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RESEARCH ARTICLE

The impact of Internet access on household dietary quality: Evidence from rural China



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Abstract

Over the past few decades, the Internet has rapidly diffused across China. The spread of the Internet has had a profound economic and social impact on Chinese rural areas. Existing research shows that Internet access significantly impacts agricultural production and improves smallholder farmers' income. Beyond these, the Internet can affect other dimensions of social welfare. However, research about the impact of Internet access on dietary quality in rural China remains scarce. This study utilizes multi-period panel data from Fixed Observation Point in rural China from 2009 to 2015 to estimate the impact of Internet access on dietary quality and food consumption of rural households and conducts a causal analysis. Regression models with time and household fixed effects allow robust estimation while reducing potential issues of unobserved heterogeneity. The estimates show that Internet access has significantly increased rural household dietary quality (measured by the Chinese Diet Balance Index). Further research finds that Internet access has increased the consumption of animal products, such as aquatic and dairy products. We also examine the underlying mechanisms. Internet access improves dietary quality and food consumption mainly through increasing household income and food expenditure. These results encourage the promotion of Internet access as a valuable tool for nutritional improvements, especially in rural areas.

Keywords: dietary quality, fixed effect model, Internet access, rural China

1. Introduction

The Internet has rapidly diffused across China in recent decades (Zhang and Zheng 2012; Zhang 2021). According to a report released by the China Internet Network Information Center (CNNIC), by June 2022, the number of Internet users in China has reached 1.051 billion, and the Internet penetration rate has reached 74.4%. China has had the largest number of Internet users in the world since 2008 (Liang and Lu 2010; Setti and Wanto 2019). The Internet infrastructure construction in Chinese rural areas has

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been comprehensively strengthened, realizing “5G connectivity at county level and broadband connectivity at village level” (CNNIC 2022), which provides a solid foundation for rural residents to access the Internet. From 2014 to 2022, the Internet penetration rate in China’s rural areas increased from 28.8 to 58.8%, and the gap between urban and rural areas narrowed from 34.0 to 24.1%. In addition, Internet users in China’s rural areas have reached 293 million (CNNIC 2022).

The spread of the Internet has had a profound economic and social impact on Chinese rural areas. Researchers have extensively explored various dimensions of the Internet’s influence, specifically examining its effects on agricultural production, land use, and the income of rural residents. In terms of agricultural production, various studies have revealed that Internet usage can reduce pesticide and fertilizer usage and improve technological efficiency (Setti and Wanto 2019; Zhao *et al.* 2021; Zhu *et al.* 2021; Ma and Zheng 2022; Zheng *et al.* 2022; Yue *et al.* 2023). The Internet’s impact on land use or land transfer has also been explored by researchers (Deng *et al.* 2019; Zhang *et al.* 2022; Zou and Mishra 2022). Internet use significantly promotes rural households’ social networks and increases their likelihood of engaging in non-farm employment and business activities, thus contributing to farmland rental decisions. Additionally, studies examining the relationship between Internet use and the income of rural residents have shown promising results. Internet use had a positive impact on rural residents’ income growth (Ma *et al.* 2020; Zhou *et al.* 2020; Leng 2022) and narrowed the income gap between urban and rural areas to a certain extent (Qiu *et al.* 2021; Wang *et al.* 2021; Ma 2022).

Some studies have examined social welfare dimensions such as social fairness and subjective well-being. A study using data from 6,205 Chinese rural households found that Internet use had a statistically significant and negative impact on social fairness perceptions (Zhu *et al.* 2020). A study using survey data from 493 rural Chinese households revealed a link between smartphone use (the primary way to access the Internet) and increased life satisfaction and happiness (Nie *et al.* 2021). Adequate nutrition is emphasized as an important component of people’s basic needs in developing countries (Behrman and Deolalikar 1988). Unbalanced diets and nutrient deficiencies are a significant issue among the rural population in China. According to the AGFEP (2022) highlights that rural residents’ consumption of fruits and aquatic products is approximately 80% lower than the recommended value stated in the Dietary Guidelines for Chinese (DGC-2016). Moreover, the intake of dairy products among rural

residents is notably deficient, being approximately 90% lower than the recommended value of the DGC-2016. However, only two researches analyzed the impact of the Internet on food consumption or nutritional intake among Chinese rural residents. One study collected data from six Chinese provinces found that the energy, protein and fat intake of rural residents who use the Internet is significantly higher than those who do not (Xue *et al.* 2021). Another study using China Health and Nutrition Survey data (2006–2011) found that the Internet is connected to a healthy diet of Chinese rural residents by increasing consumption of milk, fruits, eggs, and vegetables while reducing salt and cooking oil intake (Ma and Jin 2022). Despite the increasing popularity of the widely used Internet in rural China, there are still few empirical studies linking the Internet with the dietary quality of rural residents. Therefore, it is necessary to carry out relevant research to explore the effects of the Internet on the dietary quality of the Chinese rural population.

This study uses nationally representative data from Chinese rural areas to analyze the relationship between Internet access and dietary quality and food consumption of Chinese rural residents. This study contributes to the literature in three ways. First, it addresses the research gap by analyzing the impact of Internet access on the dietary quality and food consumption of Chinese rural residents, focusing on a population that has been understudied in this context. This study provides valuable insights into the specific effects of Internet access on the dietary quality and nutritional well-being of the rural population. Second, this study employs the Chinese Diet Balance Index (DBI₁₆) to calculate dietary quality, encompassing aspects such as balanced diet status, inadequate dietary intake, and excess dietary intake. By utilizing this comprehensive index, the study offers a more holistic and visual representation of the dietary status of rural residents. Furthermore, this study takes into account various factors, such as household members’ gender, age, physical activity level, and out-of-home work time, to appropriately adjust and convert the data on household food consumption. This consideration allows for meaningful comparisons of food consumption patterns across different family structures and provides valuable insights into household-level dietary behaviors. Third, this study empirically tests possible mechanisms, such as household income and food expenditure, to uncover additional implications and shed light on the underlying factors that may mediate the relationship between Internet access and dietary quality among Chinese rural residents.

2. Data and methods

2.1. Data

This study used the survey data from Fixed Observation Points of the Ministry of Agriculture and Rural Affairs of China. This survey was established in 1984 and covers more than 20,000 rural households and 370 administrative villages in 31 provinces, autonomous regions and municipalities in China every year. After 2003, a questionnaire including family members was included in the survey, including demographic characteristics of family members, agricultural production, land use and transfer, employment, income and expenditure, and other detailed information. The characteristics and advantages of the data generally satisfy this study's demands and provide an appropriate statistical basis for selecting complete variables. The Fixed Observation Points data did not include Internet access until 2009. It is essential to note that 2009–2015 is an important development stage for Chinese rural Internet access. During this period, the average annual growth rate of Internet penetration reached 27%, indicating a rapid expansion of Internet usage in rural areas. In this phase, the Chinese government implemented some measures and policies to promote Internet access and penetration in rural areas, such as supporting the development of rural broadband networks through universal service compensation pilot projects. Compared with the following years (the average annual growth rate of Internet penetration from 2016 to 2020 was 12%), the growth rate during this period was higher, further emphasizing the uniqueness of the rapid development of rural Internet connectivity during this period. Considering the importance of this rapid growth stage, we used Fixed Observation Points data for 2009–2015 to conduct the empirical analysis.

2.2. Measurement of key variables

The main explanatory variable is Internet access. The survey asked farmers whether their households accessed the Internet. We define Internet access as a dummy variable, where 1 refers to the households having access to the Internet and 0 otherwise.

Regarding the outcome variable, we are particularly interested in household food consumption and dietary quality. The household food consumption data used in this study were based on farmers' recall of their household consumption of 14 food groups over the past year, including cereals and tubers, vegetables, fruits, soybeans and products, meat (including pork, beef, lamb, and poultry), aquatic products, eggs, cooking oil, dairy

products, alcohol and added sugar. In order to compare food consumption in different household structures (household size, age, gender, and physical activity level of different family members), we calculated the number of standard-person in a household using information about each family member's age, gender, and physical activity level. We generated the dietary energy requirements of each family member based on the the Chinese Dietary Reference Intakes 2013. The dietary energy requirement level of a converted standard-person is 2,250 kcal (corresponding to light physical activity for men aged 18–50 years). We divided the dietary energy requirements of each household member by 2,250 to convert standard-person. Some family members, who are migrant workers, did not live at home for several months or more in a year. We further converted the number of months that the family member worked out. For example, if a farmer migrated to work within 6 months of the year (6 months divided by 12 months equals 0.5), the conversion method is the standard-person multiplied by 0.5. We summed up the standard-person in each family to generate the number of standard-person in the household. Finally, the food consumption of each household was divided by the standard number of people in the household and then divided by 365 to generate the daily food consumption of standard-person of the household.

We used the latest version of the DBI_16 to evaluate the dietary quality of sample households. DBI_16 includes 11 food subgroups and diet diversity from the DGC-2016 and the Chinese Food Guide Pagoda (He *et al.* 2018), including cereals and tubers, vegetables, fruits, dairy products, soybeans and products, red meat and poultry, aquatic products, eggs, cooking oil, alcohol, and added sugar. We chose the food intake range with an energy level of 2,200 kcal as the calculation criteria to calculate the scores of different food subgroups and diet diversity. The specific score range of each food subgroup is shown in Table 1. By summing the absolute scores for each DBI_16 food subgroup, we calculated an indicator of diet quality distance (DQD) intake ranging from 0 to 78, used to assess the degree of an imbalanced diet. A DQD score of 0 indicates "excellent" dietary intake; a score from 1 to 16 means that the dietary intake has a few imbalance problems; a score from 17 to 32 means a low level of dietary imbalance; a score from 33 to 47 means a moderate level of dietary imbalance; and a score greater than 47 indicates a high level of dietary imbalance. The absolute values of the negative scores of each DBI_16 food group were added to obtain a low bound score (LBS) ranging from 0 to 60, which was used to assess the degree of insufficient intake. When LBS is 0, it means no insufficient intake; a score from 1 to 12 points means

Table 1 Food subgroup of Chinese Diet Balance Index (DBI_16) and score range

Food subgroup	Score
Cereals and tubers ¹⁾	(-12)-12
Vegetables	(-6)-0
Fruits	(-6)-0
Dairy products	(-6)-0
Soybeans and products	(-6)-0
Red meat and poultry	(-4)-4
Aquatic products	(-4)-0
Eggs	(-4)-4
Cooking oil	0-6
Alcohol	0-6
Added sugar	0-6
Diet diversity	(-12)-0

¹⁾ Cereals and tubers include rice, wheat, dried legumes (exclude soybeans), and tuber.

less insufficient intake; a score of 13 to 24 indicates a low level of insufficient intake; a score of 25 to 36 indicates a moderate level of insufficient intake, and a score greater than 36 indicates a high level of insufficient intake. The absolute values of the positive scores of each DBI_16 food group were added to obtain a high bound score (HBS) ranging from 0 to 38, which is used to assess the degree of excess intake. When HBS was 0, it means no excess intake, and a score from 1 to 8 points means less excess intake. A score of 9 to 15 indicates a low level of excess intake. A score of 16 to 23 indicates a moderate level of excess intake, and a score greater than 23 indicates a high level of excess intake.

We include household income and food expenditure as control variables to ensure that the impact of Internet access on dietary quality is not being driven by household income and food expenditure. Household income is a crucial determinant of dietary quality (Bouis *et al.* 2011; French *et al.* 2019). Higher income levels provide households with greater financial resources to access a variety of nutritious foods and maintain a balanced diet. Food expenditure is directly related to food consumption patterns and dietary quality (Lo *et al.* 2012; Monsivais *et al.* 2012). Food expenditure reflects the financial resources available to households for purchasing food. Higher food expenditure allows for more flexibility in selecting nutrient-rich foods and incorporating a wider variety of food groups into one's diet.

2.3. Econometric strategy

We use panel data regression models with household fixed effects (FE) to analyze the effect of Internet access on dietary quality, which can remove selection bias

resulting from unobserved time-invariant heterogeneity. To implement this approach, we estimate variants of the following regression:

$$Outcome_{it} = \beta_0 + \beta_1 Internet_{it} + \beta_2 X_{it} + \beta_3 T_t + \varepsilon_{it} \quad (1)$$

where $Outcome_{it}$ is the dietary quality variables (DQD, LBS or HBS) and food consumption (cereals and tubers, cooking oil, red meat and poultry, vegetables, fruits, etc.) for household i at time t ; $Internet_{it}$ is a dummy variable equal to 1 if the household i accesses the Internet in time t and 0 otherwise; X_{it} is a vector of time-variant household characteristics, such as household income and food expenditure; T_t is a vector of time dummies for the years 2009, 2010, 2011, 2012, 2013, 2014 and 2015 (Fixed Observation Points data did not collect the information of Internet access) capturing all structural changes such as economic growth, the overall expansion of network coverage, improvements of general infrastructure; ε_{it} is an error term.

3. Results and discussion

3.1. Descriptive statistics

Table 2 shows the average daily food consumption of standard-person and dietary quality in our sample and how they developed from 2009–2015. Most of the food consumption (except cereals and tubers) has increased over time, which implies a general improvement in food consumption. All animal products showed an increase in consumption. For instance, the consumption of red meat and poultry rose from 61.96 to 80.34 g d⁻¹ (increased by 29.66%). Similarly, the consumption of aquatic products increased from 9.37 to 12.42 g d⁻¹ (increased by 32.51%). While the consumption of dairy products increased from 3.73 to 9.81 g d⁻¹ (increased by 163.5%), it is still far from the recommended values from the Chinese Food Guide Pagoda 2016 (300 g d⁻¹) or recommended values from the Chinese Food Guide Pagoda 2022 (300–500 g d⁻¹).

In this study, the average standard-person daily intake of various food groups was compared with the recommended value of the DGC-2022 in the balanced dietary pattern with reference to the 2,200 kcal energy intake level. As shown in Fig. 1, cereals and tubers consumption among rural residents exceeded the recommended value of the dietary guidelines by 93% in 2009 (the recommended value is 275 g d⁻¹). Although cereals and tubers consumption decreased in 2015, it exceeded the recommended dietary guideline value by 88%. Cooking oil consumption also increased significantly, from exceeding the recommended dietary guidelines by 50% in 2009 to exceeding the recommended dietary guidelines by 90% in 2015 (the

Table 2 Food consumption, dietary quality, Internet access, and household characteristics from 2009–2015

Variables	2009	2010	2011	2012	2013	2014	2015
Food consumption¹⁾							
Cereals and tubers	530.87	524.19	525.19	523.29	521.73	515.12	515.90
Cooking oil	45.44	47.73	49.99	50.59	53.01	55.76	56.84
Vegetables	292.57	299.44	307.59	310.01	320.50	316.30	316.87
Fruits	40.54	40.62	42.49	44.58	46.46	47.53	49.04
Soybeans and products	14.20	15.42	16.30	18.42	19.50	20.07	20.95
Red meat and poultry	61.96	64.20	68.16	70.62	72.97	77.76	80.34
Aquatic products	9.37	9.58	9.95	10.31	10.74	12.18	12.42
Eggs	14.86	15.31	16.29	17.50	18.38	18.55	19.24
Dairy products	3.73	4.22	5.56	7.07	8.01	8.76	9.81
Alcohol	30.30	31.46	32.40	32.60	33.82	33.45	33.43
Added sugar	7.65	7.40	7.61	7.57	7.56	7.51	7.34
Dietary quality index²⁾							
DQD	38.80	38.51	38.64	37.87	37.61	37.56	37.48
LBS	24.42	23.97	23.68	23.04	22.72	22.49	22.21
HBS	14.38	14.53	14.95	14.83	14.89	15.07	15.27
Internet access							
Internet	0.08	0.10	0.12	0.15	–	0.22	0.26
Household characteristics							
Family size	4.52	4.51	4.52	4.47	4.46	4.45	4.55
Age of family members	40.79	41.35	41.95	42.49	43.25	44.06	44.32
Proportion of elderly	0.19	0.21	0.22	0.24	0.25	0.27	0.28
Proportion of children	0.14	0.14	0.14	0.14	0.13	0.13	0.13
Log(Household income)	10.12	10.28	10.44	10.56	10.63	10.71	10.73
Log(Food expenditure)	8.52	8.59	8.72	8.77	8.84	8.89	8.93

¹⁾ All the food consumption has been transferred to daily food consumption of standard-person (unit: g d⁻¹).

²⁾ DQD, diet quality distance; LBS, low bound score; HBS, high bound score.

Data source: Fixed Observation Points data.

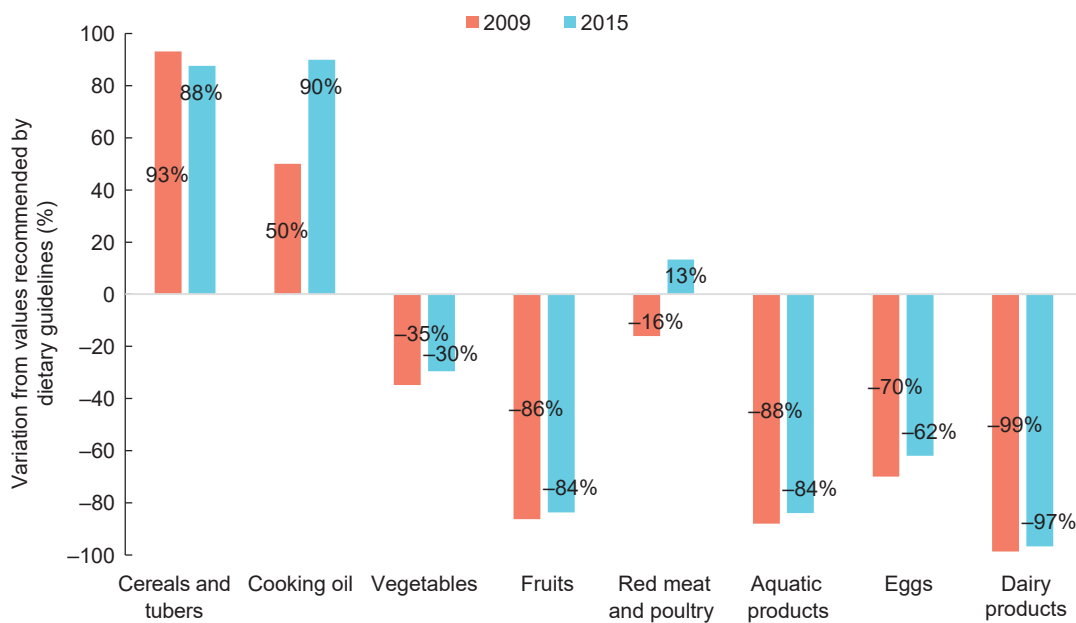


Fig. 1 Comparison of the food intake of the sample and the recommended value of the guidelines in 2009 and 2015.

recommended value is 30 g d⁻¹). Consumption of red meat and poultry showed an increasing trend from 16% below the recommended dietary guidelines in 2009 to 13% above the recommended dietary guidelines in 2015

(the recommended value is 75 g d⁻¹). The consumption of eggs, aquatic products, dairy products, vegetables, and fruits has been insufficient, below the recommended value by 62% (the recommended value is 50 g d⁻¹), 84% (the

recommended value is 75 g d⁻¹), 97% (the recommended value is 300 g d⁻¹), 30% (the recommended value is 450 g d⁻¹) and 84% (the recommended value is 300 g d⁻¹) in 2015 respectively.

In 2009, the DQD and LBS scores were 38.8 and 24.42, respectively. By 2015, the scores had decreased to 37.48 and 22.21, which indicates that the dietary quality and insufficient intake both improved. It also shows the HBS score increased from 14.38 to 15.27 between 2009 and 2015. This means that the excess intake degree increased (Table 2). Moreover, as shown in Fig. 2, moderate or high levels of imbalanced dietary intake (indicated by DQD) dropped from 83% in 2009 to 77% in 2015. The insufficient intake of rural populations has been alleviated to a certain extent; insufficient intake at moderate or high levels dropped from 48% in 2009 to 32% in 2015 (indicated by LBS). However, the excessive food intake of rural populations is at the same time becoming increasingly. The proportion of rural population with a moderate- or high-level of excessive diet increased from 27% in 2009 to 36% in 2015 (indicated by HBS).

Internet access is the key independent variable in this study. According to Table 2, it can be observed that in 2009, 8% of households had Internet access, and this number increased 26% in 2015. In terms of household characteristics, the average family size remained around 4.5 people from 2009 to 2015. The average age of family members gradually increased from 40.79 years in 2009 to 44.32 years in 2015. The percentage of elderly individuals in the household increased from 19% in 2009 to 28% in 2015, while the percentage of children in the household remained stable at 13–14%. Additionally, an observed trend between 2009 and 2015 was the growth in household income and food expenditures.

3.2. Baseline regression

Table 3 shows the estimation results of the models in eq. (1) using the FE model. Results in columns (1) to (3) suggest that Internet access is positively and significantly associated with dietary quality. The results in columns (1) to (3) are both statistically significant and almost identical, suggesting that Internet access has positive effects on dietary balance levels, insufficient intake, and excessive intake.

After controlling for other factors (household income and food expenditure), Internet users have a 0.368 lower DQD score than non-users (column 4). This indicates that, when holding other factors constant, Internet access appears to have a positive effect on the dietary balance level. Such effects were not analyzed before. Previous research hypothesized that mobile phone use may contribute to food security (Nakasone and Torero 2016), although this hypothesis had not been tested before. Using the estimates from columns (4) to (6) of Table 3, we can estimate the proportion of improvements in average dietary quality that can be attributed to increased Internet access. By multiplying the Internet access regression coefficient of column (4) with the average increase in Internet access and dividing this number by the average increase in DQD ($0.368 \times (0.256 - 0.076) / (37.48 - 38.80) = -0.050$), we find that Internet access contributed to approximately 5.0% of the improvement in DQD during the analyzed time period. Similarly, the regression coefficient for Internet access in columns (5) and (6) suggests that increases in Internet access accounted for 1.2% of improvements in LBS and 3.8% of improvements in HBS. These findings demonstrate the significance of Internet access in influencing dietary quality, highlighting

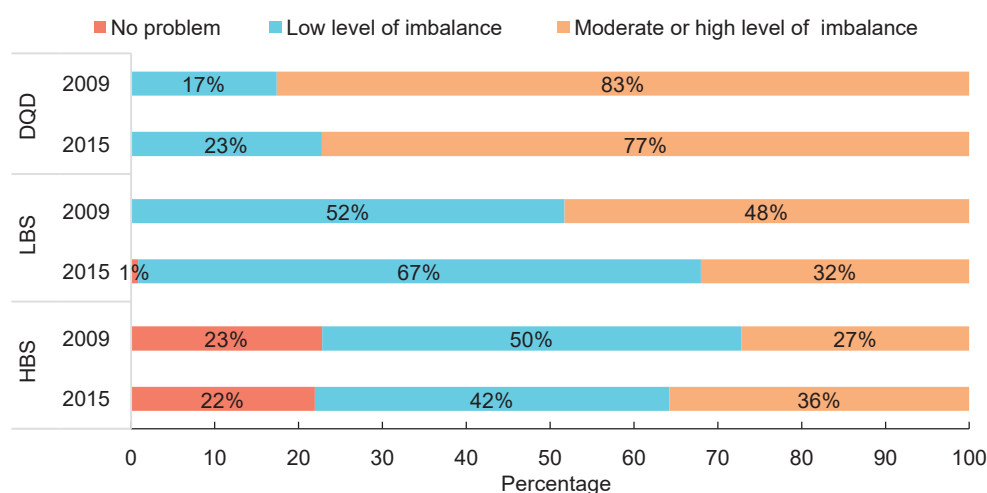


Fig. 2 Distribution of dietary quality of the sample in 2009 and 2015. DQD, diet quality distance; LBS, low bound score; HBS, high bound score.

its contribution to improvements in the levels of dietary balance (DQD), insufficient dietary intake (LBS), and excessive dietary intake (HBS).

To further analyze the effects of Internet access on food consumption, we split into 11 food groups and estimated the fixed effect model for each of these groups. The dependent variable represents the average daily food intake of different food items, including cereals and tubers, cooking oil, vegetables, fruits, red meat and poultry, eggs, aquatic products, dairy products, soybeans and products, alcohol, and added sugar. Table 4 demonstrates that Internet access has a positive effect on food consumption, particularly for animal products such as aquatic products and dairy products, which are typically associated with higher prices. In comparison to the average consumption of each food group in 2015, households with Internet access consumed a higher proportion of aquatic products (1.34%) and dairy products (9.55%) compared to households without Internet access. Additionally, our findings also indicate that households

with Internet access consumed lower proportions of cereals and tubers (1.65%), vegetables (0.97%), and added sugar (1.49%) compared to households without Internet access when compared to the average consumption of each food group in 2015.

3.3. Robustness check

Since we do not have data for the year before 2009 (the Fixed Observation Points data started to collect the information of Internet access since 2009), we do not know in which year households that already owned/used Internet in 2009. So, we excluded the households that had already accessed the Internet in 2009 and ran a balanced panel by using data from 2009 and 2015. The robustness of the results showed that Internet access still has a significant positive impact on dietary quality indicators, except for HBS. Table 5 demonstrates that Internet access significantly decreases the DQD by 0.451 and LBS by 0.498. Compared to Table 3, the impact

Table 3 Effects of Internet access on dietary quality¹⁾

Variables	DQD	LBS	HBS	DQD	LBS	HBS
	(1)	(2)	(3)	(4)	(5)	(6)
Internet	-0.389*** (0.061)	-0.121*** (0.039)	-0.268*** (0.057)	-0.368*** (0.061)	-0.089** (0.039)	-0.279*** (0.058)
Income				-0.159*** (0.043)	-0.142*** (0.028)	-0.017 (0.041)
Expenditure				-0.129*** (0.043)	-0.445*** (0.027)	0.316*** (0.041)
Constant	38.828*** (0.037)	24.517*** (0.023)	14.311*** (0.035)	41.537*** (0.494)	29.743*** (0.314)	11.794*** (0.467)
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Observations	121,771	121,771	121,771	121,771	121,771	121,771
No. of samples	21,825	21,825	21,825	21,825	21,825	21,825

¹⁾DQD, diet quality distance; LBS, low bound score; HBS, high bound score. Standard errors in parentheses. ***, $P < 0.01$; **, $P < 0.05$. Data source: Fixed Observation Points data.

Table 4 Effects of Internet access on the consumption of each food group

Variables	Cereals and tubers	Cooking oil	Vegetables	Fruits	Soybeans	Red meat and poultry	Aquatic products	Eggs	Dairy products	Alcohol	Added sugar
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Internet	-8.488*** (1.916)	-0.551** (0.219)	-4.640*** (1.546)	-0.120 (0.284)	0.008 (0.143)	0.098 (0.332)	0.167* (0.095)	-0.104 (0.119)	0.937*** (0.138)	1.041*** (0.272)	-0.109* (0.064)
Income	-3.098** (1.366)	-0.023 (0.156)	-2.602** (1.103)	1.304*** (0.202)	0.062 (0.102)	2.140*** (0.237)	0.284*** (0.067)	0.279*** (0.085)	0.852*** (0.099)	2.606*** (0.194)	0.253*** (0.046)
Expenditure	8.893*** (1.350)	0.277* (0.154)	10.971*** (1.090)	-0.230 (0.200)	0.290*** (0.100)	1.877*** (0.234)	0.487*** (0.067)	0.088 (0.084)	0.508*** (0.097)	2.797*** (0.192)	-0.010 (0.045)
Constant	482.198*** (15.554)	43.264*** (1.780)	224.702*** (12.550)	29.682*** (2.302)	10.958*** (1.157)	23.605*** (2.695)	2.051*** (0.767)	11.367*** (0.966)	-9.034*** (1.122)	-20.270*** (2.212)	5.142*** (0.519)
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	121,771	121,771	121,771	121,771	121,771	121,771	121,771	121,771	121,771	121,771	121,771
No. of samples	21,825	21,825	21,825	21,825	21,825	21,825	21,825	21,825	21,825	21,825	21,825

Standard errors in parentheses. ***, $P < 0.01$; **, $P < 0.05$; *, $P < 0.1$. Data source: Fixed Observation Points data.

coefficients of Internet access on DQD and LBS have increased to some extent. We also ran the balanced panel data of each food group (Appendix A). The results are similar to the results of Table 4 except for the vegetables, aquatic products, eggs and alcohol.

3.4. Towards explaining possible mechanisms

Columns (1), (2), and (3) in Table 3 show the estimation results without household income and food expenditure included as control variables. As expected, the Internet access effects are larger than the results in columns (4)–(6), supporting the hypothesis that income and expenditure are possible mechanisms through which Internet access improves dietary quality.

This study employs panel instrumental variable regression to analyze the impact of Internet access on household income and food expenditure, addressing potential endogeneity issues. The instrumental variable used is the Internet penetration rate within the village, excluding the household itself. The results are presented in Table 6, with Internet access as the independent variable in all models. Columns (1) and (2) include the logarithmic form of household income and food expenditure as separate dependent variables. The results reveal that Internet access leads to a 9.5% increase in household income and a 4% increase in food expenditure compared to non-users. These findings highlight the positive impact of Internet access on both household income and food spending, implying that some of the effects of Internet access on food consumption and dietary quality are channeled through these two pathways. The first-stage *F* statistics were used for the weak instruments

Table 5 Effects of Internet access on dietary quality (balanced data of 2009 and 2015)¹⁾

Variables	DQD	LBS	HBS
	(1)	(2)	(3)
Internet	-0.451*** (0.164)	-0.498*** (0.158)	0.046 (0.109)
Income	-0.148 (0.115)	0.066 (0.110)	-0.214*** (0.077)
Expenditure	-0.416*** (0.110)	0.013 (0.105)	-0.429*** (0.073)
Constant	44.028*** (1.214)	13.604*** (1.165)	30.424*** (0.808)
Year fixed effect	Yes	Yes	Yes
Observations	33,387	33,387	33,387
No. of samples	20,783	20,783	20,783

¹⁾ DQD, diet quality distance; LBS, low bound score; HBS, high bound score.

Standard errors in parentheses. ***, $P < 0.01$.

Data source: Fixed Observation Points data.

Table 6 Effects of Internet access on household income and food expenditure

Variables	Household income	Food expenditure
	(1)	(2)
Internet	0.095*** (0.005)	0.040*** (0.005)
Constant	10.114*** (0.003)	8.508*** (0.003)
Year fixed effect	Yes	Yes
Observations	121,771	121,771
No. of samples	21,825	21,825
<i>F</i> statistic of the first-stage	39.32	37.43

Standard errors in parentheses. ***, $P < 0.01$.

Data source: Fixed Observation Points data.

test. We found the first-stage *F* statistics for different models exceeded the conventional cut-off of 10 for weak instruments, which means the instrument variable was a strong instrument.

4. Conclusion and policy recommendation

Internet penetration has experienced rapid expansion in rural China and other developing regions. Although previous research has extensively examined the effects of the Internet on economic indicators — such as agricultural production, land use and transfer, and income and income gap, research on implications for broader social development is scarce. This paper focuses on dietary quality as one essential social welfare dimension. We analyze whether Internet access translates into improved dietary quality and food consumption among rural areas in China. In particular, this study utilizes a panel dataset comprising households from 31 provinces, autonomous regions and municipalities covering seven rounds from 2009 to 2015 to assess the effects of Internet access on dietary quality. Dietary quality was measured at the household level using DBI_16 indicators. We further analyze how Internet access affects the consumption of different food groups measured by a person's standard average daily intake.

The results indicate that Internet access is positively and significantly associated with dietary quality and food consumption for rural households in China, also after controlling for possible factors. Using the panel data, we can control for a wide range of economic and social factors and self-selection of households based on time-invariant characteristics. Although the main analyses are based on an unbalanced panel, we further conduct a balanced panel analysis with some observations being dropped out. The result is also supported by an additional robustness check. For the possible mechanisms,

increasing household income and food expenditure could represent an important mechanism through which Internet access improves dietary quality and food consumption.

Our study has a few limitations, two of which deserve particular attention. First, we could not control for possible bias due to unobserved time-variant heterogeneity. The selection bias cannot be ruled out completely. The panel structure of the data helped to reduce bias to some extent. Second, we could not analyze in more detail how and by whom the Internet is used within the sample households. Hence, causal interpretation should be made cautiously, although the effects described are plausible. Further scientific investigation in the future is necessary due to the insufficient information available about individuals using the Internet within households.

Despite these limitations, we cautiously conclude that Internet access can improve household dietary quality and food consumption in rural areas. Of course, results from one specific dataset should not be widely generalized. Nevertheless, the Fixed Observation Points data are quite typical for the Chinese small-farm sector in terms of farm sizes, access to infrastructure and markets, annual food consumption, Internet adoption, and other social parameters. Hence, some broader lessons can be learned. We draw several policy implications from the finding that Internet access could help improve dietary quality and food consumption. First, we recommend policymakers to further facilitate Internet use in rural areas. Beyond helping to improve dietary quality, the Internet can have many other positive effects to spur rural development, as earlier research showed (Ma *et al.* 2020; Zhou *et al.* 2020; Nie *et al.* 2021; Ma 2022; Zheng *et al.* 2022). Second, policymakers should continue to develop methods to utilize the Internet to reach and inform households about nutritional knowledge, such as information on nutritious foods and balanced diets.

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Declaration of competing interest

The authors declare that they have no conflict of interest.

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