *Income* - 0.65 * *Year* - 0.98 * *Urban* + 0.80 * *Middle* + 3.57 * *West*	0.74	8.32
Eggs	C_{EAFH} = 128.21 - 0.02 * C_{EAH} + 1.85 * *Income* -0.06 * *Year* + 1.22 * *Urban*	0.79	1.07
Meat	C_{EAFH} = 1469.91 + 0.09 * C_{EAH} + 15.59 * *Income* - 0.74 * *Year* + 3.47 * *Rural* + 2.91 * *Middle* + 4.31 * *West*	0.66	7.83
Pulses & Nuts	C_{EAFH} = 2.85 + 0.05 * C_{EAH} + 1.50 * *Income* - 2.50 * *Rural*	0.61	2.74
Milk	C_{EAFH} = 2.95 + 0.02 * C_{EAH} - 0.91 * *Householdsize* + 1.13 * *Income* + 1.12 * *Middle* + 1.47 * *West*	0.63	1.84

All the eight models passed the F test (p<0.001) and had a good accuracy (averages of adjusted R^2 = 0.67 and *RMSE* = 4.62 g/day). Among these models, the accuracy of eggs was the best with an adjusted R^2 of 0.79, while that of tuber was relatively poorer (0.51). This might be primarily attributed to frequent changes for tubers in the diet. During cereal shortages, tubers served as a substitute for staple foods (Scott, 2021; Scott et al., 2000). As their supply improves, their role will shift towards a supplement for vegetables (Scott and Suarez, 2012). Nevertheless, the Chinese government now categories tubers into staple food according to health and sustainable development goals (Wang et al., 2020).

Furthermore, we established an EAFH validation database, drawing from 13 literatures of 8 food types with nearly 40000 households (Table S2) to validate our model predictions. The results demonstrated a good alignment between our predicted results and other survey data, with the R^2 of 0.53 and *RMSE* of 15.61 g/day (Fig. S1).

3.2 The food amount of EAFH

We estimated annual per capita food consumption of EAFH from 2000 to 2020 by EAFH models for each province. All food consumptions of EAFH in urban areas are consistently larger than those of rural areas, ranging from 82g to 214g compared to 23g to 84g. Notably, we observed substantial increases in vegetables (15 to 68g compared to 9 to 25g) and meat consumption (14 to 68g compared to 8 to 23g) in both urban and rural areas. However, cereal consumption remained relatively stable at approximately 45g in urban area, while it underwent a significant increase (from 1 to 21g) in rural area. Furthermore, consumptions of other food types exhibited relatively stable patterns, with lower levels in urban (around 10g) and rural (around 5g) areas.

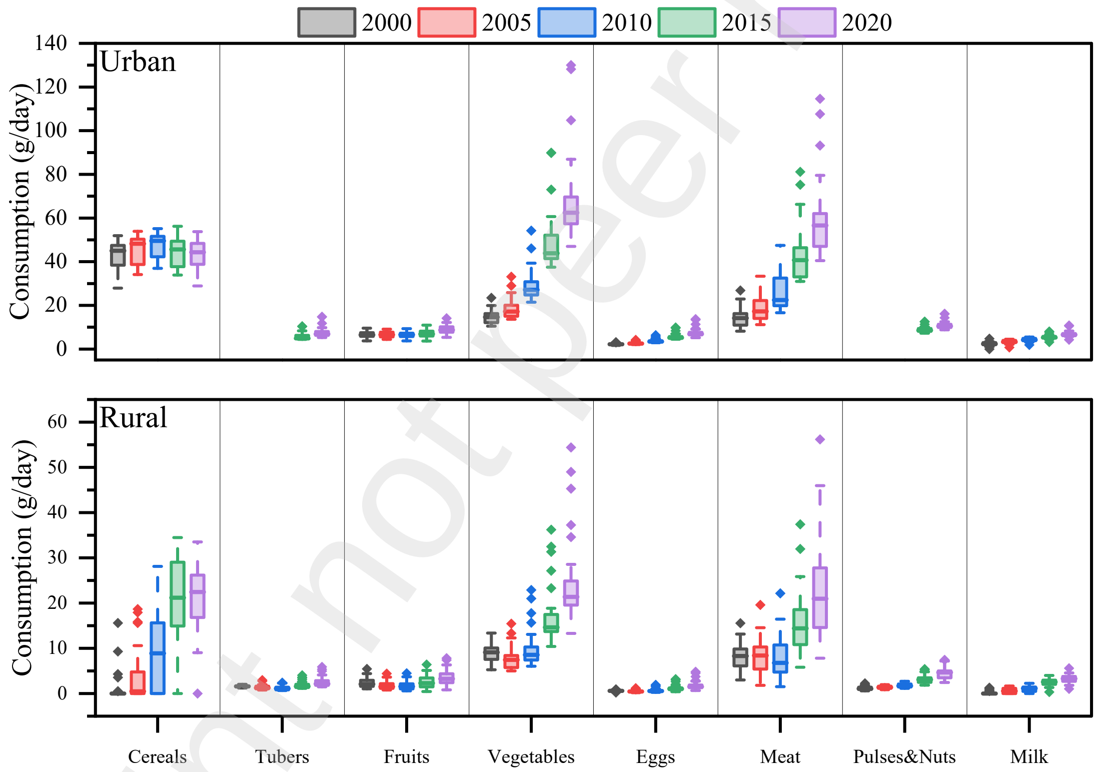

Figure 1 Per capita food consumption of EAFH every five years from 2000 to 2020. Box plots show data from all provinces. The urban data for Tubers and Pulse & Nuts is unavailable in 2000, 2005, and 2010.

To emphasize the importance of EAFH, we took the food consumption data in 2020 as an illustrative example for further analysis. We aggregated the food consumption from each province to a national scale based on food types, areas and eating behaviors (Table 3). Similarly to the provincial scale, the consumption of EAFH for all food types exceeded that of EAH at the national scale. As for the percentage of EAFH, the results clearly indicate that EAFH cannot be disregarded, particularly in urban areas where it constitutes 17.6% compared to the 7.8% in rural areas. Analyzing the specific food types, apart from fruits, the percentage of EAFH for other food types exceeded 10% in urban area. Notably, meat consumption of EAFH even approached nearly 30%. In rural areas, EAFH meat consumption accounted for most (15.3%), followed by 13.7% milk and11.5% Pulses & Nuts. These findings further highlight the urgence to accurately quantify the consumption of EAFH.

Table 2 Per capita food consumption in 2020

Food type	EAH (kg year^{-1})		EAFH (kg year^{-1})		Total (kg year^{-1})		Percentage of EAFH (%)	
	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
Cereals	88.2	126.7	15.41	7.81	103.6	134.5	14.9%	5.8%
Tubers	13.4	16.1	2.9	0.9	16.3	17.0	17.8%	5.0%
Fruits	61.1	40.4	3.4	1.3	64.5	41.7	5.2%	3.1%
Vegetables	109.5	95.7	25.8	8.5	135.3	104.2	19.1%	8.1%
Eggs	13.4	11.7	2.8	0.6	16.2	12.4	17.4%	5.0%
Meat	57.2	44.8	22.9	8.1	80.0	52.9	28.6%	15.3%
Pulses & Nuts	14.3	13.0	4.1	1.7	18.4	14.7	22.3%	11.5%
Milk	17.3	7.3	2.5	1.2	19.7	8.5	12.5%	13.7%
Total	374.3	355.7	79.7	30.0	463.6	380.2	17.6%	7.8%

* EAH: eating at home

3.3 Trends of EAFH

Applying the Sen's Slope and Mann-Kendall method, we calculated the consumption trends (only the significant trends, $p < 0.05$) of EAFH and EAH from 2000 to 2020, depicted in Fig. 2. All the identified trends were situated within the upper two quadrants, indicating an increasing trend of EAFH. Mainly cereals and vegetables consumption of EAH, exhibited a decreasing trend, which closely aligned with previous research (Wang et al., 2020). In the context of the first quadrant, most points were below the 1:1 line, indicating a lower growth rate of EAFH (0.68) in contrast to that of EAH (1.73). The average growth rate of vegetables (1.72), meat (1.51) and cereals (1.00) exhibited significant increase compared to other food types. Moreover, the average growth rate in rural areas (1.14) surpassed that in urbans

(0.36), further substantiating the previous researches (Zeng and Zeng, 2018). Among different regions, the eastern region exhibited the highest growth rate (0.91), followed by the central (0.56) and western (0.53) regions.

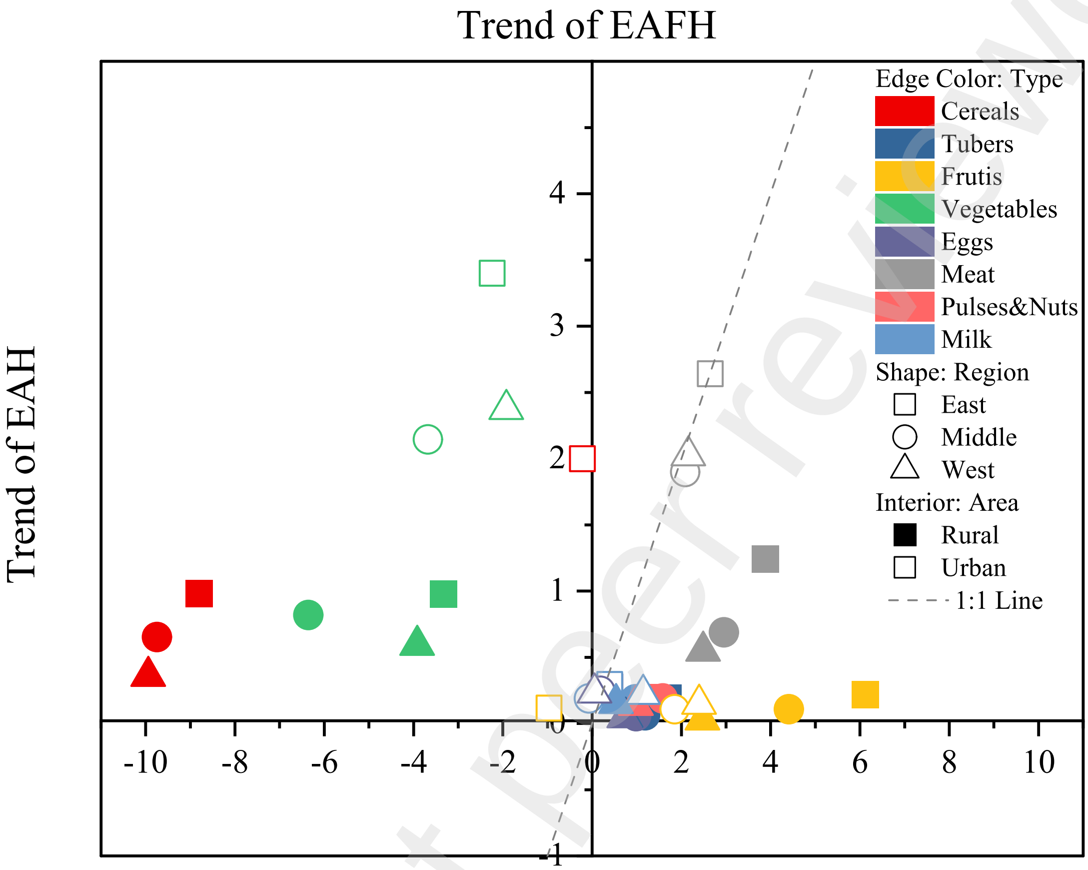

Figure 2 The trends of EAFH and EAH from 2000 to 2020

3.4 Diet Habits of EAFH

We analyzed the food structure for both EAFH and EAH for better understanding the dietary habits of EAFH (Fig. 3a-b). In urban areas (Fig. 3a), the top three types were vegetables (31.7%), meat (27.6%), and cereals (21.2%), collectively accounting for approximately 80% of the overall food consumption; conversely, other food types were generally below 5%. Additionally, eastern region exhibited a lower proportion of cereals (16.2%), higher vegetables (34.0%) and meat (30.1%), while the distinctions were less pronounced in the central and western regions. In rural areas (Fig. 3b), though the same three foods (nearly 27%) were listed on the top, the dietary structure varied hugely among provinces.

The disparity in dietary structure between EAFH and EAH in urban (Fig. 3c) suggested higher proportions of EAFH for meat (13.1%), vegetables (2.5%), pulses & nuts (1.5%), and eggs (0.1%), while lower proportions were observed for fruit (-12.0%), cereals (-3.1%), milk (-1.7%), and tubers (-0.4%) compared to EAH. Among the three regions, the middle areas showed less variability than others. A similar pattern observed in rural areas (Fig. 3d) indicating the similar gap of food structure between EAFH and EAH, with exception of egg (-0.9%) and milk (1.7%).

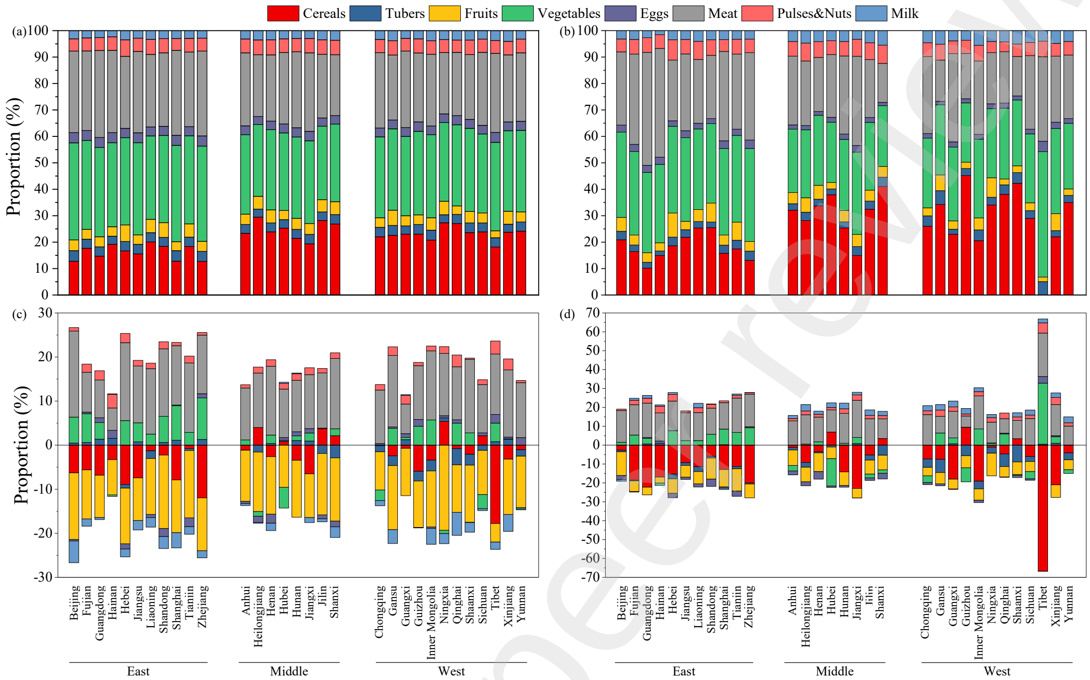

Figure 3 Diet structure for the eight food types of EAFH (a-b) and their differences to EAH (c-d) in 2020 for urban (a, c) and rural areas (b, d).

3.5 The impacts of EAFH on nutrition quality

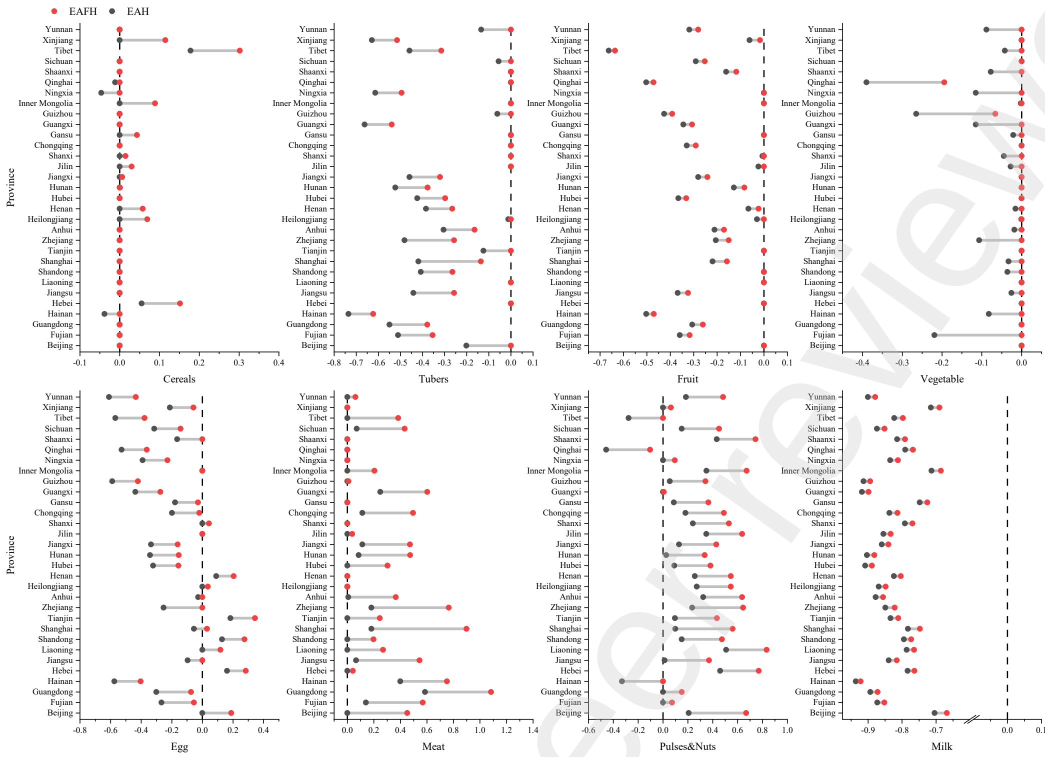

Figure 4 Dietary nutrition quality of EAH and EAFH in urban of 2020, with the gray (red) dots for food deviations of EAH (EAH+EAFH) from the dietary guidelines.

After considering EAFH, our observations in urban areas indicated that the consumption of cereals (Fig. 4a) and vegetables (Fig. 4d) generally fell within the recommended range of dietary guidelines. The consumption of tubers (Fig. 4b), fruits (Fig. 4c), eggs (Fig. 4e), and milk (Fig. 4h) remained inadequate in many provinces, even with the inclusion of EAFH. Conversely, the consumption of meat (Fig. 4f) and pulses & nuts (Fig. 4g) surpassed the recommended levels, and considering EAFH exacerbated the degree of this excessive consumption.

In terms of diet balance levels (Table S3), cereals (0.4%), fruits (-19.9%), vegetables (-5.6%), meat (7.1%), and pulses & nuts (12.4%) were categorized as the appropriate ranges. Tubers (-27.7%) and eggs (-20.0%) were grouped as a low dietary imbalance, and milk (-83.4%) as a severity dietary imbalance. When considering EAFH, tubers and eggs have shifted to the appropriate range reflecting an improved diet nutrition quality. In contrast, meat and pulses & nuts have moved to a low dietary imbalance, counteracting the improvement in nutrition quality. Other food types remained unchanged.

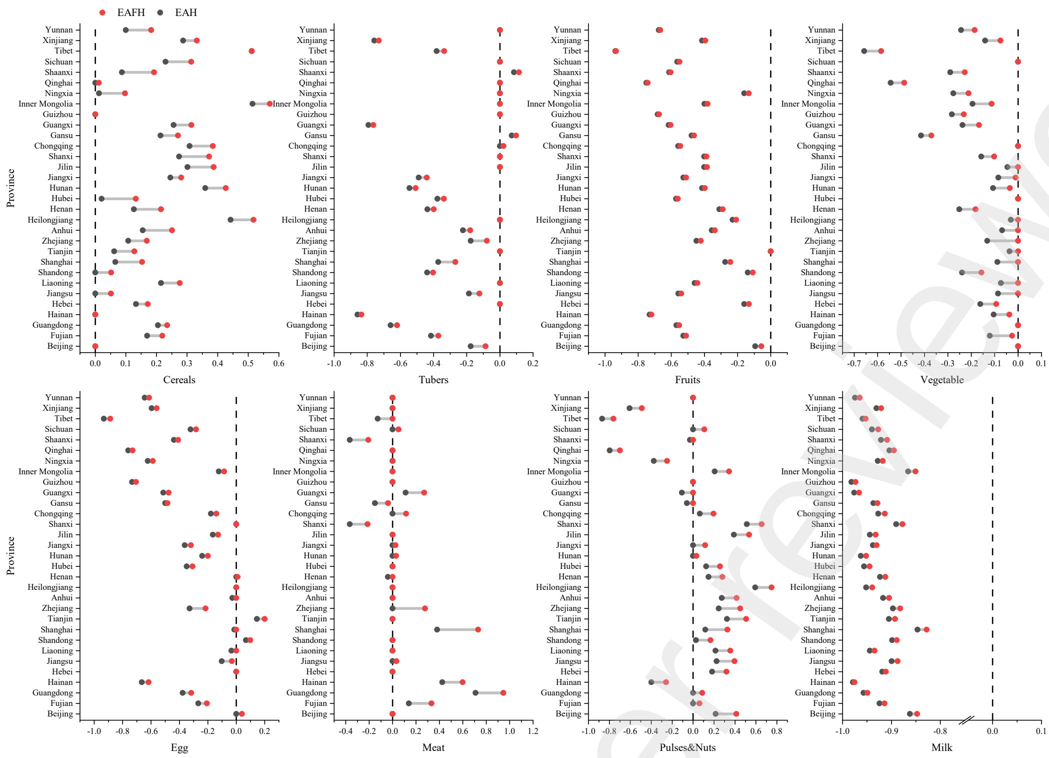

Figure 5 Dietary nutrition quality of EAH and EAFH in rural of 2020

In rural areas, the consumption of meat (Fig. 5f) generally fell within the recommended range of dietary guidelines for most provinces after considering EAFH. and tubers (Fig. 5b), fruits (Fig. 5c), vegetables (Fig. 5d), eggs (Fig. 5e), and milk (Fig. 5h) remained inadequate in many provinces, even with the inclusion of EAFH. Conversely, the consumption of cereals (Fig. 5a) and pulses & nuts (Fig. 5g) surpassed the recommended levels, and considering EAFH exacerbated the degree of this excessive consumption.

In terms of diet balance levels (Table S3), cereals (17.42%), vegetables (-16.35%), meat (2.30%), and pulses & nuts (1.98%) fell within the appropriate range. Tubers (-23.00%) and eggs (-29.29%) were grouped as a low dietary imbalance, while fruits (-45.2%) as moderate dietary imbalance and milk (-92.77%) as a severity dietary imbalance. When considering EAFH, cereals have moved to a low dietary imbalance, counteracting the improvement in nutrition quality. Other food types remained unchanged.

Indeed, the positive and negative effects of each food type on dietary nutrition considering EAFH were consistent in urban and rural areas. However, when focusing on the regional scale in rural areas, the effects of meat and pulses & nuts differed. Specifically, meat consumption had a positive impact in central (1.7%) and western (0.6%) regions in contrast to its negative impact in the eastern region (-11.5%). The consumption of pulses & nuts in the western region (2.3%) had a positive impact on nutrition quality, unlike the eastern (-12.7%) and central (-12.4%) regions. Our study provided further insights into the disparities in effects of dietary nutrition quality among the three regions of China.

3.6 EAFH contributes the improvement of overall nutrition quality

We calculated the deviations of total food consumption from the dietary guidelines for 31 provinces (Fig. 6a). Overall, there is a significant gap between the total food consumption of EAH and the dietary intake recommended by the guidelines. The diet balance level was appropriate (-17.1%) for urban areas and low imbalance (-23.1%) for rural areas. Considering EAFH did shorten the gap into -6.1% and -18.1% , respectively and shifted to appropriate range for rural areas. However, it is still worth noting that excessive intake of meat, cereals and pulses & nuts can offset the positive effects in some degree.

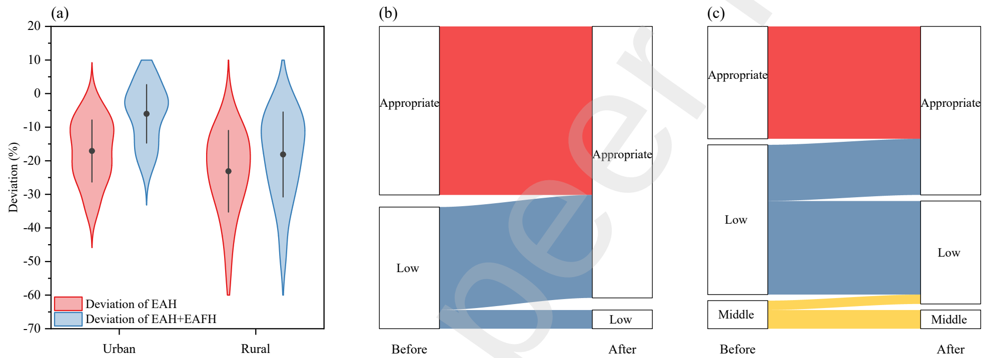

Figure 6 Dietary nutrition quality distribution for both urban and rural areas of the total consumption (a) Dietary nutrition quality transition before and after considering EAFH in urban (b) and rural areas (c)

In addition, we have assessed the changes in nutrition quality after considering EAFH. It was observed that urban areas had two levels of deviation: "Low dietary imbalance" and "In appropriate range." In contrast, rural areas had three levels of deviation: "Middle dietary imbalance," "Low dietary imbalance," and "Inappropriate range." When considering EAFH, the nutrition quality of most provinces in urban areas fell within a reasonable range of deviation from the dietary guidelines. Similarly, in rural areas, there was a significant decrease in deviation, resulting in a notable improvement in dietary nutrition quality.

3.7 Limitation

Although our study has developed a robust EAFH model for accurately estimating the dietary quantity of EAFH and EAH and assessed the nutrition quality states by different spatial scales, there are still some limitations. 1) Our model is developed on the basic of the CHNS database. The CHNS is conducted over a long time series and widely used by many studies, however, it does not cover all the provinces in China. Thus, regional variations in dietary habits could influence the accuracy of dietary estimates from our model and cause some errors (Wang et al., 2023). 2) Recently, consumer behaviors have undergone significant changes, such as the increasing popularity of takeaway food delivery services due to their convenience and speed, especially in urban areas (Ren et al., 2020). Such changes highlight the necessaries to consider the contribution of EAFH, and the high requirement to collect extensively survey data for improving dietary estimates in the future.

4.Conclusion

In this study, a robust EAFH model was constructed to estimate the food consumption of EAFH by urban and rural residents in China. We further comprehensively assessed the amount, trend, structure, and nutrition quality of food, and found the follows. The EAFH models perform well in estimating food consumption (R^2= 0.67). The EAFH consumption has increased in both urban (82g~214g) and rural (23g ~84g) from 2000 to 2020. EAFH accounted for a significant proportion of the total consumption, particularly in urban areas (17.6%). We also found that the amounts of meat, vegetables, and cereals consumed were increased more fastly, especailly in rural areas. Moreover, significant differences in the dietary structure were indicated between EAFH and EAH, with more proportion of meat, vegetables and pulses & nuts consumption from EAFH than those of EAH. We found that the impacts of EAFH on nutrition quality varied by regions and food types. Nevertheless, dietary quality of most residents in China did significantly be improved by EAFH. Our findings will benefit the related departments to make reasonable decisions for a better healthy and scientific dietary guidlines.

CRediT authorship contribution statement

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

Declaration of 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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Dietary guideline

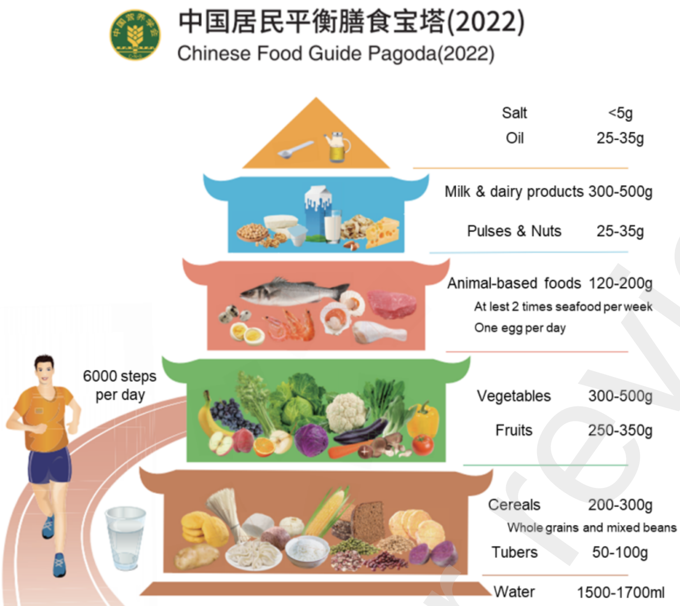

Figure S1 5th edition of the Chinese Dietary Guidelines

Salt, oil and water were excluded from the study, focusing only on the remaining food items. Animal-based foods were further categorized into meat (including livestock, poultry, and seafood) and eggs. Since the 5th edition of the Chinese Dietary Guidelines did not provide a specific recommended intake for eggs, the study referenced the 4th edition guidelines, which suggested an intake range of 40-50g for eggs and 70-160g for meat.

Definition of EAFH

In this study, eating away from home (EAFH) was defined according to the variable V41 MEAL LOCATION from the China Health and Nutrition Study (CHNS) Individual Daily Meals (nutr3_00). "At home" referred to Eating at Home (EAH). Categories including "at school or work," "restaurant or food stand," "relative's or friend's house," "nursery school," "festival/celebration," and "other" were all thought as EAFH.

Mann-Kendall test and Sen's slope estimator

The Mann-Kendall (Kendall, 1948; Mann, 1945) statistic was used to test the significance of the trend in EAFH and EAH.

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn\left(x_j - x_i\right)$$

(1)

where n is the number of data points, x_i and x_j are the data values in time series i and j ($j > i$), respectively and $sgn(x_j - x_i)$ is the sign function as:

$$sgn\left(x_j - x_k\right) = \begin{cases} +1, \text{ if } \left(x_j - x_k\right) > 0 \\ 0, \text{ if } \left(x_j - x_k\right) = 0 \\ -1, \text{ if } \left(x_j - x_k\right) < 0 \end{cases} \quad (2)$$

The variance is computed as

$$Var(S) = \frac{1}{18}\left[n(n-1)(2n-5) - \sum_{i=1}^{m} t_i(t_i-1)(2t_i+5)\right] \tag{3}$$

where n is the number of data points, m is the number of tied groups and t_i denotes the number of ties of extent i. A tied group is a set of sample data having the same value. In cases where the sample size $n >$ 10, the standard normal test statistic Z_S is computed as follows:

$$Zs = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, \text{ if } S > 0 \\ 0, \quad \text{ if } S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, \text{ if } S < 0 \end{cases} \tag{4}$$

Positive values of Z_s indicate increasing trends, while negative Z_s values show decreasing trends. Testing trends were performed at the specific α significance level. If $Zs > Z_{0.95} = 1.96$, the slope estimated is significant at a 95% confidence level in this study.

Sen's slope (Sen, 1968) developed the non-parametric procedure for estimating the slope of trend in the sample of N pairs of data:

$$Q_i = \frac{x_j - x_k}{j - k} \tag{5}$$

where x_j and x_k are the data values at times j and k ($j > k$), respectively.

$$\beta = \text{Median } (Q_i) \tag{6}$$

where $k < j$, x_j and x_k are the variables for year j and k, respectively; n is the length of the time series. A total of $n(n-1)/2$ elements of Q_i and their median β is the trend of the temporal variable series. $\beta > 0$ indicates an upward trend in a time series. Otherwise, the data series presents a downward trend.

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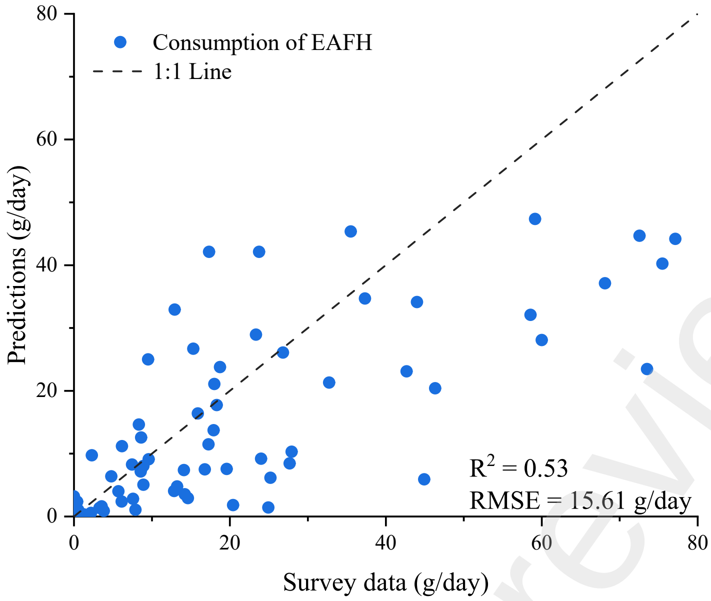

Figure S1 Validation results of EAFH models

Table S1 Descriptive statistics of CHNS

Variable	Unit	Mean	Std. Dev.	Min	Max
C_{EAFH}	g/day	80.90	89.34	0	400.47
C_{EAH}	g/day	8.02	11.79	00	72.54
Householdsize	person	3.90	0.70	2.57	5.75
Income	10000 yuan	0.65	0.48	0.14	2.49
Year	year	2010	6.06	2000	2020
Rural	-	-	-	-	-
East	-	-	-	-	-
Middle	-	-	-	-	-
West	-	-	-	-	-

Table S2 Information on EAFH data collected from other studies

Year	Food Type	Province	Area	Sample size	Reference
2000	Eggs, Meat, Milk	Jilin, Shandong, Inner Mongolia, Jiangsu, Sichuan, Guangdong	Urban, rural	633 households	Yuan et al. (2001)
2008	Meat	Tianjin, Shandong, Shanghai, Anhui, Guangxi, Hunan, Liaoning, Heilongjiang, Jilin, Gansu, Sicuan	Urban, rural	120 households	Chen (2011)
2010	Meat	Beijing, Jiangsu, Sichuan, Shaanxi, Liaoning, Fujian	Urban	2,328 households	Yuan et al. (2019)
2010	Meat	-	Urban, rural	-	Cheng et al. (2015)
2010	Meat	Heilongjiang, Sichuan, Guagnxi, Hebei, Gansu, Anhui, Hubei	Urban, rural		Xiao et al. (2015)
2005, 2010, 2015, 2020	Vegetables	Shandong, Guangdong, Beijing, Shanghai	Urban	-	Zhang et al. (2006)
2000	Cereals, Fruits, Vegetables, Eggs, Meat	Jilin, Shandong, Chongqing, Sichuan	Rural	235 households	Ma et al. (2001)
2007	Eggs, Meat, Milk	Zhejiang	Rural	120 households	Ke et al. (2010)
2015, 2016, 2017	Cereals, Tubers, Fruits, Vegetables, Eggs, Meat	Henan	Rural	29910 pearsons	Wang (2020)

2015	Cereals, Vegetables, Meat	Guangdong	Urban, rural	3489 persons	Chen et al., (2021)
2000	Cereals	-	Urban	-	Li (2005)
2000, 2005, 2010, 2015	Cereals	-	Urban, rural	-	Zhan et al. (2021)
2010	Cereals, Fruits, Vegetables, Eggs, Meat, Milk	Beijing, Jiangsu, Sichuan, Shaanxi, Liaoning, Fujian	Urban	2,328 households	Yuan et al. (2015)

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Table S3 The diet balance level

Absolute Total Deviation	Diet balance level
0%	Perfectly balanced diet
(0%, 20%]	Appropriate range
(20%, 40%]	Low dietary imbalance
(40%, 60%]	Moderate dietary imbalance
(60%, ∞)	Severe dietary imbalance