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Can information intervention improve dietary quality? Evidence from a randomized controlled trial in rural China

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A B S T R A C T

Nutrition education interventions are widely used globally but with mixed results. We conducted a randomized controlled trial to examine the effects of a nutrition education and a precise message (awareness-raising) intervention on nutrition knowledge and dietary quality of households in rural China. Treatment groups first received a lecture on the Chinese Food Guide Pagoda, and then all family members were measured for height and weight and informed of household overweight status. We analyzed 358 households before and after this intervention. Participants in the treatment group increased their dietary knowledge by 6% and improved their dietary quality by 8% after the intervention. The intervention effects were stronger for households with more than 25% and 50% of overweight people. Our study provides evidence that an intervention based on general nutrition information and delivery of a precise message to households can effectively improve dietary quality. Our findings inform the food policy debate on whether nutrition information interventions are effective. Furthermore, to the best of our knowledge, this is the first study to evaluate the effectiveness of a nutrition information intervention to improve dietary quality in rural China.

1. Introduction

A healthy diet and good nutrition are fundamental conditions for survival (Fieldhouse, 2013) and also are important indicators reflecting a country's economic level and population quality (Huang et al., 2021). With the development of the economy and the improvement of income, China is undergoing a rapid nutritional transition stage (Popkin et al., 1993; Du et al., 2002; F. Zhai et al., 2009; Huang et al., 2021), and significant steps have been taken to improve the population's nutrition over the past four decades (Huang et al., 2021). Food consumption in China has increased significantly as per capita household spending on food has risen rapidly (Feng et al., 2020). The dietary diversity of the Chinese population also has increased significantly among groups of different socioeconomic status (Popkin et al., 2002). The dietary energy intake is sufficient, and the intake of high-quality protein, such as meat, poultry, eggs, and other animal products, has continued to increase (Zhai et al., 2009; He et al., 2018).

China, however, is facing simultaneous challenges of under- and over-nutrition (Popkin et al., 2001; Dearth-Wesley et al., 2008). The intake of animal foods (mainly pork) has increased significantly, and the energy supply ratio of fat is also increasing rapidly (Du et al., 2004; Huang et al., 2021). Although the intake of fruit, vegetables, eggs, aquatic products, and dairy products has increased, it remains insufficient (Sheng et al., 2021). Moreover, unbalanced diets and deficiencies of some nutrients are particularly worse for the rural population in China. According to the China And Global Food Policy Report (2022), the intake of fruit, aquatic products and dairy products by rural residents was approximately 80 %–90 % lower than the recommended values of the Dietary Guidelines for Chinese 2016 (DGC-2016). In addition, there is a significant gap between the intake of vitamin A, vitamin C, and calcium among rural populations and the recommended values of the DGC-2016.

Governments round the world are taking measures to improve the diet of population, primarily through market environment change measures and information measures (Brambila-Macias et al., 2011; Traill, 2012). Measures aimed at changing the market environment include the taxation of unhealthy food (Mytton et al., 2012; Caro et al., 2017; Salgado & Ng, 2019), the subsidization of healthy food (An, 2013; Niebylski et al., 2015; Kaushal & Muchomba, 2015; Chakrabarti et al., 2018), the regulation of food available in the schools or workplaces

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(Wechsler et al., 2001; Bandoni et al., 2011; Brown et al., 2014; Garnett et al., 2019), and the distribution of vouchers to disadvantaged consumers (Bihan et al., 2012; McFadden et al., 2014; Lucas et al., 2015). Despite accumulating evidence regarding the effectiveness of market environment change measures in influencing dietary behavior, policy adoption remains low (Capacci et al., 2012; An, 2013). Information measures include nutrition education (Sahyoun et al., 2004; Reinbott et al., 2016), nutrition labeling (Gracia et al., 2007; Crockett et al., 2018), and advertising controls (Galbraith-Emami & Lobstein, 2013), in which nutrition education interventions are widely used but have achieved mixed results. A review of 40 nutrition education interventions found that nearly half of these interventions significantly changed participants' knowledge or dietary behavior; the other half, however, failed to achieve their objectives (Murimi et al., 2017). This has created uncertainty regarding the effectiveness of general information interventions.

Existing studies have certain limitations. First, obtaining high-quality measurements of dietary behavior is costly and time-consuming. Many existing studies used self-reporting (Bernstein et al., 2002; Poddar et al., 2010; Babatunde et al., 2011; Bihan et al., 2012) and virtual scenario-based approach (Borgmeier & Westenhoefer, 2009; Belot et al., 2020) to measure dietary behavior. However, self-reporting measure may provide inaccurate information about food consumption because of recall bias (Subar et al., 2015). The virtual scenario-based approach may not comprehensively replicate the sensations and experiences of the real environment, resulting in participants' dietary behaviors in virtual environments potentially lacking the accuracy observed in real-world settings. Second, the majority of evaluations for nutrition education and health information interventions focus on the impact of interventions on the consumption of specific foods, such as meat, fruit, or vegetables (Wechsler et al., 2001; Bernstein et al., 2002; Caro et al., 2017; Scourboutakos et al., 2017; Weingarten et al., 2022). Alternatively, they explore the impact of interventions on dietary quality from the perspective of dietary diversity (Reinbott et al., 2016; Kuchenbecker et al., 2017; Hirvonen et al., 2017; Katenga-Kaunda et al., 2021). Comprehensive dietary assessments of the impact of these interventions, which measure dietary quality in terms of the number of food categories, are lacking. Third, most of the information interventions use general information, such as common nutrition education (Sahyoun et al., 2004; Reinbott et al., 2016). Only a few studies have demonstrated the effectiveness of heuristic interventions or health information interventions, such as a diagnosis of a disease, in prompting individuals to alert their food consumption behavior (Zhao et al., 2013; Belot et al., 2020). It is challenging for health information interventions to cover an entire population, especially in China, due to the high cost of health examinations. Lastly, existing interventions tend to target specific groups, including infants and pregnant women, adolescents and children (Gratton et al., 2007; Reinbott et al., 2016; G. Fang & Zhu, 2022), the elderly (Bernstein et al., 2002; Sahyoun et al., 2004), college students (Poddar et al., 2010; Scourboutakos et al., 2017), or individuals with certain diseases (Sharifirad et al., 2009; Spiegel et al., 2012). However, research focusing on the general population, especially rural populations, is lacking. There is a need for more comprehensive and sustainable interventions that target the general population and consider the unique challenges faced by those living in rural areas, including limited access to nutritious foods and healthcare facilities, especially for rural low income groups and those with low levels of education.

In this study, we conducted a randomized controlled trial (RCT) using household-level food consumption data to examine the effects of information interventions on dietary quality, food consumption, and nutrient intake among Chinese rural residents. This study contributes to the literature in the following ways. First, this study employs multiple measures to gather accurate household food consumption information. Our team trained professional investigators who conducted interviews with respondents to gather household food consumption data using to the 24-hour dietary recall method. Well-trained investigators gathered information on food consumption, meal by meal, by questioning the respondents about the household's food intake in the previous 24 h. This approach minimizes the possibility of omissions that can occur in self-reporting. Furthermore, the investigators utilized the food standard quantity chart (Appendix 1) to assist respondents in recalling more precise food quantity, thereby increasing the accuracy of the collected data. Second, this study not only assessing the impact of the information intervention on overall dietary quality, but also analyzing food consumption and nutrient intake to provide a comprehensive evaluation of the intervention's impact. Third, this study is innovative in combining nutrition education interventions with health message to motivate rural residents to improve their dietary knowledge and dietary quality. This approach aims to explore the effectiveness of incorporating precise health message into nutrition education interventions, with the potential to achieve more impactful and behavior-changing outcomes. Lastly, this study focuses on evaluating the impact of the intervention specifically on rural residents in China, addressing the research gap created by limited research on the general population.

The remainder of this paper is organized as follows. Section 2 describes the study design and the measurement of key variables. Section 3 introduces the econometric model. Section 4 presents the findings, and Section 5 concludes the results.

2. Study design and data

2.1. Study design

We evaluated the effectiveness of the Nutrition and Health Information Intervention Program (NHIIP) in changing the dietary quality of Chinese rural household over 12-weeks period. The primary outcome of interest was the post-intervention difference between the groups who received information intervention and who did not. We hypothesized that the NHIIP intervention would improve dietary knowledge of rural residents, particularly in terms of their dietary quality, in the intervention group compared to the control group. We expected that intervention group would develop a more balanced dietary pattern after 12 weeks of the intervention, involving a reduction in the consumption of refined grains, an increase in the consumption of whole grains and vegetables, as well as higher micronutrient intake, such as calcium, vitamin A, and vitamin C. We used a cluster-RCT design, with villages as the units of randomization (cluster) and each household as the units of analysis. Data were collected at baseline and evaluation survey.

In June 2021, we conducted an initial pilot study in Quzhou County, Hebei Province, to test the questionnaire, specifically focusing on the 24-hour dietary recall section. Through convenience sampling, we interviewed approximately 30 households, where we collected their 24-hour dietary recall data and dietary knowledge data. After the pilot survey, we implemented clustered randomization at the village level to ensure an equal representation of dietary knowledge and dietary recall in both the treatment and control groups. This process also ensured that each cluster had similar sociodemographic characteristics. Our investigators, who are college students with high learning ability, undergo rigorous research training. This training equipped them with a deep understanding of the survey and information intervention content, enabling them to conduct survey with precision and ensure the high quality of the collected data. Moreover, they executed the information intervention in accordance with requirements, ensuring the intervention was properly implemented.

We used the OD (Optimal Design) software to calculate the power. The significance level,α, was set at 0.05, corresponding to a 95 % confidence level. The sample size, represented by n, was set at 20 households per village. The effect size, represented by δ (usually it 0.2), indicates the minimum detectable effect (MDE). The correlation of households within groups, denoted as ρ (usually 0.1), was considered. The R^2 represents the degree to which baseline data can explain the evaluation data and is commonly taken as 0.5. As shown in Fig. A1 in

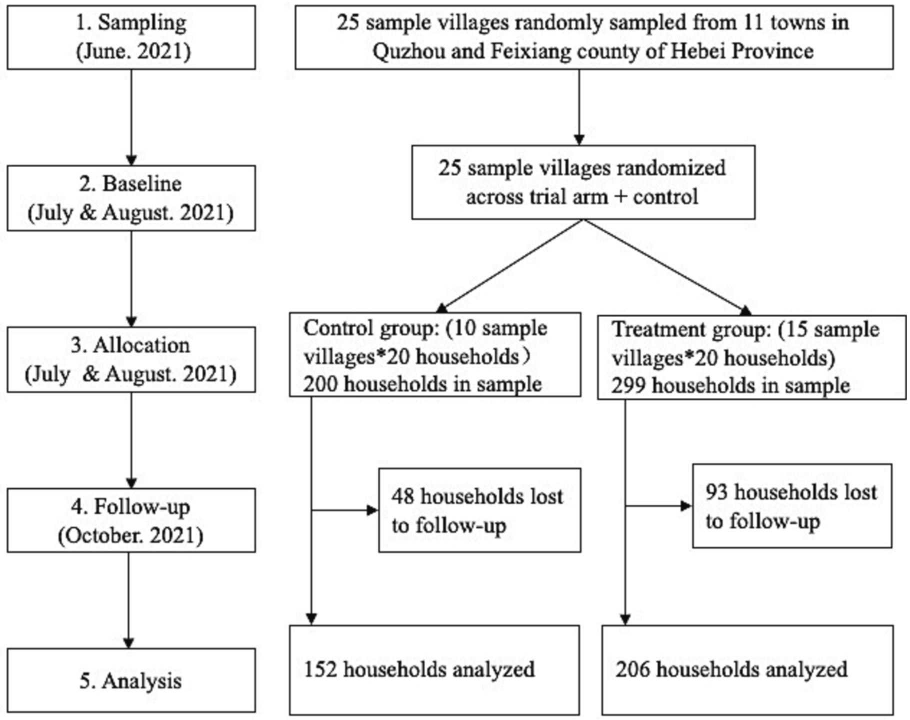

Fig 1. Flowchart of the RCT.

Appendix 2, the final number of clusters was 75 villages to achieve a statistical power of 0.8.

The baseline survey was conducted in three provinces (Henan, Hebei, and Shandong) in July and August 2021. To achieve a total of 75 villages, we aimed to have 25 villages in each province, with 20 households in each village. The final observations were 1500 households. There were 37 villages in control groups (10 from Hebei, 12 from Henan and 15 from Shandong) and 38 villages in treatment groups (15 from Hebei, 13 from Henan and 10 from Shandong). The evaluation survey was initially planned to be conducted in October 2021 in all three provinces. Unfortunately, the evaluation survey was conducted only in Hebei Province. This was a result of the COVID-19 regional control measures, which prevented the evaluation survey from being conducted in Henan and Shandong Provinces. The following discussion is based on the baseline and evaluation surveys conducted in Hebei Province. A flow chart of the experimental stages of the study is shown in Fig 1.

2.2. Setting and random allocation

To ensure adequate exposure to the intervention, we set inclusion criteria to offer the intervention to the individual responsible for daily household cooking, typically the wife or daughter-in-law of the household head. Specifically, only individuals who resided in the household for more than six months per year were eligible for participation in the survey.[1]

We randomized 25 villages into treatment and control groups in Quzhou and Feixiang County in Hebei Province. These counties, situated within Hebei Province, serve as insightful examples that mirror the socio-economic in rural areas of China. These counties are predominantly rural regions, with agriculture serving as the main economic activity, and can be seen as representative of the typical rural situation in China. In 2020, the per capita disposable income of rural residents in Quzhou County and Feixiang County was reported at 18,487 yuan,[2] which is in line with the per capita disposable income level of rural residents in China, 17,131 yuan.

To prevent the spillover of samples resulting from interactions between treatment and control groups, we divided these groups by town level, meaning all villages within a town were either control or treatment groups. Because different villages in the same town are often close to each other, it's common for friends or family members from different villages in the same town to interact, which could lead to spillover problems. The relatively long distance between towns, however, could prevent such sample spillover problems to a certain extent. We randomly selected 25 sample villages from 11 towns. The treatment group consisted of 15 villages in 7 townships and the control group consisted of 10 villages in 6 townships in baseline survey. And we surveyed 20 households in each village. However, during the evaluation survey, because of COVID-19 regional control measures, 2 villages in the control group were placed under lockdown and could not be surveyed. Due to the attrition in evaluation survey, there were 10 control groups and 13 treatment groups left. The average number of households surveyed was approximately 15.

2.3. Intervention

After the baseline survey was completed, well-trained investigators intervened with the treatment group. The information intervention for the treatment group comprised two main parts: general nutrition education intervention and precise health message intervention. The first

[1] China has a household registration system, known as the hukou system, which includes a name list for each household representing its member. However, some household member work as migrants and don't eat at home. That is why we only focus on individuals who have resided in the household for more than six months per year.

[2] The per capita disposable income of rural residents in Quzhou County in 2020 is 18,509 yuan, and the per capita disposable income of rural residents in Feixiang County in 2020 is 18,465 yuan.

part was a general nutrition education intervention. The investigators used the Chinese Food Guide Pagoda (2016)[3] to provide a detailed explanation of balanced diet pattern to the treatment group, emphasizing the types of daily food intake and the recommended daily intake values. In addition, the treatment group was educated about the health benefits of eating more of the recommended foods (such as whole grains, fruit, vegetables, and milk) and the health risks associated with foods that should be limited (such as red meat and fat). The impact of one-time on-site interventions may be limited. To ensure a lasting effect of nutrition education interventions, we also posted posters of the Chinese Food Guide Pagoda (2016) and the Food Intake Recommendations in the households of the treatment group. Appendix 3 shows these two intervention posters.

The second part was the precise health message intervention. The investigators used a weight scale and height ruler to measure the weight and height of every family member in the treatment group. After the measurements, the BMI of each family member was calculated on-site. Subsequently, the investigators provided feedback, informing the family members about their BMI and whether it fell within the normal range or the overweight/obese range. The control groups provided a comparison group that was not exposed to any intervention.

2.4. Measures

To assess dietary knowledge, we referred to the study of Zhou et al. (2017) to create comprehensive indicators measuring the level of dietary knowledge based on the China Health and Nutrition Survey (CHNS) questionnaire. As shown in Appendix 4, the CHNS questionnaire on dietary knowledge comprises 18 questions. Respondents' answers to these questions are divided into "correct" and "wrong" answers, with a score of 1 for correct answers and 0 for other answers (including "wrong" or "do not know"). The correct answers to each question are also provided in Appendix 4. By summing the scores of the 18 questions, we generated the total score and established an index of dietary knowledge to comprehensively represent the dietary knowledge level of the respondents.

We used the 24-hour dietary recall method, widely recognized as one of the most commonly used dietary survey methods (Castell et al., 2015), to collect household daily dietary information of respondents' household. Specifically, trained investigators questioned respondents about the food intake of all family members aged two and older during the previous 24 h, typically covering the three recent meals. This included inquiring about the weight of these foods and the portions consumed by each family member. Importantly, food weights were recorded in fresh state. Additionally, investigators recorded foods consumed both within and outside the home, including snacks, fruit and prepackaged food items. To minimize recall bias, the investigators used a food standard quantity chart (Appendix 1) to help respondents recall more accurate food quantity, enhancing the accuracy of the collected data. In cases where guests were eating at home, we deducted the food consumption share of the guests.

Because of budget limitations, we did not conduct 3*24-hour dietary recall (one day for weekdays and two days for the weekend) or 2*24-hour dietary recall (one day for weekdays and one day for the weekend) to distinguish food consumption between weekdays and the weekends. Fortunately, food consumption in Chinese rural areas is quite consistent on weekdays and weekends. Additionally, we did not collect the consumption of empty calories (such as cooking oil, and alcohol) and condiments (such as salt, and added sugar) in our survey. The food types included in this study were cereals (including rice, wheat, whole grain, and tuber), dark and light vegetables, fruit, red meat, poultry, aquatic products, eggs, dairy, and soybeans and nuts.

To compare the food consumption across different family structures (household size, age, gender, and energy intake level of difference family member), we calculated the number of standard-person in each household. This allowed us to compare food consumption among households with varying demographic characteristics. The survey collected information on the age, gender, and physical activity level (Appendix 5a) of every family member. We generated the dietary energy requirement of each family member based on the dietary energy requirements of Chinese residents in the Reference Intake of Dietary Nutrients of Chinese Residents (Appendix 5b). The dietary energy requirement level of a converted standard-person is set at 2,250 kcal (corresponding to light physical activity for men aged 18–50 years). We divided the dietary energy requirements of each family member by 2,250 and summed the result to generate the number of standard-person in the household. Finally, the food consumption of each household was divided by the number of standard-person in the household to generate the standard-person food consumption of the household. The standard-person food consumption was compared with the recommended value given in the DGC-2016 in the balanced dietary pattern at the 2,200 kcal dietary energy intake level.[4]

We used the Chinese Food Composition Tables Standard Edition (6 Edition) to convert the standard-person food consumption to macro- and micronutrients. The standard-person daily intake of macro- and micronutrients was compared with the recommended value given in the DGC-2016 in the balanced dietary pattern at the 2,200 kcal dietary energy intake level. The nutrients included in this study were protein, fat, vitamin A, vitamin C, vitamin E, calcium, iron, zinc, and selenium.

We used the latest version of the Chinese Diet Balance Index (DBI-16) to assess the dietary quality of sample households (Y. He et al., 2018). DBI-16, developed based on DGC-2016 and the Chinese Food Guide Pagoda (2016), comprises of 8 food components, including cereal, vegetable and fruit, dairy and soybean product, animal food, empty calories, diet diversity, condiment, and drinking water. The subgroup for each food component and the score range are shown in Appendix 6. We selected the 2200 kcal dietary energy level as scoring criteria to generate scores for each food subgroup.[5] When a food subgroup meets the recommended intake value, the score is set to 0. The emphasis "consume more" or "consume regularly" foods in the dietary guidelines focuses on evaluating the degree of insufficient intake, and the scores for these food subgroups are negative. The emphasis on "consume less" foods in the guidelines focuses on evaluating the degree of excessive intake, and the scores for these food subgroups are positive. For foods highlight as "consume in moderation" in the dietary guidelines, the scores can be either positive or negative. Limited by the survey data of NHIIP, the food subgroup included in the DBI-16 indicator in this study are cereal, vegetable, fruit, dairy, soybean, red meat and poultry, aquatic product, egg, as well as diet diversity. The diet diversity within the food subgroup can assess the diversity of dietary structure, which includes 12 food items: rice and its product, wheat and its product, whole grain and tuber, dark vegetable, light vegetable, fruit, soybean and its product, dairy product, red meat and its product, poultry and game, egg, and aquatic product. The minimum intake value for soybean and its product is 5 g, and for the other 11 food items, it is 25 g. Each food item reaching or exceeding the minimum intake value scores 0, while falling below the

[3] The latest version of the Chinese Food Guide Pagoda was released in April 2022. Since the Nutrition and Health Information Intervention Program (NHIIP) was carried out in 2021, the Chinese Food Guide Pagoda (2016) has been used.

[4] The dietary energy intake of the Dietary Guidelines for Chinese Residents 2016 in the balanced dietary pattern is divided into 11 levels. Among these, the 2,200 kcal dietary energy intake level is the closest to standard-person dietary energy intake level (2,250 kcal).

[5] DBI-16 has scoring criteria for food subgroups at 11 dietary energy intake levels. Our study selected the 2250 kcal dietary energy intake level standard, which is closest to the standard-person dietary energy intake level (2,250 kcal), to generate scores for food subgroup.

Table 1
Summary statistics for the characteristics of the total sample as well as treatment and control groups.

Variables	Total sample (1)		Control group (2)		Treatment group (3)		p-value (4)
	Mean	SD	Mean	SD	Mean	SD	
Food consumption:							
Rice	49.090	78.719	50.460	84.730	48.079	74.168	0.62
Wheat	249.340	226.771	241.042	193.905	255.462	248.538	0.70
Whole grain and tuber	103.775	144.040	107.105	182.347	101.318	107.818	0.69
Dark vegetable	180.953	262.012	164.791	187.582	192.877	305.447	0.95
Light vegetable	95.967	207.195	102.894	137.358	90.856	246.579	0.11
Fruit	28.817	114.825	28.345	113.065	29.165	116.379	0.89
Soybean	12.501	66.455	10.239	69.831	14.170	63.971	0.14
Dairy	4.515	22.796	5.923	27.817	3.476	18.234	0.13
Red meat	14.465	49.216	11.983	50.872	16.297	48.001	0.21
Poultry	5.092	40.059	2.970	27.670	6.658	47.167	0.13
Egg	27.013	40.159	29.144	39.120	25.440	40.932	0.97
Aquatic product	0.980	12.510	0.302	3.724	1.480	16.178	0.24
Nut	3.547	39.571	0.781	7.857	5.587	51.688	0.33
Nutrient intake:							
Protein	43.441	27.966	42.830	29.160	43.891	27.114	0.96
Fat	17.193	20.796	15.866	19.805	18.172	21.494	0.09
Vitamin A	231.809	277.688	247.320	291.211	220.364	267.415	0.32
Vitamin C	52.430	50.686	55.122	49.659	50.443	51.461	0.21
Vitamin E	9.901	7.884	9.614	7.021	10.112	8.475	0.63
Calcium	218.924	149.638	227.281	156.324	212.758	144.582	0.23
Iron	15.054	10.545	15.275	10.652	14.891	10.489	0.49
Zinc	6.438	4.016	6.472	4.045	6.412	4.004	0.62
Selenium	35.184	26.430	33.954	26.393	36.091	26.485	0.45
Dietary quality:							
DQD	43.877	6.143	43.803	6.128	43.932	6.168	0.41
DDS	−7.855	1.374	−7.816	1.421	−7.883	1.342	0.53
Individual characteristics:							
Dietary knowledge	12.617	2.625	12.578	2.761	12.645	2.527	0.83
Household income	5.223	10.259	4.650	5.622	5.646	12.633	0.60
Family size	3.642	1.965	3.730	2.065	3.578	1.890	0.51
Proportion of the elderly	0.366	0.405	0.371	0.404	0.362	0.407	0.91
Proportion of overweight	0.560	0.382	0.541	0.356	0.573	0.400	0.86

Notes: This table reports the means values of food consumption, nutrients, dietary quality index, dietary knowledge, and other individual characteristics for the treatment and control groups as well as the total sample. The last column displays the p-value for the *t*-test comparing the control and treatment groups. Food consumption and nutrient intake are converted to standard-person food consumption and standard-person nutrient intake (unit: g/ day for different food consumption, protein and fat; μg/ day for vitamin A, vitamin C and selenium; and mg/ day for calcium, iron and zinc).

minimum intake value scores −1 (Appendix 7). These scores were summed to generate dietary diversity score (DDS) ranging from −12 to 0, with a score closer to 0 indicating a higher level of dietary diversity. By summing the absolute scores for each DBI-16 food subgroup, we calculated an indicator of diet quality distance (DQD) ranging from 0 to 60.[6] This indicator serves to assess the degree of dietary imbalanced. A DQD score of 0 indicates "excellent" dietary intake, while a score of less than 12 means few dietary imbalanced problems. A score between 13 and 24 suggests a low level of dietary imbalance; a score between 25 and 36 means a moderate level of dietary imbalance; and a score greater than 37 indicates a high level of dietary imbalance. Compared with the Healthy Eating Index (HEI), which uses the American dietary guidelines as the standard, DBI-16 is more in line with the actual dietary nutrition status of Chinese residents. The scoring method of DBI-16 is suitable for all healthy individuals except for infants and children under two years old. It is not suitable for individuals with specific nutritional requirements, such as pregnant and lactating women, whose nutritional needs differ from the general population (Y. He et al., 2018).

3. Methodology

To estimate the average treatment effects of the information intervention, we employ a difference-in-differences (DID) framework and specifically estimate the following regression:

$$\Delta y_i = \beta_0 + \beta_1 \times Treat_i + \varepsilon_i \tag{1}$$

where Δy_i represents the change in outcome variable, which includes the dietary knowledge and the dietary quality before and after the treatment of household *i*. The dummy variable $Treat_i$ is an indicator variable, equal to one for households *i* in treatment group and zero for the control group. The coefficient of interest, β_1, measures the effect on the outcome variables of being in the treatment group, relative to the control group, after the intervention. ε_i represents the error term. When estimating equations, this study controls for village-level clustering in standard errors.

We further decomposed the outcome variable into different foods consumptions and various macro- and micronutrient intake to assess the impact of the information intervention. We construct the similar functions to evaluate the intervention effects on household-level food consumption and macro- and micronutrient intake changes. The only difference to equation (1) is that Δy_i indicates the change after and before the intervention of food consumption (such as the standard-person daily intake of rice, wheat, fruit, and red meat) and the macro- and micronutrient intake (such as vitamin A, vitamin C, vitamin E, calcium, iron, zinc, and selenium). Furthermore, we explore the heterogeneous treatment effects among different income groups and age groups, aiming to understand the effect of the interventions across different demographic groups.

DID requires a parallel trend assumption. The parallel trend assumption implies that the change in the outcome variable would have been the same in both trial arms if there had been no treatment, meaning

[6] Since data on the consumption of empty calories, condiments, and drinking water were not collected, the score evaluation range of DQD were adjusted accordingly.

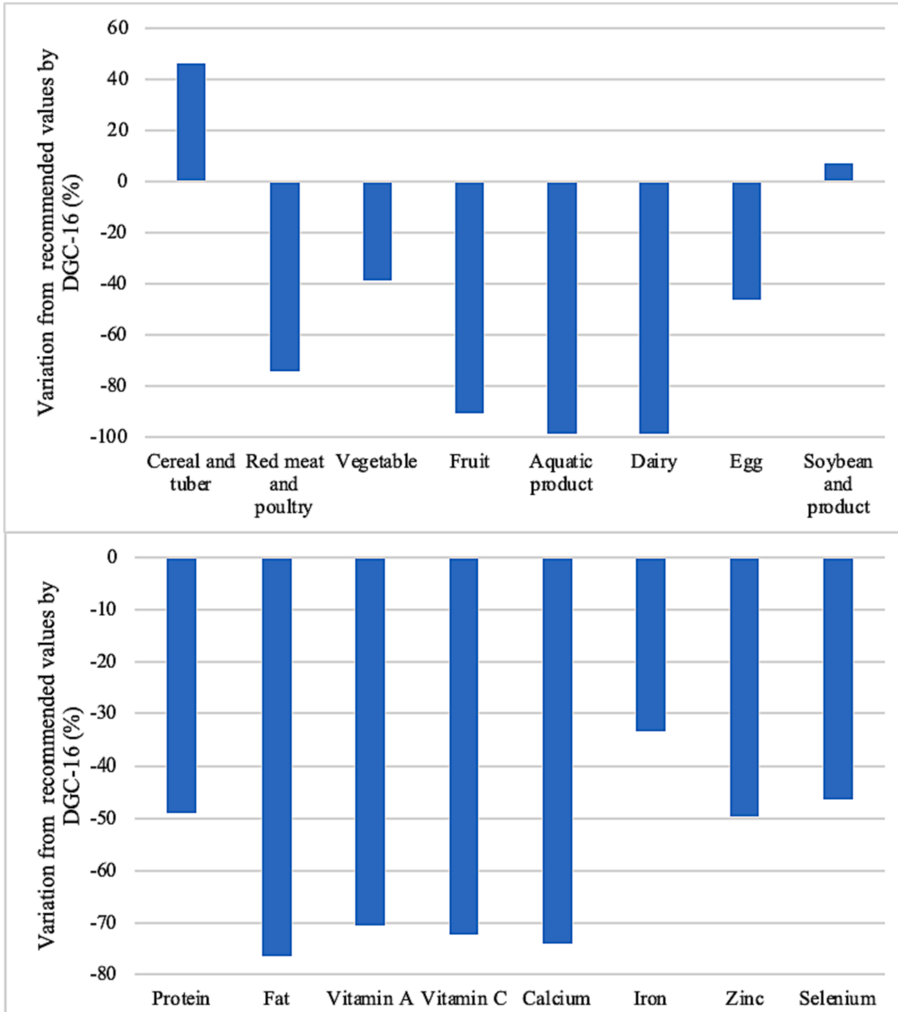

Fig. 2. Comparison of the food groups and nutrients intake of sample households and the recommended value of DGC-16.

that differences in outcome changes can be attributed to the treatment alone. As discussed in section 4.2, there are no systematic differences in key variables between the control and treatment groups across the baseline and evaluation. Thus, this assumption is held.

To enhance the efficiency of the estimation and control for heterogeneities, we extended the unadjusted model in equation (2) by including a set of control variables. This extension enabled us to compare the relative change in a series of outcomes between the treatment group and control group, as follows:

$$\Delta y_i = \beta_0 + \beta_1 \times Treat_i + \delta X + \varepsilon_i \quad (2)$$

Where X is an exogenous vector that includes household characteristics, such as household income, household size, and the ratio of elderly people. The coefficient of interest in equation (2) is β_1, representing the estimated impact of the treatment on nutrition knowledge and a various of dietary outcomes. We expect this coefficient to be positive, indicating that the information intervention improves dietary knowledge as well as dietary quality.

4. Results and discussion

4.1. Sample characteristics

Table 1 reports the summary statistics for the characteristics of the total sample as well as treatment and control groups considering attrition. Table 1 gives the demographic characteristics for the 13 villages randomized to the treatment group and the 10 villages randomized to the control group. The sample size is 358 households, with 152 in the control and 206 in the treatment. We first present the food consumption, nutrient intake, dietary quality, and individual and family characteristics of the baseline sample in column 1. A comparison of means examines the balance between the treatment and control groups (column 2 and 3). Table 1 shows the overall balance of most variables observed between the treatment and control groups.

The upper part of Fig. 2 reports the gap between the standard-person food consumption and the recommended values provided in the balanced dietary pattern of DGC-2016.[7] It is evident that there is a substantial gap between standard-person food consumption and the recommended values from DGC-16 across various food groups. In particular, the consumption of cereal and tuber exceed the recommended value by 46 %, while red meat and poultry fall short by 74 %. Vegetable consumption is 38 % below the recommended value, while fruit consumption is significantly lower by 90 %. Aquatic product consumption is 99 % below the recommended value, and dairy consumption is 98 % below. Egg consumption is also 46 % below the recommended

[7] The recommended daily food intake in the balanced dietary pattern (at the 2200 kcal level) according to DGC-2016 is as follows: 275 g/person for cereal and tuber, 75 g/person for red meat and poultry, 25 g/person for cooking oil, 450 g/person for vegetable, 300 g/person for fruit, 75 g/person for aquatic product, 300 g/person for dairy, and 50 g/person for egg.

Table 2
Comparisons of the characteristics between the remaining samples and the attrite samples.

Variables	Remaining		Attrition		Mean diff.
	Num	Mean	Num	Mean	
Food consumption:					
Rice	358	49.090	141	44.850	−4.240
Wheat	358	249.340	141	258.120	8.780
Whole grain and tuber	358	103.775	141	118.276	14.501
Dark vegetable	358	180.953	141	199.691	18.738
Light vegetable	358	95.967	141	62.553	−33.414*
Fruit	358	28.817	141	23.698	−5.119
Soybean	358	12.501	141	11.290	−1.211
Dairy	358	4.515	141	7.551	3.036
Red meat	358	14.465	141	15.309	0.844
Poultry	358	5.092	141	7.099	2.007
Egg	358	27.013	141	23.626	−3.386
Aquatic product	358	0.980	141	0.949	−0.031
Nut	358	3.547	141	2.916	−0.630
Nutrient intake:					
Protein	358	43.441	141	45.065	1.625
Fat	358	17.193	141	18.805	1.612
Vitamin A	358	231.809	141	206.001	−25.808
Vitamin C	358	52.430	141	49.621	−2.809
Vitamin E	358	9.901	141	9.652	−0.248
Calcium	358	218.924	141	226.757	7.833
Iron	358	15.054	141	15.184	0.130
Zinc	358	6.438	141	6.389	−0.049
Selenium	358	35.184	141	33.964	−1.220
Dietary quality:					
DQD	358	43.877	141	43.893	0.016
DDS	358	−7.855	141	−7.765	0.090

Notes: This table presents the means of outcome variables, including standard-person food consumption and nutrients intake, and dietary quality indexes between the attrition and remaining samples. Food consumption and nutrient intake are converted to standard-person food consumption and standard-person nutrient intake (unit: g/ day for different food consumption, protein and fat; μg/ day for vitamin A, vitamin C and selenium; and mg/ day for calcium, iron and zinc). The last column displays the differences in means, and * indicates a significance level of 10%.

Table 3
Estimation results of information intervention on the dietary knowledge score.

Variables	Dietary knowledge score			
	Total sample (1)	Overweight = 0 (2)	Overweight ≥ 25 % (3)	Overweight ≥ 50 % (4)
Treat	0.961***	−0.009	1.222***	1.224***
	(0.052)	(0.546)	(0.045)	(0.047)
Household income	0.001	−0.163	0.003	0.006
	(0.009)	(0.131)	(0.007)	(0.007)
Family size	−0.094	−0.191	−0.056	−0.071
	(0.094)	(0.296)	(0.114)	(0.129)
Elder population	0.550	0.673	0.516	0.413
	(0.461)	(1.136)	(0.539)	(0.538)
Fixed villages	Yes	Yes	Yes	Yes
Constant	0.625*	2.671**	0.226	0.289
	(0.341)	(1.136)	(0.443)	(0.493)
Observations	358	81	274	251
R-squared	0.053	0.272	0.070	0.079

Notes: Clustered standard errors of village are given in parentheses. “Overweight = 0” represents households without overweight family members, “Overweight > 25 %” represents households with overweight family members accounting for more than 25 %, “Overweight > 50 %” represents households with overweight family members accounting for more than 25 %. “Yes” means village fixed effects are controlled in the model. *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$, which represent significance levels at 1 %, 5 %, and 10 %, respectively.

Table 4
Estimation results of information intervention on the DQD.

Variables	DQD			
	Total sample (1)	Overweight = 0 (2)	Overweight ≥ 25 % (3)	Overweight ≥ 50 % (4)
Treat	−2.559***	1.605	−3.016***	−4.013***
	(0.838)	(1.150)	(0.825)	(0.392)
Household income	0.040	0.008	0.031	0.036
	(0.032)	(0.240)	(0.028)	(0.030)
Family size	0.306	−0.005	0.328	0.359
	(0.288)	(0.481)	(0.429)	(0.452)
Elder population	1.293	−0.766	1.579	1.641
	(1.321)	(2.780)	(1.566)	(1.615)
Fixed villages	Yes	Yes	Yes	Yes
Constant	1.724	3.009	1.740	1.596
	(1.216)	(2.364)	(1.743)	(1.823)
Observations	358	81	274	251
R-squared	0.062	0.201	0.080	0.089

Notes: Clustered standard errors of village are given in parentheses. “Overweight = 0” represents households without overweight family members, “Overweight > 25 %” represents households with overweight family members accounting for more than 25 %, “Overweight > 50 %” represents households with overweight family members accounting for more than 25 %. “Yes” means village fixed effects are controlled in the model. *** $p < 0.01$, which represents significance levels at 1 %, 5 %, and 10 %, respectively.

value, while soybean and products exceed the recommended intake by 6 %.

In order to check whether the food consumption varies across seasons, we conduct a *t*-test of the food consumption between the baseline and evaluation surveys of the control groups. The results are presented in Appendix 8. It is evident that, except for vegetable, the consumption of most food groups does not exhibit significant differences between the baseline and evaluation surveys of the control groups. Specifically, there is a preference for dark vegetable (e.g., spinach, tomato, etc.) during the summer and light vegetable (e.g., cabbage, turnip, etc.) during the autumn. However, the total vegetable consumption remains similar.

The lower part of Fig. 2 reports the gap between the standard-person nutrients intake and the recommended values provided in the balanced dietary pattern of DGC-2016.[8] There is a substantial disparity between standard-person nutrients intake and the recommended values from DGC-16 across various nutrients. As shown in Fig. 2, protein and zinc intakes are about half of the recommended values. Fat, vitamin A, vitamin C, and calcium intakes are less than 70 % of the recommended values. Iron intake is less than 33 % of the recommended value. Selenium intake is less than 46 % of the recommended value.

The DQD score of the sample households is 43.93, indicating a high level of dietary imbalance. Specifically, 88.58 % of the sample households exhibit a high level of dietary imbalance, and 11.42 % show a moderate to low level of dietary imbalance. The dietary imbalance level of sample households is higher than that in related studies (China And Global Food Policy Report, 2022; Y. He et al., 2018). This difference may be because the survey was is carried out in rural areas. Influenced by local dietary habits and region’s economic development, cereal consumption is high, while the consumption of animal food, fruit, milk, and soybean products is comparatively low, resulting in a lower dietary quality. Furthermore, we also calculate dietary diversity score (DDS) as another important indicator of dietary quality, ranging from − 12 to 0,

[8] The recommended daily nutrients intake in the balanced dietary pattern (at the 2200 kcal level) according to DGC-2016 is as follows: 86 g/person for protein, 75 g/person for fat, 766 μg/person for vitamin A, 187 μg/person for vitamin C, 859 mg/person for calcium, 22.6 mg/person for iron, 12.8 mg/person for zinc, 64.9 μg/person for selenium.

Table 5
Estimation results of information intervention on the DDS.

Variables	DDS			
	Total sample (1)	Overweight = 0 (2)	Overweight ≥ 25 % (3)	Overweight ≥ 50 % (4)
Treat	0.540***	−0.853	0.643***	0.678***
	(0.157)	(1.417)	(0.217)	(0.130)
Household income	−0.001	0.019	−0.001	−0.003
	(0.007)	(0.033)	(0.008)	(0.007)
Family size	−0.069	0.202**	−0.108	−0.127*
	(0.048)	(0.095)	(0.073)	(0.074)
Elder population	0.012	0.661	−0.218	−0.273
	(0.256)	(0.466)	(0.370)	(0.382)
Fixed villages	Yes	Yes	Yes	Yes
Constant	0.230	0.627	0.203	0.290
	(0.218)	(0.373)	(0.320)	(0.331)
Observations	358	81	274	251
R-squared	0.038	0.221	0.044	0.038

Notes: Clustered standard errors of village are given in parentheses. "Overweight = 0" represents households without overweight family members, "Overweight > 25 %" represents households with overweight family members accounting for more than 25 %, "Overweight > 50 %" represents households with overweight family members accounting for more than 25 %. "Yes" means village fixed effects are controlled in the model. *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$, which represent significance levels at 1 %, 5 %, and 10 %, respectively.

with 0 being the optimal score. The mean DDS is − 7.80, which is consistent with Y. He et al. (2018).

Because of rainfall, some respondents were unable to participate in the evaluation survey as they had to hasten the collection of crops. Consequently, the evaluation survey encountered a sample attrition issue, with 141 participants dropping out. We conduct a means comparison between the remaining samples and the attrition samples, accounting for sample selection, as detailed in Table 2. As shown in the table, we cannot reject the null hypothesis of the systematic selection of any of the variables except for the light vegetables at 10 % significance. Therefore, we can conclude that sample attrition does not cause significant bias in this study.

4.2. RCT results

The impact of the information intervention on dietary knowledge score, DQD and DDS is shown in Table 3-5. To further explore the effect of precise health message, we divide the sample households into three subgroups: households without overweight family members, households with overweight family members accounting for more than 25 %, and households with overweight family members accounting for more than 50 %. We hypothesize that as the proportion of overweight family members increase, the impact of precise health message would become more significant, leading to a greater effect of the information intervention on dietary knowledge and dietary quality.

Table 3 reports the effect of the information intervention on dietary knowledge score. In Column 1 of Table 3, it is observed that after the intervention, the dietary knowledge score of treatment group significantly increases by 0.961 points. From column 2, no effect of the information intervention on households without overweight family members is evident. Columns 3 and 4 reveal that, for households with overweight family members accounting for more than 25 % and more than 50 %, the information intervention significantly increases dietary knowledge score by 1.222 and 1.224 points, respectively. Compared with the mean dietary knowledge score of the treatment group at baseline survey, the information intervention increases dietary knowledge score by 8–10 % in the treatment group compared with control group. Other control variables, such as household income, household size, and the ratio of elderly people, do not show significant effects on dietary knowledge score. Some studies have found that nutrition education can improved nutrition knowledge (Babatunde et al., 2011; Clifford et al., 2009; Duncan et al., 2013; Rustad & Smith, 2013), which is consistent with our results. Our findings also indicate that not only nutrition education needed, but there is also a facilitating effect of delivering health message on improving dietary knowledge level. When people know more about the health status of family members, it may encourage them to make more effort to learn about nutrition.

Table 4 reports the effect of the information intervention on DQD. In the first column of Table 4, it can be observed that after the intervention, the DQD of treatment group significantly decreases by 2.559 points, indicating that the information intervention effectively improves the dietary quality level of the sample households. For households without overweight family members, we still obtain insignificant results (Table 4, column 2). Interestingly, we find that the impact of the information intervention on DQD is greater as the family overweight proportion increased. Specifically, for households with overweight family members accounting for more than 25 %, the information intervention significantly reduces DQD in the treatment group by 3.016 points. For households with overweight family members accounting for

Table 6
Estimation results of information intervention on the different food groups.

Variables	Rice (1)	Wheat (2)	Whole grain and tuber (3)	Vegetable (4)	Fruit (5)	Meat (6)	Poultry (7)	Aquatic product (8)	Egg (9)	Dairy (10)	Soybean and nut (11)
Panel A: Overweight ≥ 25 %											
Treat	−60.756***	18.792	100.438***	111.171***	1.884	11.099	3.683	−0.795	−4.968	2.243	−13.984
	(11.072)	(32.151)	(30.523)	(24.769)	(7.248)	(15.667)	(5.969)	(6.130)	(9.248)	(8.824)	(14.917)
Other controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fixed villages	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	274	274	274	274	274	274	274	274	274	274	274
R-squared	0.046	0.024	0.076	0.044	0.055	0.029	0.035	0.053	0.034	0.055	0.062
Panel B: Overweight ≥ 50 %											
Treat	−58.548***	−2.835	100.309***	95.378***	−0.928	10.226	4.490	−1.723	−3.763	4.734	−2.553
	(11.536)	(35.896)	(30.911)	(21.129)	(9.914)	(17.028)	(7.016)	(6.723)	(7.041)	(10.254)	(11.970)
Other controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fixed villages	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	251	251	251	251	251	251	251	251	251	251	251
R-squared	0.045	0.031	0.075	0.043	0.050	0.030	0.036	0.057	0.042	0.057	0.071

Notes: Clustered standard errors of village are given in parentheses. Food consumption and nutrient intake are converted to standard-person food consumption and standard-person nutrient intake (unit: g/ day). The other controls included annual household income, family size, proportion of elderly (aged 60 years or older). "Yes" means village fixed effects are controlled in the model. *** $p < 0.01$ represents significance levels at 1 %.

Table 7
Estimation results of information intervention on the intake of nutrients.

Variables	Protein (1)	Fat (2)	Vitamin A (3)	Vitamin C (4)	Vitamin E (5)	Calcium (6)	Iron (7)	Zinc (8)	Selenium (9)
Panel A: Overweight ≥ 25 %									
Treat	4.767	−0.694	14.876	33.284***	−0.187	4.569	2.603	1.281	2.776
	(4.392)	(4.213)	(18.638)	(3.815)	(1.708)	(21.379)	(1.634)	(0.855)	(3.522)
Other controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fixed villages	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	274	274	274	274	274	274	274	274	274
R-squared	0.037	0.054	0.025	0.046	0.040	0.071	0.041	0.040	0.036
Panel B: Overweight ≥ 50 %									
Treat	3.467	−0.833	−21.376	25.465***	0.230	5.707	2.105	1.124	1.842
	(4.225)	(4.015)	(13.990)	(2.874)	(1.663)	(27.743)	(2.041)	(0.997)	(3.614)
Other controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fixed villages	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	251	251	251	251	251	251	251	251	251
R-squared	0.038	0.058	0.029	0.047	0.040	0.066	0.039	0.041	0.039

Notes: Clustered standard errors of village are given in parentheses. Food consumption and nutrient intake are converted to standard-person food consumption and standard-person nutrient intake (unit: g/ day for protein and fat; μg/ day for vitamin A, vitamin C and selenium; and mg/ day for calcium, iron and zinc). The other controls included annual household income, family size, proportion of elderly (aged 60 years or older). "Yes" means village fixed effects are controlled in the model. *** $p < 0.01$ represents significance levels at 1 %.

Table 8
Effect of information intervention on different income and age groups.

Variables	DQD				
	Total sample (1)	Lower income (2)	Upper income (3)	Elder ratio = 0 (4)	Elder ratio > 0 (5)
Treat	−2.559***	−5.189***	2.955	−6.110***	−0.565
	(0.838)	(0.925)	(2.980)	(1.907)	(2.443)
Household income	0.040	−0.794	0.030	0.014	0.185
	(0.032)	(0.675)	(0.035)	(0.027)	(0.114)
Family size	0.306	0.348	0.561	0.785**	−0.169
	(0.288)	(0.480)	(0.425)	(0.335)	(0.483)
Elder population	1.293	2.320	0.154	–	2.293
	(1.321)	(1.616)	(2.041)	–	(2.844)
Fixed villages	Yes	Yes	Yes	Yes	Yes
Constant	1.724	2.386	1.134	0.709	1.206
	(1.216)	(1.729)	(2.046)	(1.168)	(3.005)
Observations	358	188	170	150	208
R-squared	0.062	0.121	0.089	0.165	0.065

Notes: Clustered standard errors of village are given in parentheses. "Yes" means village fixed effects are controlled in the model. *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$, which represent significance levels at 1 %, 5 %, and 10 %, respectively.

more than 50 %, the information intervention significantly reduces DQD in the treatment group by 4.013 points. Compared with the mean DQD of the treatment group at baseline survey, the information intervention increases DQD by 6–9 % in the treatment group compared with control group. The results show that rural household received nutrition education and health message of family members can improve the family dietary quality after 3 months.

Since we initially selected three provinces but only conducted two survey waves in one province, we are concerned about the possibility of a power issue. We used the OD (Optimal Design) software to calculate the power. The significance level, α is 0.05, which is significant at 95 % level. The sample size n is 15; initially, there were 20 households per village in the baseline survey, but due to attrition during the evaluation survey, the final n is 15.the effect size δ is derived from the intervention's impact, as shown in Table 4, where the intervention decreases the DQD by 2.559, and the standard deviation (SD) of DQD is 6.35, resulting in an effect size of about 0.4 SD. The correlation of households within groups ρ is usually summed to be 0.1. R^2 represents the degree to which baseline data can explain the evaluation data, typically taken as 0.5. With 23 clusters (villages), according to the results from OD, the power is higher than 0.8, indicating that the probability of not making the type II error is higher than 0.8.

Table 5 reports the effect of the information intervention on DDS as another indicator of dietary quality. In the first column of Table 5, it is observed that after the intervention, the DDS of treatment group significantly decreases by 0.540 points, indicating that the information intervention effectively improves the dietary diversity of the sample households. For households without overweight family members, we still obtain insignificant results (Table 5, column 2). Specifically, for households with overweight family members accounting for more than 25 %, the information intervention significantly reduces DDS in the treatment group by 0.643 points. For households with overweight family members accounting for more than 50 %, the information intervention significantly reduces DDS in the treatment group by 0.678 points. Compared with the mean DDS of the treatment group at baseline survey, the information intervention increases DDS by 7–9 % in the treatment group compared with control group. These findings confirm the result of the effect of information intervention on dietary quality. In order to check whether there is a jump between the coefficients of models (1) and (2), we reports the result of the model (1), and find that the results of models (1) are similar with model (2) (Appendix 9–Appendix 11).

This study further focuses on the effect of the information intervention on food consumption and nutrient intake, specifically analyzing and comparing the sample households with overweight family members accounting for more than 25 % and 50 %. Table 6 reports the effect of the information intervention on the consumption of different food groups. The information intervention significantly reduces the standard-person food consumption of refined grains, such as rice, by 60.756 g and 58.548 g in the treatment group where family members' overweight proportion exceeds 25 % and 50 %, respectively. Meanwhile, the information intervention significantly increases the standard-person food consumption of whole grains and tubers, by 100.438 g and 100.309 g in the treatment groups with family members' overweight proportion exceeding 25 % and 50 %, respectively. Studies have indicated that increasing the intake of whole grains, but not refined grains, can reduce the risk of chronic diseases such as cardiovascular disease and type 2 diabetes (Slavin et al., 1997; Seal & Brownlee, 2015), and is significantly inversely associated with body weight, BMI, and waist circumference (Newby et al., 2007; Cho et al., 2013). Additionally, the information intervention significantly increases the standard-person food

Table 9
Mechanism analysis of information intervention on the DQD and DDS.

Variables	DQD				DDS			
	Total sample (1)	Overweight = 0 (2)	Overweight ≥ 25 % (3)	Overweight ≥ 50 % (4)	Total sample (5)	Overweight = 0 (6)	Overweight ≥ 25 % (7)	Overweight ≥ 50 % (8)
Treat*knowledge	−0.312***	0.171***	−0.368***	−0.417***	0.045***	−0.027	0.049**	0.050**
	(0.082)	(0.052)	(0.070)	(0.065)	(0.013)	(0.115)	(0.021)	(0.016)
knowledge	0.072	−0.491**	0.101	0.047	−0.030	−0.032	0.002	0.019
	(0.139)	(0.169)	(0.151)	(0.152)	(0.047)	(0.142)	(0.051)	(0.049)
Household income	0.042	0.010	0.033	0.038	−0.001	0.016	−0.001	−0.003
	(0.024)	(0.303)	(0.025)	(0.028)	(0.009)	(0.033)	(0.009)	(0.008)
Family size	0.283	−0.068	0.308	0.337	−0.068	0.178	−0.106	−0.123*
	(0.184)	(0.453)	(0.278)	(0.337)	(0.048)	(0.151)	(0.063)	(0.062)
Elder population	1.220	−0.547	1.435	1.513	0.024	0.601**	−0.223	−0.279
	(1.015)	(2.544)	(0.941)	(1.040)	(0.186)	(0.249)	(0.281)	(0.292)
Fixed villages	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.876	9.372***	0.520	1.085	0.617	1.135	0.175	0.026
	(2.073)	(2.255)	(2.335)	(2.539)	(0.663)	(2.071)	(0.633)	(0.608)
Observations	358	81	274	251	358	81	274	251
R-squared	0.072	0.216	0.092	0.103	0.040	0.218	0.046	0.041

Notes: Clustered standard errors of village are given in parentheses. "Overweight = 0" represents households without overweight family members, "Overweight > 25 %" represents households with overweight family members accounting for more than 25 %, "Overweight > 50 %" represents households with overweight family members accounting for more than 25 %. "Yes" means village fixed effects are controlled in the model. *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$, which represent significance levels at 1 %, 5 %, and 10 %, respectively.

consumption of vegetables by 111.171 g and 95.378 g in the treatment groups with family members' overweight proportion exceeding 25 % and 50 %, respectively. According to Fig. 2, vegetable consumption was insufficient. The information intervention is beneficial to narrow the gap between vegetable intake and dietary guidelines.

Table 7 reports the effect of the information intervention on nutrient intake. The information intervention significantly increases the standard-person intake of vitamin C by 33.284 μg and 25.465 μg in the treatment groups with family members' overweight proportion exceeding 25 % and 50 %, respectively. Although nutrients like protein, calcium, iron, zinc and selenium show an increase in the intervention group after intervention, these differences are not statistically significant when compare with the control group. As found in Fig. 2, vitamin C intakes intake is insufficient among sample households. The information intervention is beneficial to increase vitamin C intake and narrow the gap between vitamin C intake and dietary guidelines.

4.3. Heterogeneous treatment effects

In order to further explore the effects of the intervention in different subgroups, conducting heterogeneity analysis is essential. This approach facilitates a comprehensive and detailed understanding of interventions effects across different demographic groups, improving the precision and targeting of interventions and ensuring a more thoughtful approach to meet the diverse needs of the rural residents. Many studies have indicated that people with low incomes have poorer dietary quality than those with higher incomes (Du et al., 2004; Darmon & Drewnowski, 2008; Leung et al., 2012; Carlson & Frazão, 2014). Different income groups have different food choice behaviors in response to nutrition information (Barreiro-Hurlé et al., 2010). Age can also influence how nutritional information is processed, given the age-related changes in basic cognitive abilities that may alter information processing and decision-making (Miller & Cassady, 2012). To explore this, we assess whether the treatment effect varies among different income groups and age groups.

We first analyze the heterogeneous effects of the information intervention on DQD among different income groups. The sample households are divided into two groups based on the mean of annual household income, namely the lower income group and the upper income group. In the second and third columns of Table 8, it can be observed that after the intervention, the DQD of lower income group significantly decreases by 5.189 points, while there is no significant effect on the DQD of the upper income group. This suggests that the information intervention is more effective for the group with low income group. Second, we analyze the heterogeneous impact of the proportion of the elderly. According to the proportion of the elderly (aged over 60 years) in the family, the sample households are divided into two groups: the group with the proportion of the elderly in the family is equal to 0 (elder ratio = 0) and the group with the proportion of the elderly in the family is greater than 0 (elder ratio > 0). We find that the information intervention has a greater impact on dietary quality in young families (the proportion of elderly is equal to 0). Specifically, DQD decreases significantly by 6.110 points, and there is no significant effect on DQD in the group with the proportion of elderly greater than 0 (Table 8, column 4 and column 5). One possible explanation is that the young people are more easier be affected by the intervention, leading to changes in their dietary patterns (Drewnowski & Shultz, 2001; Inelmen et al., 2008).

4.4. Mechanism

In this section, we focus on possible mechanism by which informational interventions can improve dietary quality. To examine how the intervention affects dietary quality, we generate an interaction term (knowledge*treat). The coefficient of the interaction term can indicate whether the effect of the informational intervention depends on the dietary knowledge. Table 9 displays the effects for the treatment group after the intervention with interaction terms of dietary knowledge. For simplicity, only results for dietary quality including DQD and DDS are reported.

The results in Table 9 indicate a statistically significant positive effect of dietary knowledge on the impact of the information intervention on the dietary quality. As shown in column 1 of Table 9, the coefficient of the interaction term suggests that the information intervention has a greater impact on DQD in sample households with higher dietary knowledge levels in the intervention group compared to other households. The coefficient of the interaction term in column 5 of Table 9 indicates that the information intervention has a greater impact on DDS in sample households with higher dietary knowledge in the intervention group compared with other households, indicated by a greater improvement in their dietary diversity. Further, both column 4 and column 8 of Table 9 reveal that interaction term coefficients are higher than those in other columns and are statistically significant. This implies

Fig. A1. The power calculation of original design.

that households with more overweight household members are learning more from the intervention and more likely to improve their dietary quality. We therefore conclude that the information intervention affects the dietary quality through the dietary knowledge.

5. Conclusion

This study builds on prior research that explores the impact of information intervention aimed at enhancing dietary knowledge and dietary quality of Chinese rural populations. Our findings reveal that dietary changes occurred as a result of both general nutrition education intervention and precise health message intervention. Households in the treatment group increase their dietary knowledge by 6 %, improved their dietary imbalance level by 8 % and enhanced dietary diversity level by 7 %. By contrast, no commensurate nutrition knowledge or dietary shifts occurred in the control group. Dividing the estimated effects of the food groups and nutrients groups, these results support the conclusion that the information intervention improves dietary quality in the treatment group. Furthermore, these results vary among different income groups and age groups.

Utilizing the combined information intervention of a nutrition education and a precise health message can motivate Chinses rural residents to improve their dietary quality. Although our study was conducted in a particular population (rural households in central China), the findings exhibit external validity in settings with similar features. Unlike other dietary interventions that primarily focus on providing nutrition education, our intervention also contains precise health message on overweight status of all family members in addition to providing nutrition education. In contrast to nudges that change the choice architecture to steer decision-making, our intervention is a kind of policy designed to help people not only obtain the nutrition information but also become aware of the health issue that arise from their diet. Future information interventions should pay attention to both the nutrition education and the precise health message given to promote the consumption of nutritious and healthy food and also improve people's dietary quality and health.

Our study has valuable policy implications. Because we track actual behavior, our findings are more reliable and relevant for policymakers compared to studies relying on self-reported outcomes, which may be prone to recall bias. A recent report (China And Global Food Policy Report (2022)) emphasizes that it is difficult to completely change food consumption behavior by economic measures alone. In the long term, information intervention becomes imperative to guide residents in developing balanced food consumption concepts, changing food consumption behavior, and optimizing their dietary structure. Our information intervention, incorporating nutrition education and delivering a precise health message to encourage shifts in food consumption behavior, emerges as one of the effective measures that policymakers and program administrators could consider adopting.

Our study contributes to the expanding literature in behavioral economics, utilizing RCT and other experimental evidence to examine the role of information intervention in behavioral change. Although some studies suggest that nutrition information interventions have little or even no effect (French et al., 2010; Lowe et al., 2010; Wilcox et al., 2013), a growing body of research indicates that such information intervention does impact specific groups. These effects have been observed in (1) enhancing the health of school-age children (Q. Zhao & Yu, 2020); (2) improving the nutrition of infants and pregnant women (Kuchenbecker et al., 2017; Katenga-Kaunda et al., 2021); (3) benefiting the elderly (Bernstein et al., 2002; Sahyoun et al., 2004); (4) influencing university students (Poddar et al., 2010; Scourboutakos et al., 2017); and (5) aiding patients with certain diseases (Sharifirad et al., 2009; Spiegel et al., 2012). In each of these cases, nutrition information intervention led to better outcomes, although a comprehensive discussion of the general population, especially the rural population, is lacking. The design of public policies increasingly reflects insights from the

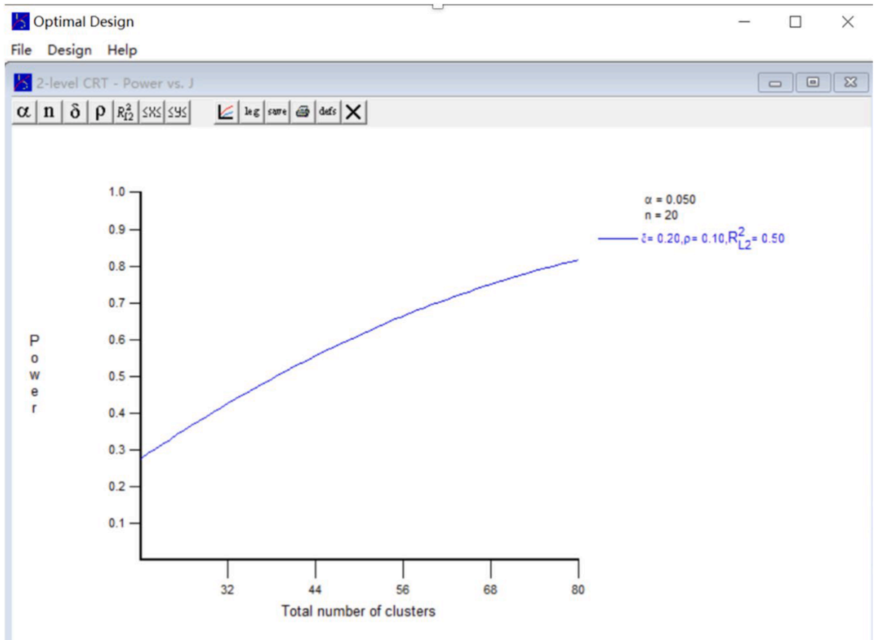

Fig. A2. Chinses Food Guide Pagoda poster (Chinese and English version).

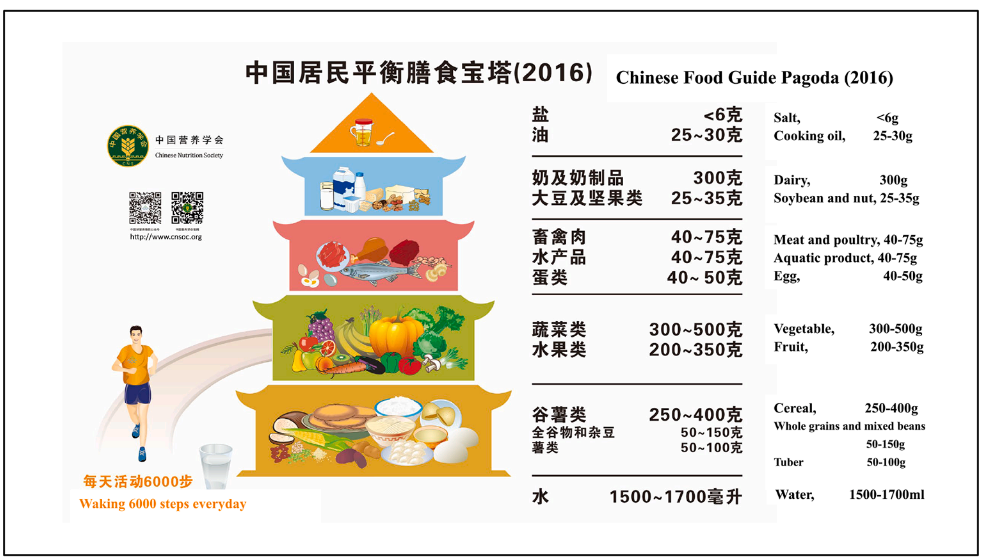

Fig. A3.1. Food Intake Recommendations poster (Chinese version).

field of behavioral economics (Madrian, 2014). Our study demonstrates that information intervention can lead to higher dietary knowledge and better dietary quality, adding to the rapidly growing literature in behavioral economics. Furthermore, it contributes valuable insights from behavioral economics to ongoing policy debate on food and nutrition.

Despite the unique nature of our data and the robustness of our findings, we acknowledge certain limitations in our study. First, our survey encountered challenges due to the disruption caused by COVID-19 pandemic, particularly impacting the evaluation survey. We lacked a treatment group that exclusively received the intervention of nutrition education, preventing us from estimating the isolated effect of the delivery of a precise health message. Second, our study relied solely on 24-hour dietary recall and did not gather information on condiment consumption. Research increasingly indicates that Chinese diets are often characterized by high salt and cooking oil intake (Zhai et al., 2014; Yuan et al., 2017; Fang et al., 2020). Our study may underestimate the issue of the imbalanced dietary pattern of Chinese rural populations and cannot estimate the intervention effect of condiments because of the data limitation. Third, the external validity of our study may be constrained by the food consumption habits of the sample region, given that households in Hebei Province primarily consumed cereal and tuber, with limited intake of other food. This could potentially limit the generalizability of our findings to regions with different dietary patterns. Moreover, our study was conducted in rural households in central China. Whether these results would carry over to other populations likely depends on the design and implementation of other interventions.

CRediT authorship contribution statement

Yi Cui: Data curation, Formal analysis, Methodology, Writing – original draft. **Qiran Zhao:** Data curation, Formal analysis,

Fig. A3.2. Food Intake Recommendations poster (English version).

Methodology, Supervision, Validation, Writing – review & editing. **Wei Si:** Funding acquisition, Writing – review & editing. **Shenggen Fan:** Funding acquisition, Writing – review & editing.

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.

Data availability

Data will be made available on request.

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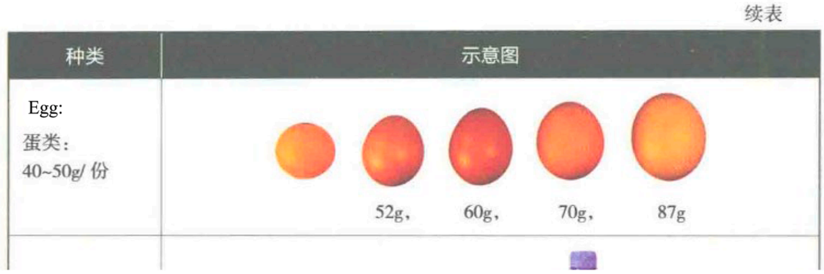
Appendix 1. Food standard quantity chart

续表

种类	示意图
	65g 带鱼段（可食部 50g） 65g 带鱼段（可食部 50g）
Shrimp: 虾 40~50g/ 份	85g 草虾（可食部 50g） 50g 小银鱼
Soybean and its product: 豆类 20~25g 大豆 / 份	20g 大豆 = 60g 北豆腐 = 45g 豆干 = 150g 内酯豆腐
Dairy: 奶类：200~250ml/ 份	200ml 牛奶 = 25g 奶酪 = 一份酸奶（125ml×2）
Nut: 坚果类：10g/ 份	10g 瓜子仁 = 24g 瓜子 20g 花生米，2 份 = 28g 花生



续表

种类	示意图
Egg: 蛋类：40~50g/ 份	52g，60g，70g，87g

Source: Dietary Guidelines for Chinese Residents (2016)

Appendix 2. The power calculation

See Fig. A1

Appendix 3. Posters for nutrition education intervention

See Figs. A1–A3.2

Appendix 4. Question of Dietary knowledge in China Health and Nutrition Survey.

Do you strongly agree, somewhat agree, somewhat disagree or strongly disagree with this statement?	True/ False
* Please note that the question is not asking about your actual habits.	
Q1: Choosing a diet with a lot of fresh fruits and vegetables is good for one's health.	T
Q2: Eating a lot of sugar is good for one's health.	F
Q3: Eating a variety of foods is good for one's health.	T
Q4: Choosing a diet high in fat is good for one's health.	F
Q5: Choosing a diet with a lot of staple foods [rice and rice products and wheat and wheat products] is not good for one's health.	T
Q6: Consuming a lot of animal products daily (fish, poultry, eggs and lean meat) is good for one's health.	F
Q7: Reducing the amount of fatty meat and animal fat in the diet is good for one's health.	T
Q8: Consuming milk and dairy products is good for one's health.	T
Q9: Consuming beans and bean products is good for one's health.	T
Q10: Physical activities are good for one's health.	T
Q11: Sweaty sports or other intense physical activities are not good for one's health.	T
Q12: The heavier one's body is, the healthier he or she is.	F
Q13: Eating salty foods can cause hypertension.	T
Q14: Refined grains (rice and wheat flour) contain more vitamins and materials than unrefined grains.	T
Q15: Lard is healthier than vegetable oils.	T
Q16: Vegetables contain more starch than staple foods (rice or wheat flour).	T
Q17: Eggs and milk are the important sources of high-quality protein.	T
Q18: Each person should drink at least 1200 ml (8 cups) of water per day	T
Source: China Health and Nutrition Survey (CHNS)	

Appendix 5a. Classification of physical activity levels.

Physical activity level	Occupation type
Light	Working in a sitting position, e.g., office worker, watch repairer, etc.
	Working in standing position, e.g., salesperson, laboratory technician, teacher, etc.
Moderate	Student, driver, electrician, etc.
	No working ability (under age 7)
Heave	Farmer, dancer, steel worker, athlete, etc.
	Loader, logger, miner, stonecutter, etc.
Source: China Health and Nutrition Survey (CHNS).	

Appendix 5b. The dietary energy requirements of Chinese residents.

Age(year)	Light physical activity level		Moderate physical activity level		Heavy physical activity level	
	Male	Female	Male	Female	Male	Female
0-	–	–	90	90	–	–
0.5-	–	–	80	80	–	–
1-	–	–	900	800	–	–
2-	–	–	1100	1000	–	–
3-	–	–	1250	1200	–	–
4-	–	–	1300	1250	–	–
5-	–	–	1400	1300	–	–
6-	1400	1250	1600	1450	1800	1650
7-	1500	1350	1700	1550	1900	1750
8-	1650	1450	1850	1700	2100	1900
9-	1750	1550	2000	1800	2250	2000
10-	1800	1650	2050	1900	2300	2150
11-	2050	1800	2350	2050	2600	2300
14-	2500	2000	2850	2300	3200	2550
18-	2250	1800	2600	2100	3000	2400
50-	2100	1750	2450	2050	2800	2350
65-	2050	1700	2350	1950	–	–
80-	1900	1500	2200	1750	–	–
Maternity (early stage)	–	+0	–	+0	–	+0
Maternity (middle stage)	–	+300	–	+300	–	+300

(continued on next page)

(*continued*)

Age(year)	Light physical activity level		Moderate physical activity level		Heavy physical activity level	
	Male	Female	Male	Female	Male	Female
Maternity (late stage)	–	+450	–	+450	–	+450
Foster-nurse	–	+500	–	+500	–	+500

Appendix 6. Components of DBI-16.

Components	Subgroup	Score
C1-Cereal	Rice, wheat, whole grain and tuber	(−12)-12
C2-Vegetable and fruit	Vegetable	(-6)-0
	Fruit	(-6)-0
C3– Dairy product Soybean and soybean product	Dairy product	(-6)-0
	Soybean product	(-6)-0
C4-Animal food	Red meat and product, poultry and game	(-4)-4
	Aquatic product	(-4)-0
	Egg	(-4)-4
C5-Empty calories	Cooking oil	0–6
	Alcoholic beverage	0–6
C6-Diet diversity	Dietary diversity score	(−12)-0
C7-Condiments	Added sugar	0–6
	Salt	0–6
C8-Drinking water	Drinking water	(−12)-0

Appendix 7. Elements of dietary diversity score.

Food subgroups	Score	Representative foods
F1-Rice and its product	(-1)-0	Steamed/boiled rice, rice products
F2-Wheat and its product	(-1)-0	Wheat bun, wheat noodles, what pancake
F3-Corn, whole grain and product, starchy roots and its product	(-1)-0	Corn, barley grain, foxtail millet, buckwheat, Sweet potato, yam, taro, potato, green bean, red bean
F4-Dark vegetable	(-1)-0	Spinach, carrot, tomato
F5-Light vegetable	(-1)-0	Cabbage, cucumber, pickles
F6-Fruit	(-1)-0	Fresh and dried fruit
F7-Soybean and its product	(-1)-0	Soybean, black bean, bean curd
F8-Dairy product	(-1)-0	Milk, milk powder, cheese
F9-Red meat and its product	(-1)-0	Beef, pork, lamb, liver, sausage
F10-Poultry and game	(-1)-0	Chicken, duck, rabbit
F11-Egg	(-1)-0	Hen egg, duck egg
F12-Aquatic product	(-1)-0	Fish, shrimp, mussel

Note: The minimum intake value for soybean and its product is 5 g, and for the other 11 food items, it is 25 g.

Appendix 8. Summary statistics for characteristics of the control groups in baseline and evaluation.

Variables	Baseline		Evaluation		p-value
	Mean	SD	Mean	SD	
Rice	50.460	84.730	48.942	134.631	0.91
Wheat	241.042	193.905	243.869	191.665	0.90
Whole grain and tuber	107.105	182.347	118.428	130.603	0.53
Dark vegetable	164.791	187.582	82.530	176.268	0.00***
Light vegetable	102.894	137.358	168.205	170.441	0.00***
Vegetable	267.686	221.702	250.735	233.609	0.45
Fruit	28.345	113.065	19.529	51.778	0.38
Soybean	10.239	69.831	13.498	48.602	0.18
Dairy	5.923	27.817	9.989	42.338	0.61
Red meat	11.983	50.872	21.979	75.095	0.29
Poultry	2.970	27.670	1.687	14.543	0.85
Egg	29.144	39.120	30.017	41.799	0.32
Aquatic product	0.302	3.724	2.230	21.957	0.64
Nut	0.781	7.857	2.260	13.769	0.25

Notes: The unit of food consumption is g/ day. *** $p < 0.01$ which represents significance levels at 1 %.

Appendix 9. Estimation results of information intervention on the dietary knowledge score.

Variables	Dietary knowledge score							
	Total sample (1)	Total sample (2)	Overweight = 0 (3)	Overweight = 0 (4)	Overweight ≥ 25 % (5)	Overweight ≥ 25 % (6)	Overweight ≥ 50 % (7)	Overweight ≥ 50 % (8)
Treat	1.033***	0.961***	−0.569	−0.009	1.263***	1.222***	1.263***	1.224***
	(0.000)	(0.052)	(0.621)	(0.546)	(0.000)	(0.045)	(0.000)	(0.047)
Household income		0.001		−0.163		0.003		0.006
		(0.009)		(0.131)		(0.007)		(0.007)
Family size		−0.094		−0.191		−0.056		−0.071
		(0.094)		(0.296)		(0.114)		(0.129)
Elder population		0.550		0.673		0.516		0.413
		(0.461)		(1.136)		(0.539)		(0.538)
Fixed villages	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.467***	0.625*	2.500***	2.671**	0.154***	0.226	0.154***	0.289
	(0.000)	(0.341)	(0.000)	(1.136)	(0.000)	(0.443)	(0.000)	(0.493)
Observations	358	358	81	81	274	274	251	251
R-squared	0.041	0.053	0.208	0.272	0.063	0.070	0.072	0.079

Notes: Clustered standard errors of village are given in parentheses. “Overweight = 0” represents households without overweight family members, “Overweight > 25 %” represents households with overweight family members accounting for more than 25 %, “Overweight > 50 %” represents households with overweight family members accounting for more than 25 %. “Yes” means village fixed effects are controlled in the model. *** p < 0.01, ** p < 0.05, and * p < 0.1, which represent significance levels at 1 %, 5 %, and 10 %, respectively.

Appendix 10. Estimation results of information intervention on the DQD.

Variables	DQD							
	Total sample (1)	Total sample (2)	Overweight = 0 (3)	Overweight = 0 (4)	Overweight ≥ 25 % (5)	Overweight ≥ 25 % (6)	Overweight ≥ 50 % (7)	Overweight ≥ 50 % (8)
Treat	−2.688**	−2.559***	1.504**	1.605	−3.296***	−3.016***	−4.247***	−4.013***
	(0.878)	(0.838)	(0.582)	(1.150)	(1.034)	(0.825)	(0.098)	(0.392)
Household income		0.040		0.008		0.031		0.036
		(0.032)		(0.240)		(0.028)		(0.030)
Family size		0.306		−0.005		0.328		0.359
		(0.288)		(0.481)		(0.429)		(0.452)
Elder population		1.293		−0.766		1.579		1.641
		(1.321)		(2.780)		(1.566)		(1.615)
Fixed villages	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	3.267***	1.724	2.500***	3.009	3.385***	1.740	3.385***	1.596
	(0.000)	(1.216)	(0.000)	(2.364)	(0.000)	(1.743)	(0.000)	(1.823)
Observations	358	358	81	81	274	274	251	251
R-squared	0.055	0.062	0.199	0.201	0.073	0.080	0.080	0.089

Notes: Clustered standard errors of village are given in parentheses. “Overweight = 0” represents households without overweight family members, “Overweight > 25 %” represents households with overweight family members accounting for more than 25 %, “Overweight > 50 %” represents households with overweight family members accounting for more than 25 %. “Yes” means village fixed effects are controlled in the model. *** p < 0.01, ** p < 0.05, and * p < 0.1, which represent significance levels at 1 %, 5 %, and 10 %, respectively.

Appendix 11. Estimation results of information intervention on the DDS.

Variables	DDS							
	Total sample (1)	Total sample (2)	Overweight = 0 (3)	Overweight = 0 (4)	Overweight ≥ 25 % (5)	Overweight ≥ 25 % (6)	Overweight ≥ 50 % (7)	Overweight ≥ 50 % (8)
Treat	0.546**	0.540***	−0.492	−0.853	0.689**	0.643***	0.719***	0.678***
	(0.177)	(0.157)	(1.571)	(1.417)	(0.229)	(0.217)	(0.103)	(0.130)
Household income		−0.001		0.019		−0.001		−0.003
		(0.007)		(0.033)		(0.008)		(0.007)
Family size		−0.069		0.202**		−0.108		−0.127*
		(0.048)		(0.095)		(0.073)		(0.074)
Elder population		0.012		0.661		−0.218		−0.273
		(0.256)		(0.466)		(0.370)		(0.382)
Fixed villages	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.000	0.230	1.500***	0.627	−0.231***	0.203	−0.231***	0.290
	(0.000)	(0.218)	(0.000)	(0.373)	(0.000)	(0.320)	(0.000)	(0.331)
Observations	358	358	81	81	274	274	251	251
R-squared	0.032	0.038	0.185	0.221	0.035	0.044	0.025	0.038

Notes: Clustered standard errors of village are given in parentheses. “Overweight = 0” represents households without overweight family members, “Overweight > 25 %” represents households with overweight family members accounting for more than 25 %, “Overweight > 50 %” represents households with overweight family members accounting for more than 25 %. “Yes” means village fixed effects are controlled in the model. *** p < 0.01, ** p < 0.05, and * p < 0.1, which represent significance levels at 1 %, 5 %, and 10 %, respectively.

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