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EDITED BY

Sanzidur Rahman,
University of Reading, United Kingdom

REVIEWED BY

Elise Mognard,
Taylor's University, Malaysia
Dyah Aring Hepiana Lestari,
Lampung University, Indonesia

*CORRESPONDENCE

Rong Li
✉ lr@hzu.edu.cn

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Eating right and food accessibility: education level, market accessibility, and dietary diversity among rural households in China

Rong Li^{1,2*}, Linxiang Ye³ and Long Qian¹

¹Institute of Food and Strategic Reserves, Nanjing University of Finance and Economics, Nanjing, China, ²School of Economics and Management, Huizhou University, Huizhou, China, ³School of Economics, Nanjing University of Finance and Economics, Nanjing, China

Introduction: Over the past half-century, China's rural residents have gradually resolved inadequate dietary energy intake, yet still face coexisting undernutrition and overnutrition due to insufficient dietary diversity. Education can effectively enhance nutritional awareness, boost rural household income, and thereby improve household and individual dietary diversity.

Methods: Using data from 10,958 rural households in the 2010 and 2014 waves of the China Family Panel Studies (CFPS), this paper examines the association between education and dietary diversity by adopting an analytical framework integrating fixed-effects model, heterogeneity analysis, and mediation effect analysis.

Results: Fixed-effects model results show that each additional year of household heads' education is associated with an improvement in household and individual dietary diversity scores by 0.064 and 0.054 units, respectively. Further heterogeneity analysis shows that education's promotive effect on dietary diversity varies by market accessibility: it is stronger when market accessibility is lower, especially significant for female-headed households while insignificant for male-headed ones. When market accessibility is higher, education's marginal effect diminishes, yet its nutritional knowledge and income effects still significantly enhance dietary diversity.

Discussion: These findings highlight the critical role of household heads' education in enhancing dietary diversity among rural households, and further emphasize the need for targeted strategies based on regional differences in market accessibility to improve rural dietary quality.

KEYWORDS

cognitive effect, dietary diversity, education level, income effect, market accessibility

1 Introduction

Over the past five decades, China's agricultural productivity and output have risen steadily, thereby effectively alleviating food shortages from the supply side. Specifically, China's per capita grain production increased from 319 kg in 1978 to 493 kg in 2023.¹ Concurrently, following the 1978 economic reforms, rural residents' incomes rose steadily to boost their food purchasing power. Driven by both improved food supply capacity and purchasing power, China's rural residents have overcome absolute food shortages and now enjoy sufficient calorie intake. For instance, in 2023, their annual per capita grain

1 National Bureau of Statistics of China. <https://data.stats.gov.cn/easyquery.htm?cn=C01>.

consumption was 160 kg (10% lower than in 2013) and meat consumption was 40 kg (nearly double that of 2013) (see text footnote 1).

However, rural residents' dietary quality has not improved proportionally, and their dietary choices have overlooked the role of dietary diversity in securing critical micronutrients. For example, their diet is heavily reliant on grains, vegetables, and livestock meat, while intake of fish and shrimp, dairy products, and other foods falls far short of the *Chinese Dietary Guidelines 2022* (CDG 2022) recommendations. This results in insufficient intake of high-quality protein and micronutrients. Data from 2020 shows that rural residents' intake of micronutrients like vitamin A, vitamin C, calcium, and selenium is severely insufficient—only 50% of CDG 2022 recommendations.²

Meanwhile, some rural residents consume excessive high-calorie, high-salt, and high-fat food, raising their risk of weight gain and obesity. For instance, in 2020, the prevalence of overweight and obesity among Chinese adults reached 50.7%, compared to 19% in 6–17-year-old adolescents and 10.4% in children under 6. Notably, the obesity rate among rural residents rose significantly faster than urban areas.

These phenomena indicate that poor dietary quality has led to the coexistence of undernutrition and overnutrition in rural areas (Yuan et al., 2019), which in turn increases residents' risk of nutrition-related chronic diseases (Miller V. et al., 2017; He et al., 2019; Bechthold et al., 2017; Sheng et al., 2021; Mozaffari et al., 2021; Wang Y. Y. et al., 2022; Ward et al., 2024).

Dietary diversity is an important indicator for assessing dietary quality (FAO, 2013; Chinese Nutrition Society, 2022). Not only is it a crucial foundation for healthy eating, but it also exhibits a significant positive correlation with nutritional adequacy (Lachat et al., 2018; Verger et al., 2021; Akerele et al., 2017). Furthermore, it has become a widely recognized proxy for micronutrient adequacy (Akerele et al., 2017; Kuczmarski et al., 2019; Ickowitz et al., 2019; Hanley-Cook et al., 2023). Given that micronutrients and beneficial bioactive components vary across different food types, no single natural food can provide all the nutrients required by the human body. Thus, a balanced combination of diverse foods is essential to maximize energy and nutrient supply, as well as to reduce the risk of diet-related chronic diseases.

Dietary diversity is primarily influenced by sociodemographic factors (women's empowerment, education, income) and supply factors (diversity of agricultural production, market accessibility). Among these, education is a factor that appears to have a fundamental influence on dietary diversity (Bhandari and Smith, 2000; Worsley et al., 2004; Barker et al., 2009; Chen and Li, 2009; Boedecker et al., 2019; Ma, 2019; Mwale et al., 2020; Wei and Sun, 2023; Abokyi et al., 2023; Adugna et al., 2024; Li, 2024). Well-educated individuals tend to have greater food and nutrition knowledge, and human capital from education may also indirectly improve dietary quality by boosting income levels.

However, existing literature mostly focuses on the average impact of education on farmers' dietary diversity and fails to address the variation in the strength of their relationship across

different levels of market accessibility. In fact, market accessibility exerts a significant moderating effect on education's role in promoting dietary diversity among rural households—education has a stronger promotional effect when market accessibility is low and this effect is weakened when it is high. Specifically, when market accessibility is low (i.e., high transaction costs), the nutritional knowledge gained from education helps residents select better food combinations from limited supplies; when it is high (i.e., low transaction costs), residents can easily access diverse foods through the market so education diminishes in its cognitive advantages and its marginal contribution to dietary diversity also decreases accordingly.

This study measures dietary quality using a dietary diversity score and develops a composite market accessibility index by integrating three indicators (distance to the nearest market, total number of stores, and store density) via the entropy method. Drawing on 10,958 rural households from the 2010 and 2014 waves of the China Family Panel Studies (CFPS), this paper employs a fixed-effects model to empirically estimate the impact of education on dietary diversity and the moderating role of market accessibility. It further analyzes how education improves dietary diversity through two pathways: income effects and cognitive effects.

The remainder of this paper is structured as follows: Section 2 presents a simplified analytical framework to explain potential pathways, as well as the moderating role of market accessibility, alongside an empirical model for examining the impact of education on household and individual dietary diversity, Section 3 covers the measurement of key variables and descriptive analysis. Section 4 reports the empirical results and heterogeneity analysis. Section 5 discusses the results and puts forward policy recommendations; Section 6 concludes.

2 Theoretical framework and empirical model

2.1 Theoretical framework

Education enables people to improve social status (Mirowsky and Ross, 2003), fostering confidence and capacity to control their lives (Worsley et al., 2004). Research shows that more educated women have greater life control than less educated ones and that they enjoy better dietary quality (Barker et al., 2009). Grossman (1972) proposed that more education not only alters the allocation of resources to health but also helps the more educated produce health more efficiently with a given level of investment.

Cutler and Lleras-Muney (2008) decomposed the mechanisms through which education influences dietary quality, finding that income accounts for 30% of the explanatory power. Human capital theory posits that education, as a key form of human capital investment, directly boosts income growth by enhancing individuals' knowledge, skills, and labor productivity (Mincer, 1958; Becker, 1975; Heckman, 1976). For the rural population, research shows more educated farmers adopt new technologies and equipment faster, thereby increasing farm income; they can also secure higher wages via non-agricultural employment. Higher income expands households' food budgets and purchasing power, enabling them to afford relatively expensive foods (e.g., fish, shellfish, dairy products) that were previously less consumed due

² Academy of Global Food Economics and Policy, 2022 China and Global Food Policy Report. <https://agfep.cau.edu.cn/module/download/downloadfile.jsp?filename=6126661309c24b57b410176ec60f5d32.pdf>.

to high prices (Broeck et al., 2020; Gao et al., 2020; Gupta et al., 2024).

Meanwhile, human capital from education not only indirectly influences dietary choices via income but also directly enhances cognitive abilities related to information processing, behavioral decision-making, and critical thinking (Hanushek and Woessmann, 2008; Baker et al., 2011). Enhanced cognitive abilities help individuals more accurately understand and apply nutritional knowledge (Hou et al., 2021), and this nutritional knowledge advantage makes them more inclined to adopt healthy dietary behaviors. Among the pathways through which education influences health, cognitive abilities account for roughly 30% of the observed impact (Cutler and Lleras-Muney, 2008).

Based on the above exploration of education's "income effect" and "cognitive effect" on dietary diversity, this paper proposes the following hypothesis:

H1. Higher education levels can enhance household and individual dietary diversity, primarily by increasing income and enhancing cognitive abilities.

Additionally, market accessibility exerts a regulatory effect on the intensity of education's impact on household and individual dietary diversity. Such regulation stems primarily from the distinct pathways through which these two factors impact dietary diversity: education functions by enhancing residents' nutritional knowledge, dietary decision-making capabilities (e.g., optimizing food combinations), and income levels; market accessibility operates mainly by lowering transaction costs associated with accessing diverse foods (e.g., time and transportation costs related to market travel).

Specifically, when low market accessibility raises transaction costs, nutritional knowledge from education helps farmers rationally combine limited foods and replace scarce foods with readily available substitutes (e.g., substituting meat with legumes to supplement protein). This aligns with the principle of substitution effect: "When one factor is scarce, the marginal utility of another increases." Notably, this substitution is only partial (not complete) at the marginal level—education cannot replace the market's food supply function.

Conversely, high market accessibility substantially lowers transaction costs. Markets not only broaden food access and enhance convenience (Morrissey et al., 2024; Jones, 2017; Kihiu and Amuakwa-Mensah, 2020; Sibhatu and Qaim, 2016; Murendo et al., 2018; Olabisi et al., 2021; Ren et al., 2022; Usman and Haile, 2022; Wan et al., 2022; Wang et al., 2024) but also provide farmers with food-related information (Ickowitz et al., 2019). In this context, while education's marginal effect on dietary diversity diminishes, its nutritional knowledge and income effects still significantly improve dietary diversity.

To conclude, market accessibility regulates the relationship between education and dietary diversity by influencing food supply richness and access convenience. Accordingly, the following hypothesis is proposed:

H2. Market accessibility has a moderating effect on the relationship between education level and dietary diversity, and this effect can alter the intensity of education's impact on dietary diversity.

2.2 Empirical model

To examine the relationship between the education level of the household head and the outcome variables of interest, we use the following panel data regression equation:

$$HDDS_{ht} = \alpha_1 + \alpha_2 Education_{iht} + \alpha_3 MA_{jt} + \alpha_4 X_{iht} + \eta_p + \delta_t + \varepsilon_{ht} \quad (1)$$

$$IDDS_{iht} = \beta_1 + \beta_2 Education_{iht} + \beta_3 MA_{jt} + \beta_4 X_{iht} + \eta_p + \delta_t + \varepsilon_{it} \quad (2)$$

In Equation 1, $HDDS_{ht}$ denotes the dietary diversity of household h in year t ; $Education_{iht}$ refers to the education level of household head i in household h ; MA_{jt} represents indices measuring market accessibility in village j in year t ; and X_{iht} refers to all other covariates, including individual, family, and village characteristics. This set of covariates primarily includes the household head's age, gender, marital status, self-assessed health score, farming diversity, off-farm income, household size, child dependency ratio, elderly dependency ratio, village environment, and village elevation. α_1 is the constant term, δ_t denotes the time fixed effect, and ε_{ht} is the error term.

To address unobserved regional heterogeneity, this study controls for provincial fixed effects in the estimation. Separately, households in the same village tend to have similar dietary diversity—this similarity may give rise to heteroskedasticity and inter-household correlations within villages, which could bias estimation results. We thus further adjust standard errors by clustering at the village level.

Household-level dietary diversity may vary across individuals, so this paper also estimates the impact of the household head's education level on the household head's individual dietary diversity. In Equation 2, $IDDS_{iht}$ refers to the dietary diversity of the household head i in year t , with all other variables having the same definitions as in Equation 1.

2.2.1 Subgroup analysis by level of market accessibility

We run the two-way fixed effects regressions as in Equations 1, 2 for three groups representing increasing market accessibility levels. Households are divided into low-, medium-, and high-market-accessibility groups using terciles of market accessibility.

2.2.2 Subgroup analysis by gender

Female and male household heads differ in dietary decision-making patterns and resource acquisition pathways, meaning the interaction between education and market accessibility may vary by household head gender. For instance, the impact of female household heads' education on dietary choices may be more market-dependent, whereas male household heads may experience less market moderation due to their advantages in resource acquisition. To explore this, we group households by household head gender and run Equations 1, 2 separately for female- and male-headed households—this helps understand how

the relationship between education, market accessibility, and dietary diversity varies by gender.

3 Data sources and description

3.1 CFPS dataset

We use 2010 and 2014 data from the China Family Panel Studies (CFPS), which contain extensive information on household and individual diets. Administered by Peking University's Institute of Social Science Survey, the CFPS covers approximately 16,000 urban and rural households annually across 25 Chinese provinces, offering highly representative and scientifically rigorous data.

For this study, the household head is defined as the person responsible for food preparation. To mitigate extreme value interference in regression analysis, we apply 1% bilateral winsorization to household per capita net income and wage income, and exclude individual samples with an abnormal dietary diversity score of 0. After merging individual, household, and village-level data and retaining only agricultural households, we obtained 10,958 rural household samples from the two survey waves. Detailed sample information is provided in the next section.

3.2 Variables and measurements

3.2.1 Household and individual dietary diversity

To assess dietary diversity, we use two adapted indicators: the Household Dietary Diversity Score (HDDS) and the Individual Dietary Diversity Score (IDDS) (for household heads). These indicators offer a more nuanced view of dietary diversity—bridging household-level dietary trends and individual behaviors to enable more accurate assessment of nutritional status within households.

The HDDS is the most widely used dietary diversity indicator, counting food groups consumed over a specific period (Waha et al., 2022; Usman and Haile, 2022; Tacconi et al., 2023). Currently, there is no uniform standard for defining or measuring dietary diversity, leading to varied HDDS applications in the literature. These discrepancies mainly relate to measurement time frames and food groupings.

This paper adopts a 7-day recall period (Jones et al., 2014; Sibhatu and Qaim, 2016; Muthini et al., 2020; Mulenga et al., 2021) and categorizes food into 9 groups: (1) cereals; (2) meat; (3) fish and other aquatic products; (4) fresh vegetables and fruits; (5) milk and dairy products; (6) soy products; (7) eggs; (8) pickled foods (e.g., pickled mustard tuber); (9) puffed/fried foods (e.g., potato chips, fries). Dietary diversity scores are the sum of consumed food groups (ranging from 0 to 9), with higher scores indicating greater diversity (i.e., more food groups consumed).

Unlike the HDDS (measured at the household level), the IDDS focuses on the dietary diversity of the household head who is often responsible for food procurement and allocation. The IDDS, based on the consumption of 9 food groups (with a 7-day recall period), ranges from 1 to 9 and shares the same food classification as the HDDS. Examining the household head's individual dietary

profile helps us understand how their decision-making role shapes personal dietary choices and how individual nutritional needs differ from the household average.

3.2.2 Household head education level

The household head's education level is measured by years of schooling. Years of schooling are calculated based on the number of years for the head's highest completed education level, plus years from their unfinished last education stage (for those currently enrolled, withdrawn midway, or dropped out). The number of years for each highest education level is set as follows: no formal schooling = 0; primary school graduation = 6; junior high school graduation = 9; senior high school, secondary technical school, or vocational high school/technical school graduation = 12; junior college graduation = 15; bachelor's degree = 16; postgraduate education = 19.

3.2.3 Market accessibility

Market accessibility refers to the ease with which households can access markets and conduct economic exchanges. To address the limitations of single-indicator measures, this study uses the entropy method to synthesize three core indicators into a single market accessibility score (ranging from 0 to 1). These indicators are: (1) Market distance: the distance from the household to the nearest market (where residents primarily purchase food); (2) Number of stores: total food stores in the village, with more stores meaning greater food availability; (3) Store density: calculated as stores per household in the village, capturing the spatial concentration of food suppliers.

3.2.4 Income level

Income level is the dependent variable in this study's mechanism analysis. We use two indicators to measure household income: the first is household per capita net income—calculated as household net income divided by total members—which includes the sum of all members' wage income, net business income, property income, transfer income, and other income; the second is wage income, referring to after-tax wages, bonuses, and in-kind benefits earned by household members from agricultural or non-agricultural employment.

3.2.5 Cognitive skills

Cognitive ability is another dependent variable in the mechanism analysis. This study uses word recognition and math computation scores from the 2010 and 2014 CFPS waves to measure household heads' cognitive ability. Both scores come from assessments with one set each of word recognition and math questions: final scores are determined by the number of the hardest questions respondents answered correctly, which reflects their cognitive level. Specifically, the word recognition score ranges from 0 to 34, and the math computation score from 0 to 24.

TABLE 1 Definition of variables and descriptive analysis.

| Variables | Definition | Mean | SD | Min | Max |
|---|--|-----------|-----------|--------|------------|
| Dietary diversity indicators | | | | | |
| Household dietary diversity score (HDDS) | Number of food groups consumed by each household, derived from 7-day food recall data | 6.01 | 1.89 | 1.00 | 9.00 |
| Individual dietary diversity score (IDDS) | Dietary diversity score of the household head | 5.20 | 1.82 | 1.00 | 9.00 |
| Mediator variables | | | | | |
| Per capita household net income | Calculated as household net income divided by household size; household net income includes wage income, net operating income, property income, transfer income, and other income of all household members | 7,196.62 | 6,819.25 | 166.67 | 37,275.00 |
| Wage income | Post-tax wages, bonuses, and in-kind benefits earned by household members from agricultural labor or non-farm employment | 19,147.75 | 23,135.37 | 0.00 | 114,000.00 |
| Word recognition | Ability to memorize, recognize, and reproduce Chinese characters accurately | 12.01 | 10.53 | 0.00 | 34.00 |
| Mathematical skills | Application of mathematical knowledge in calculations, logical reasoning, and problem-solving | 6.76 | 5.82 | 0.00 | 24.00 |
| Core explanatory variables | | | | | |
| HH head education level | Years of schooling of the household head | 4.90 | 4.21 | 0.00 | 22.00 |
| Market accessibility | Computed via entropy method, incorporating 3 variables: market distance, number of stores, store density (stores per household) | 0.12 | 0.10 | 0.00 | 0.82 |
| Individual characteristics | | | | | |
| HH head age | Age of the household head in years | 48.82 | 13.43 | 18.00 | 78.00 |
| HH head gender | Male = 1, Female = 0 | 0.27 | 0.44 | 0.00 | 1.00 |
| HH head marital status | Married = 1, single/divorced/widowed = 0 | 0.88 | 0.32 | 0.00 | 1.00 |
| Self-assessed health score | 5-point scale: 1 = “unhealthy”, 5 = “very healthy” | 3.48 | 1.33 | 1.00 | 5.00 |
| Households' characteristics | | | | | |
| Farming diversity | Number of cultivated plants (rice, wheat, maize, cotton, forest products) and raised livestock species (swine, cattle, goats, fish) per household in the past 12 months | 2.21 | 1.19 | 0.00 | 8.00 |
| Off-farm income | Yes = 1, no = 0 | 0.85 | 0.35 | 0.00 | 1.00 |
| Household size | Total number of household members | 3.73 | 1.71 | 0.00 | 14.00 |
| Child dependency ratio | Ratio of population under 15 to working-age population (15–64 years old) | 0.34 | 0.42 | 0.00 | 7.00 |
| Elderly dependency ratio | Ratio of population aged 65 and above to working-age population (15–64 years old) | 0.17 | 0.35 | 0.00 | 6.00 |
| Villages' characteristics | | | | | |
| Village environment | 7-point scale: 1 = “very messy”, 7 = “very tidy” | 4.31 | 1.49 | 1.00 | 7.00 |
| Village elevation | 0 = below 200 m, 1 = 200 m and above | 0.60 | 0.49 | 0.00 | 1.00 |

Per capita household net income and wage income are measured in Chinese Yuan (CNY).

3.2.6 Other covariates

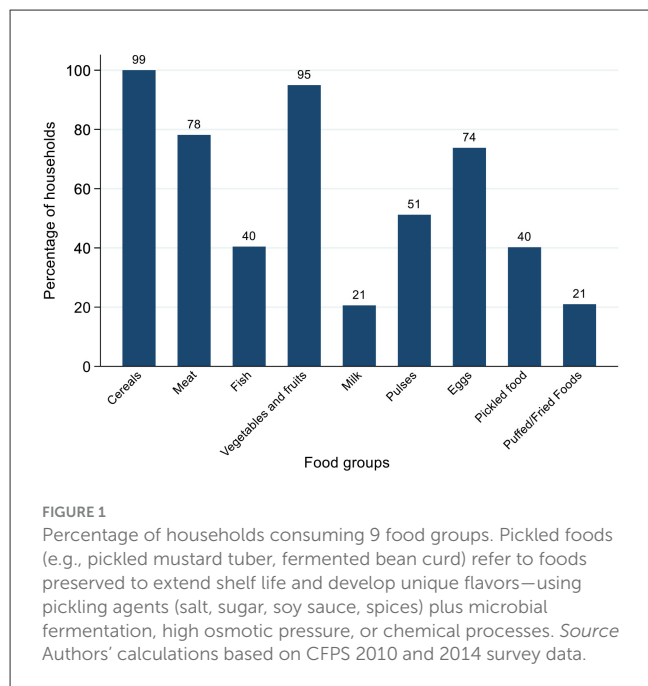
We control for individual, household, and village characteristics—including the household head's age, gender, marital status, and self-assessed health score; farming diversity; off-farm income; household size; child dependency ratio; elderly dependency ratio; village environment; and village elevation.

The child dependency ratio is defined as the share of under-15 population to working-age population (15–64), reflecting working-age individuals' child support burden. The elderly dependency ratio is the share of population aged 65+ to working-age population (15–64), measuring their elderly support burden.

For elevation (a topographic feature), villages are categorized into two groups: those below 200 m above sea level are assigned a value of “0”, and those above 200 m “1”.

3.3 Descriptive analysis

Table 1 presents definitions and summaries of key variables used in the empirical analysis. The total sample includes 10,958 households, of which approximately 73% are female-headed, indicating women predominantly handle food preparation in rural



Chinese households. Notably, sample households consumed an average of 6 food groups in the past week, compared to 5.2 for household heads.

Household heads have an average of 5 years of schooling (equivalent to primary school graduation), correlating with their relatively advanced age (49 years). Additionally, approximately 85% of households have non-agricultural income, with average wage income reaching 19,148 yuan (CNY); household per capita net income during the sample period is 7,197 yuan (CNY). These households also have an average of 3–4 members, with child and elderly dependency ratios at 34% and 17%, respectively. Finally, household heads exhibit limited cognitive abilities, with word recognition scores of 12 and math skills scores of 7.

Figure 1 presents the food groups consumed by sample households over a 7-day period. Nearly all sample households consume grains (primarily rice, wheat, and coarse grains like sorghum and oats) which form the foundation of daily diets. Vegetables, fruit, meat, and eggs are highly consumed: 95% of households eat vegetables and fruit, 78% eat meat, and 74% eat eggs during this period. In contrast, fish and legumes consumption is lower, with only 40% consuming fish and 51% consuming legumes. Milk consumption is the lowest among all food groups, with only 21% of households consuming it.

Figure 2 presents household (Panel A) and individual (Panel B) Diet Diversity Scores (DDS) by household heads' education levels. As household heads' education levels increase, mean household and individual DDS rise gradually. In Panel A, the mean household DDS is 6.6 for heads with high school education or above, compared to only 5.7 for illiterate or semi-illiterate heads. In Panel B, the mean individual DDS is 5.8 for households with heads with high school education or above, vs. 4.9 for those with illiterate or semi-illiterate heads.

Figure 3 presents household (Panel A) and individual (Panel B) Diet Diversity Scores (DDS), stratified by household heads' education levels and market accessibility. For Panel A, across all

market accessibility levels, dietary diversity is consistently positively associated with education. At the same market accessibility level, household DDS rises with household heads' education; at the same education level, household DDS scores increase as market accessibility improves. Panel B shows the same pattern for individual DDS.

4 Results

4.1 Impact of education level on HDDS and IDDS in rural China

We first examine the relationship between household heads' education levels and DDS via scatter plots with linear regression lines. Results show higher education is associated with higher household DDS (Figure 4A). Meanwhile, household heads' individual DDS also increases with their education (Figure 4B). Further, Figure 4C shows fitted lines for all market accessibility groups (low/medium/high) have positive slopes, but the marginal effect of education on household dietary diversity varies across market accessibility levels. Similarly, Figure 4D shows the marginal effect of education on individual dietary diversity also exhibits heterogeneity.

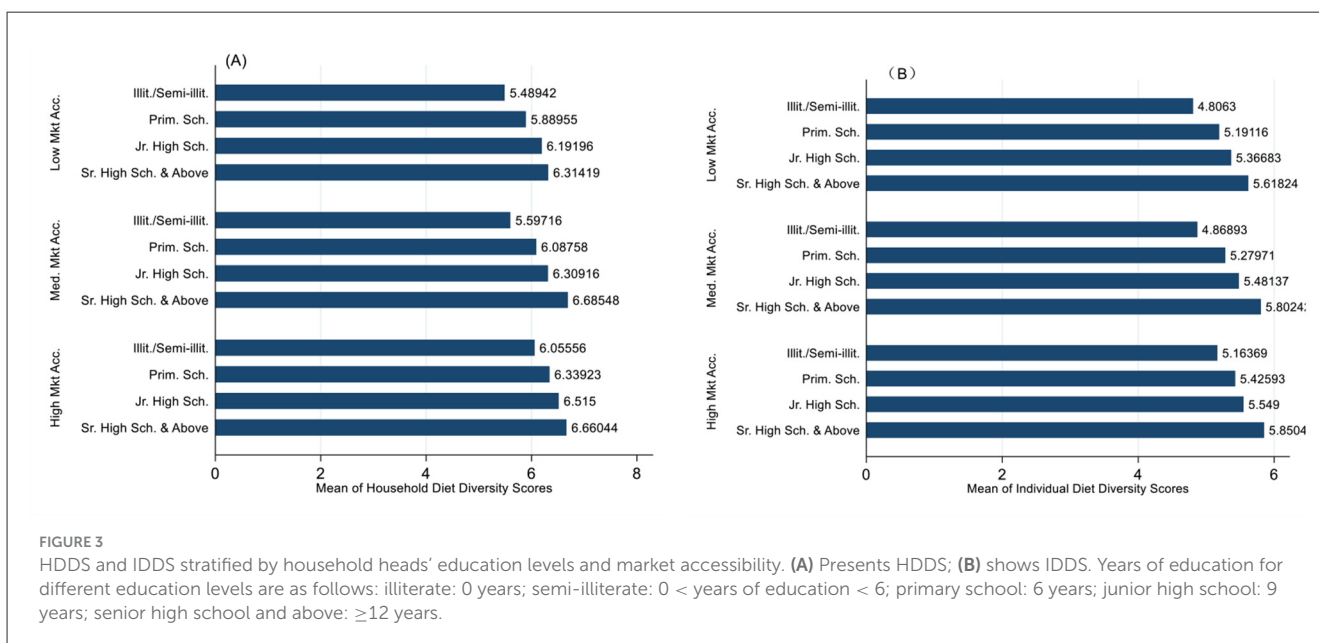
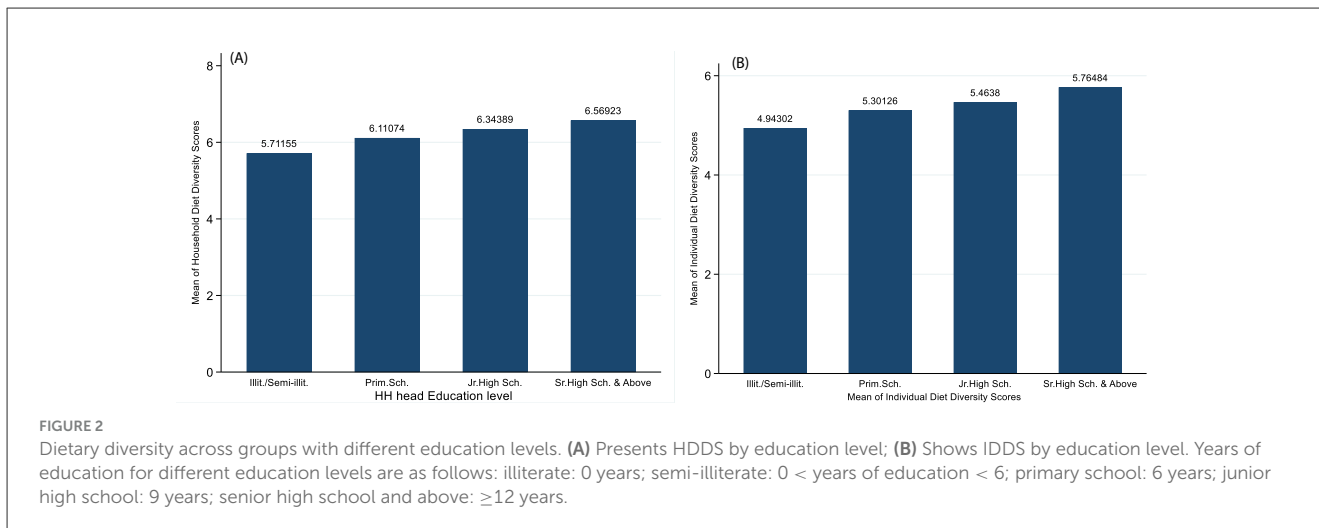
To mitigate potential impacts of individual and temporal factors on results, this study further uses a two-way fixed effects model for empirical testing. Table 2 presents the estimated impacts of household heads' education levels on HDDS and IDDS. Specifically, household heads' education levels have a statistically significant positive effect on both HDDS and IDDS, aligning with preliminary findings in Figures 4A, B. For instance, holding other variables constant, each additional year of education increases HDDS by 0.064 units and IDDS by 0.054 units (Table 2, Columns 1 and 2). Additionally, HDDS and IDDS are higher with greater village market accessibility.

Further, household head, household, and village characteristics influence dietary diversity. For example, households with older, female, married heads and higher self-rated health scores tend to have higher dietary diversity. Off-farm income correlates positively and significantly with both HDDS and IDDS. Larger households also exhibit higher household and individual dietary diversity.

4.2 Heterogeneous effects of market accessibility

Using the market accessibility index distribution, this study applies the tertile method to divide the sample into three groups (low, medium, high market accessibility) to examine heterogeneity in the relationship between household heads' education levels and household/individual dietary diversity.

Fixed effects model results (Table 3) show the positive impact of household heads' education levels on household/individual dietary diversity is significant at the 1% level ($p < 0.01$) across all three groups, but the strength of this association varies by tertile. Specifically, across low/medium/high market accessibility groups, each one-unit increase in household heads' education raises HDDS by at least 0.05 units and IDDS by at least 0.04 units, respectively;



the marginal effect of education on dietary diversity is strongest in the medium group but weakens in the high group.

4.3 Gender heterogeneity in the moderating effect of market accessibility

To examine if market accessibility's moderating effect on the education-dietary diversity relationship differs by household head gender, this study introduces interaction terms (household heads' education level × market accessibility) for female and male heads into baseline regression Equations 1, 2, respectively. Table 4 presents regression results testing gender differences in this moderating effect.

Results show female heads' education level significantly boosts both HDDS and IDDS (Columns 1 and 2). The "female heads' education level × market accessibility" interaction term is significantly negative (Column 1), indicating market accessibility weakens the positive impact of female heads' education on

household dietary diversity. Male heads' education level also significantly boosts dietary diversity (Columns 3 and 4), but their "education level × market accessibility" interaction term is insignificant (Columns 3 and 4), meaning market accessibility does not moderate the impact of male heads' education on dietary diversity.

4.4 Mechanism analysis

To clarify the specific pathways through which household heads' education levels affect dietary diversity, this study further examines the underlying mechanisms, focusing on two key pathways: education's income effect and cognitive effect.

4.4.1 Education's income effect

We use two outcome variables to measure income: household per capita net income and wage income. Both are regressed on education level and other control variables.

TABLE 2 Impact of education level on HDDS and IDDS (fixed effect model).

| Explanatory variables | (1) | (2) |
|----------------------------|----------------------|----------------------|
| | HDDS | IDDS |
| HH head education level | 0.064*** (0.005) | 0.054*** (0.006) |
| Market accessibility | 1.924*** (0.659) | 1.746** (0.739) |
| HH head age | 0.008*** (0.002) | 0.004** (0.002) |
| HH head gender | -0.428*** (0.045) | -0.190*** (0.046) |
| HH head marital status | 0.144** (0.057) | 0.107** (0.053) |
| Self-assessed health score | 0.084*** (0.016) | 0.124*** (0.015) |
| Farming diversity | 0.045* (0.025) | 0.045* (0.024) |
| Off-farm income | 0.339*** (0.060) | 0.228*** (0.057) |
| Household size | 0.222*** (0.014) | 0.025* (0.013) |
| Child dependency ratio | -0.526*** (0.052) | -0.114** (0.051) |
| Elderly dependency ratio | -0.012 (0.060) | 0.064 (0.057) |
| Village environment | 0.060** (0.026) | 0.043* (0.025) |
| Village altitude | -0.323*** (0.084) | -0.282*** (0.082) |
| Constant | 3.588*** (0.206) | 3.616*** (0.200) |
| Provincial FE | Yes | Yes |
| Year FE | Yes | Yes |
| Observations | 10,958 | 10,958 |
| R-squared | 0.245 | 0.197 |

Robust standard errors clustered at the village level are reported in parentheses. Statistical significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Province and year fixed effects are included.

Table 5 presents regression results for the impact of household heads' education on household per capita net income and wage income. Column 1 shows that each additional year of household heads' education significantly increases household per capita net income by 3.1%. Column 2 indicates that household heads' education significantly boosts household wage income, with each additional year increasing it by 2.8%. This confirms that higher

educational attainment significantly raises rural household per capita net income while also increasing wage income.

4.4.2 Education's cognitive effect

We use two outcome variables to measure cognitive ability: word recognition and mathematical skills. Both are regressed on education level and other control variables.

Table 6 presents the marginal effects of education on cognitive ability: Column 1 uses word recognition, and Column 2 uses mathematical skills. For both measures, education has a significant impact on cognitive ability ($p < 0.01$), indicating it enhances household heads' cognitive ability.

4.5 Alternative market accessibility measure

Infrastructure (e.g., highways, railways, public buses) determines whether farmers can access food from the market they cannot produce themselves (Chegere and Kauky, 2022). Accordingly, this study uses "whether villages added new infrastructure in 2014 (relative to 2010)" as a proxy for market accessibility to further examine how education's impact on dietary diversity varies by market accessibility. Specifically, it examines whether education's impact on dietary diversity differs in the same villages between pre-2010 (no new infrastructure) and post-2014 (new infrastructure added). Relevant regression results are presented in Table 7.

Based on Columns 1–4 of Table 7, household heads' education level has a significant positive impact on both household and individual dietary diversity. However, this effect is not uniform but varies with market accessibility, which aligns with the overall findings in Table 3. Further comparison shows that in villages without new infrastructure, household heads' education has a more pronounced effect on enhancing both dimensions of dietary diversity. Conversely, in villages with new infrastructure, this effect diminishes.

5 Discussion

This paper examines the role of education in shaping dietary diversity and explores the moderating effect of market accessibility as well as the mediating roles of income and cognitive ability. First, findings reveal household heads' education levels and market accessibility are both significantly and positively correlated with household and individual dietary diversity. This finding is consistent with previous studies (e.g., Worsley et al., 2004; Chen and Li, 2009; Huang and Tian, 2019; Miller L. C. et al., 2017; Usman and Haile, 2022; Wei and Sun, 2023; Li, 2024).

Further analysis shows education's impact on dietary diversity is not constant but varies with market accessibility: in areas with lower accessibility, household heads' education has a stronger positive impact on dietary diversity; in areas with higher accessibility, its positive impact weakens. This is likely because residents in low-accessibility areas have limited access to diverse foods, so more educated heads can allocate food resources

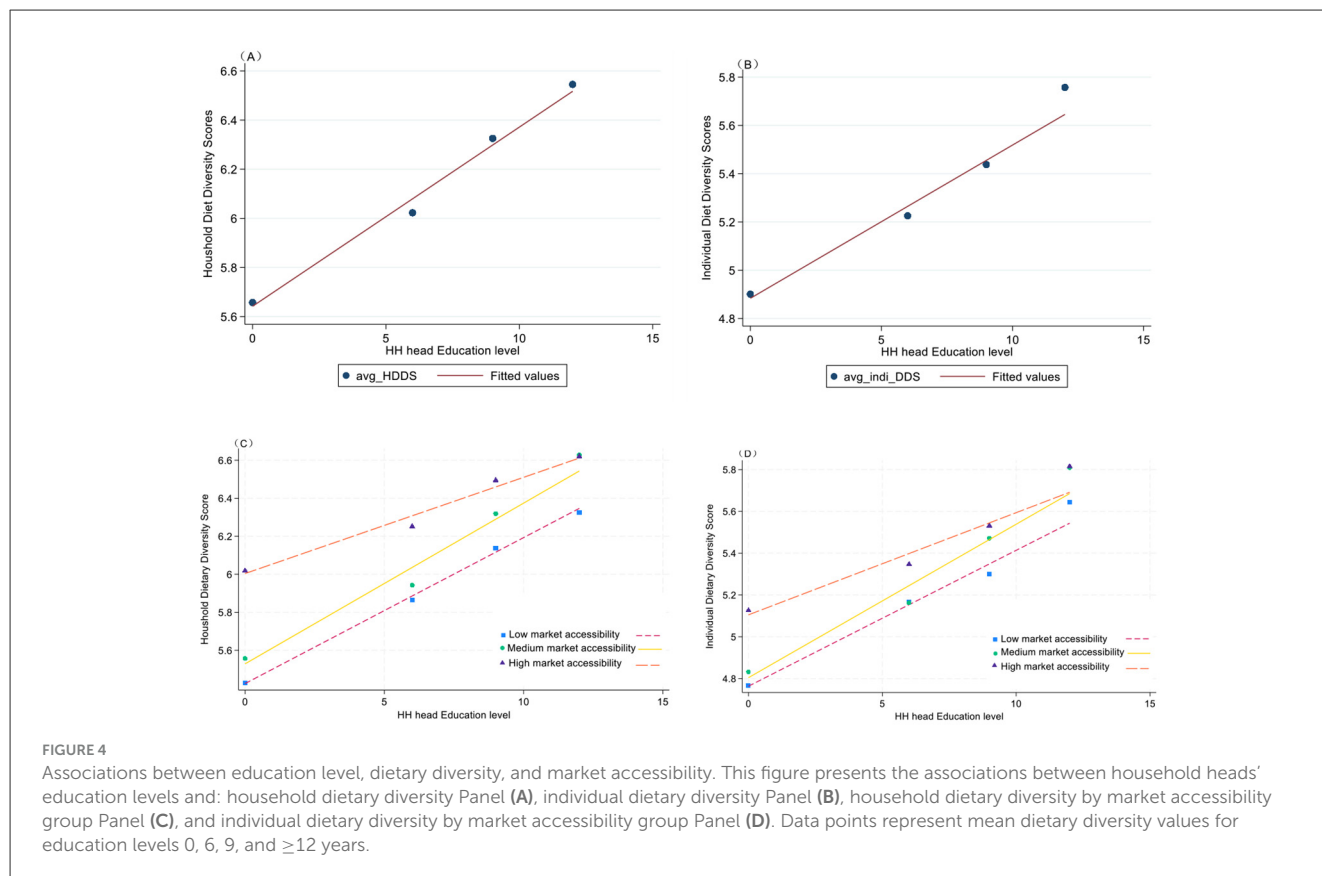


FIGURE 4

Associations between education level, dietary diversity, and market accessibility. This figure presents the associations between household heads' education levels and: household dietary diversity Panel (A), individual dietary diversity Panel (B), household dietary diversity by market accessibility group Panel (C), and individual dietary diversity by market accessibility group Panel (D). Data points represent mean dietary diversity values for education levels 0, 6, 9, and ≥ 12 years.

TABLE 3 Impact of education level on HDDS and IDDS by market accessibility tertiles (fixed effect model).

| Explanatory variables | (1) | (2) | (3) | (4) | (5) | (6) |
|-------------------------|--------------------------|---------------------|-----------------------------|---------------------|---------------------------|---------------------|
| | Low market accessibility | | Medium market accessibility | | High market accessibility | |
| | HDDS | IDDS | HDDS | IDDS | HDDS | IDDS |
| HH head education level | 0.048*** (0.009) | 0.038*** (0.009) | 0.077*** (0.010) | 0.065*** (0.010) | 0.059*** (0.008) | 0.054*** (0.009) |
| Constant | 4.177*** (0.299) | 4.261*** (0.283) | 3.804*** (0.342) | 3.878*** (0.323) | 3.869*** (0.322) | 3.644*** (0.333) |
| Provincial FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 3,778 | 3,778 | 3,636 | 3,636 | 3,544 | 3,544 |
| R-squared | 0.300 | 0.253 | 0.261 | 0.236 | 0.205 | 0.167 |

Separate regressions are estimated for households in the lowest, medium, and highest market accessibility tertiles, presented in Columns (1), (3), and (5), respectively. Columns (2), (4), and (6) report results for models focusing on individuals (household heads) in the same subsamples. Robust standard errors (clustered at the village level) are reported in parentheses. Statistical significance: *** $p < 0.01$. Province and year fixed effects are included. Control variables are the same as in Table 2.

more effectively using their nutritional knowledge. For instance, substituting hard-to-access protein sources (e.g., dairy products) with readily available alternatives like legumes.

By contrast, rural households in high-accessibility areas have greater access to diverse foods. This convenience reduces reliance on the nutritional cognitive ability that education provides. Education still significantly promotes dietary diversity, but its marginal effect is weakened. This phenomenon stems from humans' evolved biological preference for high-fat, high-calorie

foods. Moreover, high-calorie food intake activates the dopamine pathway in the human brain, generating a sense of pleasure that further reinforces the innate preference for sugary and fatty foods (Stover et al., 2023). Thus, improved market accessibility expands dietary choices for rural residents, who tend to select foods based on this ingrained biological preference, which in turn weakens the need to rely on education-derived nutrition literacy.

Another notable finding is that market accessibility weakens the positive effect of female household heads' education on household

TABLE 4 Moderating effect of market accessibility by gender (fixed effect model).

| Explanatory variables | (1) | (2) | (3) | (4) |
|---|----------|----------|----------|----------|
| | HDDS | IDDS | HDDS | IDDS |
| Female-headed HH education level | 0.061*** | 0.048*** | | |
| | (0.006) | (0.006) | | |
| Market accessibility | 1.865*** | 1.836** | | |
| | (0.622) | (0.757) | | |
| Female-headed HH education level × market accessibility | -0.089* | -0.059 | | |
| | (0.054) | (0.053) | | |
| Male-headed HH Education level | | | 0.081*** | 0.075*** |
| | | | (0.009) | (0.009) |
| Market accessibility | | | 2.131* | 1.256 |
| | | | (1.125) | (1.068) |
| Male-headed HH Education level × Market accessibility | | | 0.058 | 0.050 |
| | | | (0.097) | (0.100) |
| Provincial FE | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes |
| Observations | 8,107 | 8,107 | 2,851 | 2,851 |
| R-squared | 0.236 | 0.195 | 0.253 | 0.212 |

Models (1) and (2) examine the moderating effect of market accessibility on the relationship between female household heads' education levels and HDDS/IDDS. Models (3) and (4) examine this moderating effect for male household heads. Robust standard errors clustered at the village level are reported in parentheses. Statistical significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Province and year fixed effects are included. Control variables are the same as in Table 2.

dietary diversity, yet exerts no such significant impact on male heads. This gendered disparity is rooted in the gendered care and feeding responsibilities embedded in the structural norms of rural Chinese society (Hao et al., 2021; Fan and Xin, 2019; Tian et al., 2018). Indeed, within traditional rural Chinese families, women are assigned the normative role of household food managers, typically taking charge of food purchasing and meal preparation.

Specifically, when market accessibility is low, well-educated female heads leverage their nutrition knowledge to rationally combine limited food resources, maximizing dietary diversity within resource constraints. This practice aligns with their role as household health guardians. However, when accessibility improves, they can easily access a broader range of foods from the market and acquire new food-related information to try novel varieties (Ickowitz et al., 2019). By contrast, well-educated male heads gain an advantage primarily through their stronger social networks and resource access channels. Unlike women, they are rarely constrained by the day-to-day burden of food management responsibilities. Even in low-accessibility areas, they can secure high-quality, diverse foods through higher incomes or social connections to overcome geographical supply limitations. This explains why their education-driven positive effect on dietary diversity remains consistent regardless of variations in market accessibility.

TABLE 5 Mechanism: income effect.

| Explanatory variables | (1) | (2) |
|-------------------------|--------------------------------------|------------------|
| | Ln (per capita household net income) | Ln (wage income) |
| HH head education level | 0.031*** | 0.028*** |
| | (0.003) | (0.003) |
| Constant | 8.134*** | 8.598*** |
| | (0.075) | (0.087) |
| Provincial FE | Yes | Yes |
| Year FE | Yes | Yes |
| Observations | 11,797 | 9,605 |
| R-squared | 0.146 | 0.156 |

The outcome variables, household per capita net income and wage income, are log transformed.

Robust standard errors clustered at the village level are reported in parentheses. Statistical significance: *** $p < 0.01$. Province and year fixed effects are included. Regressions control for individual and household variables.

TABLE 6 Mechanism: cognitive effect.

| Explanatory variables | (1) | (2) |
|-------------------------|------------------|---------------------|
| | Word recognition | Mathematical skills |
| HH head education level | 1.592*** | 1.075*** |
| | (0.024) | (0.012) |
| Constant | 12.474*** | 3.095*** |
| | (0.583) | (0.270) |
| Provincial FE | Yes | Yes |
| Year FE | Yes | Yes |
| Observations | 10,958 | 10,958 |
| R-squared | 0.584 | 0.685 |

Robust standard errors clustered at the village level are reported in parentheses. Statistical significance: *** $p < 0.01$. Province and year fixed effects are included. Regressions control for individual and household variables.

This study also explores the pathways by which education affects dietary diversity. Specifically, education enhances individuals' nutritional cognitive through systematic knowledge sharing and cognitive development; in turn, this enhanced cognitive ability enables them to better understand and apply nutrition-related knowledge, thereby optimizing their daily food choices. Beyond this cognitive pathway, household heads' higher education significantly increases family income, which eases food budget constraints and boosting purchasing power for diverse foods, which indirectly enhances dietary diversity.

5.1 Study limitations

This study does not account for the impact of e-commerce development on market accessibility (Wang Q. et al., 2022); furthermore, its exclusive focus on physical access overlooks additional dimensions of food access. In addition, the study fails to

TABLE 7 Impact of education level on dietary diversity, by whether new infrastructure was added (fixed effect model).

| Explanatory variables | (1) | (2) | (3) | (4) |
|-------------------------|-----------------------------|--------------------------------|-----------------------------|--------------------------------|
| | HDDS | | IDDS | |
| | 2010: No new infrastructure | 2014: New infrastructure added | 2010: No new infrastructure | 2014: New infrastructure added |
| HH head education level | 0.079*** (0.010) | 0.069*** (0.010) | 0.067*** (0.010) | 0.064*** (0.010) |
| Constant | 3.493*** (0.332) | 3.826*** (0.342) | 3.320*** (0.325) | 3.318*** (0.351) |
| Provincial FE | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes |
| Observations | 2,129 | 2,148 | 2,129 | 2,148 |
| R-squared | 0.177 | 0.082 | 0.115 | 0.042 |
| Test for equal coeff. | $p = 0.010$ | | $p = 0.030$ | |

Separate multiple linear regressions are estimated for households without new infrastructure in 2010 (Column 1) and with new infrastructure in 2014 (Column 2), respectively. Columns 3 and 4 present results for models focusing on individuals in the same two subsamples. Robust standard errors are reported in parentheses. Statistical significance: *** $p < 0.01$. Empirical p -values are used to test the significance of differences in household heads' education level coefficients between groups, which are obtained via 1,000 bootstrap replications. Control variables are the same as in Table 2.

consider the complementary role of short-form video platforms in disseminating dietary information to support nutrition education (Yang and Zhu, 2025). It also only distinguishes dietary diversity at the individual and household levels, without disaggregating data for specific subgroups (e.g., children, the elderly); nor does it capture the quality-related dimensions of dietary diversity. Specifically, our dietary diversity measure captures only the quantity of food categories consumed, and fails to account for the relative intake amounts, health contributions of different food groups, and the frequency of food consumption. Finally, the analysis treats household heads' education level as the primary explanatory variable while overlooking the potential reverse effect of children's education on household heads' food decisions (Ma, 2019).

Beyond these methodological limitations, food choice is a multifaceted behavior shaped not only by economic factors but also by cultural food identities (Alonso et al., 2018), dietary habits (Zhai et al., 2021; Wen et al., 2024), intergenerational family food practices, as well as power dynamics (Gupta et al., 2024). However, the theoretical framing of this study is limited by its focus on individual cognitive and economic factors, and future research should incorporate cultural, social, and structural dimensions to provide a more comprehensive explanation of food choice.

5.2 Policy implications

This study adds a new dimension to policies for improving rural dietary quality in China by accounting for regional variations in market accessibility that influence the association between education and dietary quality. Against this backdrop of regional variations in market accessibility, targeted strategies to enhance rural dietary quality should be tailored to these distinct contexts:

In rural areas with low market accessibility, the Chinese government should prioritize educational investments. These efforts include expanding basic education and implementing targeted, culturally adapted nutritional literacy programs to strengthen residents' ability to select optimal food combinations from limited supplies. To mitigate the risk of reinforcing unpaid gendered labor in women-focused interventions, these educational initiatives should be paired with guidelines for equitable household food management labor sharing. This approach avoids framing women exclusively as the sole agents responsible for advancing dietary quality.

In regions with high market accessibility, the government should leverage the synergy between education and markets. While enhancing rural residents' nutritional literacy through education to help them make nutritionally sound dietary choices, the government should also increase investment in rural infrastructure (e.g., transportation networks, cold-chain logistics) and retail outlets to ensure rural residents can access the foods they need. Furthermore, infrastructure investments should be aligned with the preservation of local food culture. This alignment ensures that expanded market access does not displace traditional, nutritionally valuable dietary patterns.

6 Conclusion

This study focuses on dietary diversity among rural Chinese households and individuals, examining education's foundational impact on dietary diversity, the moderating effect of market accessibility, and the mediating roles of income and cognitive ability. We find that when market accessibility is low, education exerts a substitution effect on market supply; when accessibility is high, education and market accessibility demonstrate a complementary relationship. Based on these findings, we argue

that improving rural households' dietary diversity requires synergy between education and markets.

To elaborate, in regions with low market accessibility, education has a stronger marginal effect on dietary diversity—education-derived cognitive capacity (e.g., balancing nutrition with limited ingredients) can partially offset shortages in market supply. Yet relying solely on education while neglecting rural market development may trap rural households in the predicament of limited access to diverse foods.

In contrast, in regions with high market accessibility, while education's marginal effect diminishes, the diverse food supply from markets still depends on education-derived cognitive capacity to guide informed food choices. If rural market development is prioritized exclusively while sidelining education, rural households may fall into the inefficient situation of “having access to foods but lacking the knowledge to choose.”

Ultimately, rural households can significantly increase dietary diversity only by coordinately enhancing “choice capacity” (cultivated through education) and “supply capacity” (enabled by market development).

Data availability statement

The micro-survey data used in this paper was collected by the Institute of Social Science Survey, Peking University. The authors accessed the data via their institutional membership. The authors had no special access privileges to the data that others would lack. Data on Chinese residents' economic and non-economic well-being, educational outcomes, and health status is freely available at <http://iss.pku.edu.cn/cfps/>.

Author contributions

RL: Conceptualization, Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. LY: Supervision, Writing – review & editing. LQ: Methodology, Writing – review & editing.

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