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Low energy density, high nutrient adequacy and high nutrient density are each associated with higher diet costs in Chinese adults from Henan Province

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Abstract

Objectives Food price is a determining factor in food choice which affect diet quality accordingly. However, the association between food price and diet quality has not been thoroughly discussed among Chinese adults. This study aimed to analyze the association of daily energy-adjusted dietary costs (CNY/2000 kcal) and diet quality among Chinese adults.

Methods A total of 680 Chinese adults aged above 25 years from Henan province were investigated in 2020. Three indices were adopted for evaluating diet quality: the nutrient-rich foods 9.2 (NRF 9.2) index for evaluating nutrient density, the mean adequacy ratio (MAR) for evaluating nutrient adequacy, energy density (ED) based on solid foods only for evaluating energy density. The daily energy-adjusted diet cost was calculated by dividing the estimated daily diet costs (CNY/day) by the energy intake per day (kcal/day) and multiplying the result by 2000.

Results Subjects who closely adhered to the NRF9.2, MAR, and ED paid ¥8.92, ¥13.17, and ¥14.34 more for daily food consumption, respectively, than those who weakly adhered to these dietary patterns did. Furthermore, multiple linear regression analysis adjusted covariance revealed that an increase in ¥1 of the energy-adjusted diet cost per day was associated with changes of 0.494 units ($P < 0.001$), 0.003 units ($P < 0.001$), and −0.018 units ($P < 0.001$) in the NRF9.2, MAR, and ED, respectively.

Conclusion Higher energy-adjusted diet cost was associated with higher quality diets. This might be important for public health policies to develop strategies to promote healthy diets by regulating food supply and its costs.

Keywords Dietary cost, Diet Quality, NRF9.2, MAR, ED

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Introduction

Unfavorable diet quality is a significant public health issue worldwide. High intake of sodium, low intake of whole grains and fruits were the leading dietary risk factors for deaths and DALYs globally in many countries including China, highlighting the urgent need to improve diet quality [1]. A large body of epidemiologic data showed that diet quality follows a socioeconomic gradient [2]. The cost and affordability of healthy foods (for example: the proportion of monthly household income spend on food products) has been underscored as one of the strongest barriers against diet quality, perhaps exerting an even more powerful influence on food choice than taste, promotions, and convenience [3]. Meanwhile, the World Health Organization's (WHO) global action plan for the prevention and control of NCDs from 2013 to 2020 encouraged member states to take action to increase the availability, affordability, and acceptability of healthier food products to improve diet quality [4]. It has been shown that economic constraints lead to the consumption of less healthy diets. As the cross-sectional dietary surveys have noted that the consumption of lower energy density was associated with higher energy-adjusted diet costs among the United States of American adults [5] and French adults [6]. Conversely, the high cost of food was often seen as a significant obstacle to improving diet quality [7]. The monetary diet cost was positively associated with healthy eating index among the United States of Americans [8] and Malaysians [9]. Subjects who closely adhered to higher diet quality paid more for food consumption than those who weakly adhered to healthy diet pattern [10]. However, there is no consensus on this issue. According to the intervention studies, meals of higher quality do not always cost more than diets of lower quality and even be less costly [11, 12].

The associations between dietary cost and diet quality remained mostly unexplored among Chinese adults. Unhealthy diets that included an excessive amount of sodium and red meat, and inadequate amounts of whole grains and fruits were the leading dietary risk factors for death (17.4% of total risk factors) and DALYs (11.6% of total risk factors) in China [13], and diets based on dietary guideline reduce the incidence of NCDs [14]. The disadvantaged socioeconomic status was associated with higher mortality and shorter life expectancy in China [15]. Xiao Zhang et al. reported that energy-adjusted diet cost was independently and positively associated with diet quality among Chinese school-aged children in Southwest China [16]. Drewnowski [17] and Bernstein [18] et al. found that dietary cost was significantly correlated with food purchasing. Economic constraints, and their effects on food choices should be taken into account for promoting diet quality in China. The aim of the study was to investigate whether freely chosen diet costs were related to diet quality, which will likely have greater direct influence on nutrition policy and practice.

Subjects and methods

Study design and population

A cross-sectional study was conducted in 3 communities by convenience sampling method during the year of 2020 in Zhengzhou City, China. The participants aged above 25 years was selected, and with mental illness and severe liver or kidney dysfunction were excluded. In total, 785 individuals agreed to participate in the investigation. Individuals with incomplete data, including missing data on 24-h dietary recalls ($n = 26$), anthropometry ($n = 21$), and covariates ($n = 20$), as well as those with unusual total energy intake (< 500 or > 3,500 kcal per day for women and < 800 or > 4,200 kcal per day for men) [19], were excluded from the dataset ($n = 38$). A total of 680 participants were analyzed in this study. The study was conducted according to the guidelines of the Helsinki Declaration, and the study protocol was approved by Ethics Committee. All participants gave their informed consent.

Dietary and covariant assessment

The dietary assessment was conducted through two non-consecutive 24-hour dietary recalls by face-to-face interviews. Participants were asked to report dining places, types, brands, amounts of all foods and beverages consumed in the preceding 24 h. Food models were used to assist the respondents in providing correct answers during dietary data collection. Data on food and nutrients intake from the 24-h recalls were analyzed using a nutrition calculator (NCCW software) based on the China Food Composition Table [20]. The personal basic information was collected by a structured questionnaire which included gender, age, marital status, personal income, family number, family income, education, job and so on.

Evaluation of nutrient-rich food index scores

The NRF9.2 index, which was based on the limits of 9 beneficial nutrients and 2 nutrients and used an algorithm based on sums and 100 kcal, was the best-predicted model for Chinese adults, and was selected in this study [21]. The daily reference intakes of nutrients were based on the recommended nutrient intake (RNI) or adequate intake (AI) of adults, except for saturated fat, which was based on acceptable macronutrient distribution ranges [22]. All the foods consumed by each subject were scored using the NRF9.2 algorithm, followed by the NRF9.2 score per 100 kcal [23].

$$NRF9.2/100\ kcal = (NR9 - LIM2) \times 100.$$

$$NR9 = \Sigma 1{-}9(Nutrient_i/NRV_i)/ED \times 100.$$

$Nutrient_i$= content of nutrient i in 100 kcal edible portion.
NRVi = Nutrient i based on Chinese Dietary Reference Intakes.
ED = Energy density of 100 g edible portion of food.
i = 1–9 (protein, dietary fiber, vitamins A, C, E, Ca, Fe, Mg, K).

$LIM2 = \Sigma 1-2(L_i/MNRV_i)/ED \times 100.$

L_i = nutrient i content of 100 g edible portion of food.
$MNRV_i$ = Maximum reference intake of nutrient i.
i = 1–2(saturated fat, sodium).

Assessment of nutrient adequacy

Nutrient adequacy was measured by computing the mean adequacy ratio (MAR) [24]. To compute the MAR and nutrient adequacy ratio (NAR), 10 nutrients, including energy, protein, vitamin A, vitamin C, calcium, iron, phosphorus, vitamin B_1, vitamin B_2, and niacin, were included. NAR was calculated using Chinese Dietary Reference Intakes (DRIs) [22]. The MAR was calculated as described by Madden et al. [24].

$$\mathrm{NAR} = \frac{\text{Actual nutrient intake of a nutrient (per day)}}{\text{Chinese daily reference intakes of the nutrient}}$$

$$\mathrm{MAR} = \frac{\sum \mathrm{NAR}\ (\text{each truncated at 1})}{\text{Number of nutrients}}$$

Calculation of energy density

The daily dietary energy density (ED, kcal/g) was computed by dividing energy by total food weight. Energy density values vary widely, depending on whether water or noncaloric or calorie-containing beverages have been included or excluded from the analysis [25, 26]. Based on past studies [25], the present calculations were based on solid foods only because the energy density of a substantial part of the diet is reported to be a better indicator of dietary quality than energy density based on food and energy-yielding beverages. Diet porridge was divided according to its ingredients and converted into purchasable forms. For example, a bowl of rice porridge was divided into two separate ingredients, rice and water, and water was also excluded when the ED was calculated.

ED (kcal/g) = energy (kcal)/the weight of solid foods only (g).

Daily diet costs

The monetary costs of the diet obtained from the 24-hour dietary recalls (CNY/day) were calculated by multiplying the amount of food consumed (100 g/day) by the estimated price of each food (CNY/100 g) and summing the products. The procedure for estimating costs was based on the assumption that all foods were purchased and then prepared and consumed at home. Ultimately, 428 food and beverage items were analyzed. The price of each food was initially obtained from the Zhengzhou Municipal Development and Reform Commission website [27], which were calculated by averaging the monthly prices from different districts over the past 12 months (59 of 428 items; 13.8%). The price of fast food items (13 of 428 items; 3.0%) were taken from fast-food restaurants (McDonald's, KFC, DICOS in Zhengzhou City) and its prices more stable which were not affected by seasons. The prices of the other food items were taken from four supermarkets and three farmers' markets, and the average prices were used in the analysis (356 of 428 items; 83.2%). The price survey was conducted in four seasons of the year, and the average annual unit price for each item was calculated by averaging the prices of the four seasons. Discounted prices were not used to determine food costs.

The calculations included correction for preparation and waste using the China Food Composition database [20]. Prices was expressed in Chinese yuan (CNY, ¥) per 100 gram. Because monetary diet cost was strongly associated with energy intake ($\gamma = 0.58$), diet cost per 2000 kcal of energy intake per day (hereinafter, energy-adjusted diet cost) was calculated by dividing the daily diet cost (CNY/day) by the energy intake per day (kcal/day) and multiplying 2000.

Quality control

Quality control was carried out throughout the entire process. First, the questionnaire used in the investigation was revised after a pilot study and expert discussion. Second, the questionnaire survey was conducted by face-to-face interviews which was trained through training manual by team leader Quanjun Lyu and Junya Zhai. Finally, all the data were input by two persons, and logical error detection and review were carried out.

Statistical analysis

All the statistical analyses were performed using SAS statistical software (version 9.3, 2011). All the data were normally distributed; hence, parametric analyses were employed. All calculated *P* values were two-tailed and were considered statistically significant at $P < 0.05$ for a single variable. Data for daily diet cost and daily energy-adjusted diet cost were compared according to sociodemographic characteristics. We calculated the crude means of food group intake and nutrient intake within each quartile of the daily energy-adjusted diet cost. The stepwise multiple linear regression analysis was used to determine the association of daily energy-adjusted diet costs and the diet quality indices (NRF9.2, MAR, and ED). Moreover, multivariate linear models were also used to provide covariate-adjusted means of the diet quality index among strata of daily energy-adjusted diet costs. The covariates included age (years), gender (male or female), family income level (<¥2000/month/person, ¥2000–¥5000, ≥¥5000), and food intake (kcal).

Results

Sample characteristics

We analyzed data from a sample of 680 Chinese adults from Henan province. Estimates of the mean daily diet costs and daily energy-adjusted diet costs were provided for the demographic and socioeconomic groups in Table 1. The mean daily diet costs and daily energy-adjusted diet costs were ¥14.05/day and ¥19.14/2000 kcal, respectively. The daily diet cost was slightly higher for men (¥14.51/day) than for women (¥13.32/day). However, the difference reversed after adjusting for energy.

Table 1 Mean estimated daily dietary cost and energy-adjusted dietary cost by demographic and socioeconomic strata among Chinese adults from Henan Province

	n	Daily diet cost (CNY/d)[1]		Daily Energy-adjusted diet cost (CNY/2000kcal)[2]	
		Mean	SD	Mean	SD
Total	680	14.05	10.08	19.14	12.75
Gender					
Men	422	14.51	11.23	18.43	13.54
Women	258	13.32	7.81	20.30	11.26
Age					
< 50	102	14.55	8.19	20.54	10.08
50–65	422	14.00	8.59	18.99	13.18
> 65	156	13.88	14.18	18.63	13.13
Family income level *					
< ¥2000/month/person	125	12.12	7.53	16.89	9.64
¥2000–5000/month/person	387	13.60	8.13	18.78	13.12
>¥5000/month/person	168	16.54	14.47	21.66	13.55
Educational level					
< 6 years	87	12.52	9.26	17.68	11.29
6–12 years	437	14.07	10.67	18.92	13.52
> 12 years	156	14.87	8.69	20.58	11.11
Occupation*					
Manual	110	11.66	7.58	17.03	9.51
Professional	85	13.62	8.74	18.59	10.82
Retired	335	14.67	8.90	19.35	11.45
Others	150	14.67	13.97	20.54	17.58
Marriage					
Yes	621	14.07	10.21	19.23	13.01
Others	59	13.89	8.69	18.21	9.55

1. Values are presented as the means and standard deviations (SDs)

2. Values are presented as the means and SDs. Energy-adjusted diet cost was calculated by dividing the estimated daily diet costs (CNY/day) by the energy intake per day (kcal/day) and multiplying by 2000

3. The general characteristics of the distributions of daily diet costs and energy-adjusted diet costs were tested using t tests or analysis of variance test, and differences are marked with a star (*) indicating p values < 0.05

For each 2,000 kcal of dietary energy, men spent ¥18.43, whereas women spent ¥20.30. The daily and energy-adjusted diet costs of the higher-income groups were greater than those of the lowest-income groups (Table 1).

Means of food group intake and nutrients within each quartile of daily energy-adjusted diet cost

Because monetary diet cost was strongly associated with energy intake (γ = 0.58), daily energy-adjusted diet cost was adopted in the following analysis. At the food level, participants in the higher quartiles of daily energy-adjusted diet cost had higher mean values of diet cost for fruit, milk and milk products, beans, nuts, meat and poultry, fish and lean meat, and other food groups and had lower mean values of diet cost for the grain foods (Table 2). At the nutrient level, higher daily energy-adjusted diet costs were associated with greater intakes of protein, vitamin B_2, niacin, vitamin A, vitamin C, vitamin E, potassium, calcium, zinc, and MAR and lower intakes of energy, fat, and carbohydrates (Table 3).

Multiple linear regression for the association of daily energy-adjusted diet costs with diet quality

Significant positive associations were observed in the multivariate models for NRF9.2 (β = 0.284, P for trend < 0.0001), MAR (β = 44.77, P for trend < 0.0001), and ED (β =-11.51, P for trend < 0.0001) (Table 4). Compared with those who weakly adhered to these dietary patterns, those who closely adhered to the NRF9.2, MAR, and ED daily paid ¥8.92, ¥13.17, and ¥14.34 per 2000 kcal more for food consumption, respectively.

Multiple linear regression for the association of diet quality with daily energy-adjusted diet costs

Adjusted linear regression analysis revealed that an increase in ¥1 of the energy-adjusted diet cost per day was associated with a change of 0.494 units ($P < 0.001$), 0.003 units ($P < 0.001$), and − 0.018 units ($P < 0.001$) in the NRF9.2, MAR, and ED, respectively (Table 5).

Discussion

This study was investigated the associations of the dietary cost and diet quality in a sample of Chinese adults from Henan province. As expected, dietary nutrient density, mean adequacy ratio (MAR), and dietary energy density was each independent related to daily energy-adjusted diet cost. Diets with higher energy density cost less, and those with higher nutrient density and nutrient adequacy cost more. These associations were not influenced by age, gender, energy intake, or family income.

Participants reported spending ¥14.05 on food and non-tap water beverages during every 24-hour observation period while spending ¥19.14 per 2000 kcal, which were similar to the estimated mean expenditures on food

Table 2 Means of food group intake within each quartile of daily energy-adjusted diet cost [1]

Food group	Daily energy-adjusted diet cost [2]				P值[3]
	Q1	Q2	Q3	Q4	
n	170	169	171	170	
Energy-adjusted diet cost	8.81 ± 1.20	13.81 ± 1.20	19.22 ± 2.05	34.69 ± 16.26	< 0.0001
Grains	465.02 ± 176.29	466.06 ± 192.17	398.27 ± 174.96	321.44 ± 166.45	< 0.0001
Vegetables	157.35 ± 104.89	172.76 ± 133.51	154.71 ± 124.94	159.24 ± 146.29	0.6
Fruits	44.01 ± 84.55	140.63 ± 165.23	271.92 ± 277.20	342.84 ± 400.42	< 0.0001
Milk and milk products	8.51 ± 36.79	43.54 ± 111.07	50.34 ± 109.35	45.41 ± 114.62	< 0.0001
Beans	16.26 ± 38.05	18.99 ± 55.36	27.15 ± 71.87	19.74 ± 88.63	< 0.0001
nuts	3.48 ± 8.15	11.88 ± 36.83	14.48 ± 47.53	13.67 ± 42.50	0.03
Meat, poultry	23.41 ± 45.09	37.57 ± 54.94	71.23 ± 111.04	114.67 ± 163.62	< 0.0001
Fish	1.54 ± 9.85	4.20 ± 18.55	8.54 ± 33.94	28.46 ± 65.26	< 0.0001
Egg	43.31 ± 46.15	50.63 ± 53.80	45.23 ± 43.53	40.95 ± 47.73	0.3
Oil	13.74 ± 9.78	16.97 ± 14.60	16.12 ± 14.86	15.85 ± 15.20	0.2
Others[4]	11.25 ± 25.13	21.93 ± 63.66	39.26 ± 94.80	80.89 ± 256.97	< 0.0001

1. Values are presented as the means ± SDs

2. Q1, 1st quartile; Q2, 2nd quartile; Q3, 3rd quartile; and Q4, 4th quartile

3. Differences in food group intake among the quartiles of energy-adjusted diet costs were tested using analysis of variance

4. Snacks include cookies, fast food, and sugar-preserved fruits

Table 3 Means of nutrient intake within each quartile of daily energy-adjusted diet cost [4]

Energy and nutrients	Daily energy-adjusted diet cost [1]				P值[3]
	Q1	Q2	Q3	Q4	
n	170	169	171	170	
Energy (kcal)	1474 ± 427	1605 ± 448	1587 ± 508	1449 ± 427	0.03
Protein (g)	47.18 ± 18.14	53.05 ± 17.76	53.03 ± 18.24	55.77 ± 22.34	0.001
Fat (g)	31.06 ± 13.53	42.15 ± 21.02	44.28 ± 21.17	40.10 ± 19.38	< 0.0001
Carbohydrate (g)	253 ± 78	255 ± 74	246 ± 91	218 ± 76	< 0.000
Fiber (g)	11.74 ± 6.87	13.42 ± 5.84	12.99 ± 5.89	13.02 ± 8.96	0.2
Vitamin B_1 (mg)	0.71 ± 0.31	0.76 ± 0.32	0.80 ± 0.37	0.78 ± 0.38	0.1
Vitamin B_2 (mg)	0.53 ± 0.23	0.66 ± 0.28	0.72 ± 0.30	0.79 ± 0.39	< 0.0001
Niacin (mg)	7.82 ± 4.61	9.23 ± 4.26	10.58 ± 4.57	11.06 ± 5.86	< 0.0001
Vitamin A (μgRAE)	347 ± 372	403 ± 340	451 ± 520	568 ± 731	0.001
Vitamin C (mg)	46.35 ± 36.12	62.88 ± 51.29	68.15 ± 46.56	83.58 ± 63.18	< 0.0001
Vitamin E (mg*a*-TE)	16.08 ± 7.79	18.85 ± 8.60	20.64 ± 11.82	19.64 ± 14.68	0.002
Potassium (mg)	1168 ± 654	1420 ± 469	1573 ± 587	1660 ± 685	< 0.0001
Calcium (mg)	228 ± 147	298 ± 158	309 ± 159	342 ± 214	< 0.0001
Iron (mg)	14.05 ± 6.49	15.02 ± 5.25	15.40 ± 6.23	17.42 ± 28.04	0.2
Magnesium (mg)	224 ± 95	237 ± 75	234 ± 90	248 ± 124	0.2
Phosphorous (mg)	750 ± 236	806 ± 251	785 ± 259	807 ± 301	0.2
Zinc (mg)	6.93 ± 2.63	7.67 ± 2.51	7.78 ± 2.65	8.57 ± 4.06	< 0.0001
Selenium (μg)	40.27 ± 17.90	40.60 ± 18.92	38.57 ± 18.76	43.93 ± 25.59	0.1
MAR	0.53 ± 0.13	0.60 ± 0.13	0.63 ± 0.13	0.64 ± 0.14	< 0.0001

1. Values are presented as the means ± SDs

2. Q1, 1st quartile; Q2, 2nd quartile; Q3, 3rd quartile; and Q4, 4th quartile

3. Differences in nutrient intake among the quartiles of energy-adjusted diet costs were tested using analysis of variance

(¥19.99/2000 kcal) based on retail prices in the Nantong city of China [28], and were similar to the cost among school-aged children in Southwest China (¥11.0/1000kal) [16]. The differences between several sociodemographic characteristics and daily diet costs or daily energy-adjusted diet costs were explored. Populations characterized through lower SES might be spent less on food, which confirm the past observations that family income appears to be essentially correlated with food expenditure patterns [29].

This study revealed that participants in the higher quartiles of daily energy-adjusted diets spent more on fruit, high-protein foods, and other food groups and less on grain foods, and spent more on energy, total fat, and

Table 4 Daily energy-adjusted diet cost (CNY/2000 kcal) of foods according to adherence to the diet quality indices (NRF9.2, MAR, and ED)

	NRF9.2 Index [2]				**β**	***P* for trend[3]**
	Q1	**Q2**	**Q3**	**Q4**		
Daily energy-adjusted diet cost						
Unadjusted model	16.42(14.83, 18.19)	17.50(15.81, 19.19)	17.60(15.91, 19.28)	25.31(23.66, 26.96)	0.296	< 0.0001
Adjusted model[4]	16.42(14.76,18.09)	17.44(15.75,19.12)	17.74(16.05,19.43)	25.34(23.67,27.00)	0.284	< 0.0001
	MAR				β	*P for trend*[3]
	Q1	Q2	Q3	Q4		
Daily energy-adjusted diet cost						
Unadjusted model	15.50(13.80, 17.21)	18.52(16.82, 20.21)	19.64(17.94, 21.34)	22.33(20.63, 24.04)	20.86	< 0.0001
Adjusted model[4]	12.59(10.57, 14.61)	17.97(16.21, 19.72)	20.60(18.67, 22.33)	25.76(23.75, 27.76)	44.77	< 0.0001
	ED(all food)				β	*P for trend*[3]
	Q1	Q2	Q3	Q4		
Daily energy-adjusted diet cost						
Unadjusted model	28.83(27.11, 30.54)	17.92(16.21, 19.63)	16.41(14.70, 18.12)	13.42(11.70, 15.12)	−13.14	< 0.0001
Adjusted model[4]	28.49(26.83, 30.15)	18.59(17.01, 20.16)	16.74(15. 61, 18.32)	14.15(12.53, 15.77)	−11.51	< 0.0001

1. Values are model-adjusted least-squares means; 95% CIs are in parentheses

2. Calculated by dividing the estimated daily diet costs (CNY/day) by the energy intake per day (kcal/day) and multiplying by 2000

3. Linear trends (P for trend) were obtained with the ordinal median daily energy-adjusted diet cost (CNY/2000 kcal) for each quartile as a continuous variable

4. Adjusted for age (years), gender (male or female), family income level (<¥2000/month/person, ¥2000–5000/month/person, ≥¥5000/month/person) and food intake (kcal/d)

Table 5 Multiple linear regression least-squares means and 95% confidence intervals for the associations of daily energy-adjusted diet costs with diet quality ($n = 702$)[1]

	Daily energy-adjusted diet cost [2]				**β**	***P* for trend[3]**
	Q1	**Q2**	**Q3**	**Q4**		
n	170	169	171	170		
NRF9.2 Index						
Unadjusted model	37.04(34.82, 39.26)	37.85(35.67, 40.02)	40.52(38.36, 42.68)	47.60(45.43, 49.76)	0.504	< 0.0001
Adjusted model[4]	36.93(34.49, 39.36)	37.94(35.65, 40.23)	40.26(38.03, 42.48)	47.20(44.91, 49.49)	0.494	< 0.0001
MAR						
Unadjusted model	0.53(0.51, 0.55)	0.60(0.59, 0.61)	0.63(0.51, 0.65)	0.64(0.62, 0.66)	0.003	< 0.0001
Adjusted model[4]	0.56(0.54, 0.57)	0.59(0.57, 0.60)	0.61(0.60, 0.63)	0.66(0.65 0.68)	0.003	< 0.0001
ED (all food)						
Unadjusted model	1.92(1.86, 1.98)	1.62(1.56, 1.68)	1.47(1.41, 1.54)	1.39(1.33, 1.46)	–0.017	< 0.0001
Adjusted model[4]	1.91(1.85, 1.98)	1.61(1.55, 1.67)	1.49(1.43, 1.55)	1.41(1.34, 1.45)	–0.018	< 0.0001

1. Values are model-adjusted least-squares means; 95% CIs are in parentheses

2. Calculated by dividing the estimated daily diet costs (CNY/day) by the energy intake per day (kcal/day) and multiplying by 2000

3. Linear trends (P for trend) were obtained with ordinal median diet quality (NRF9.2 INDEX, MAR, ED) for each quartile as continuous variables

4. Adjusted for age (years), gender (male or female), family income level (<¥2000/month/person, ¥2000–5000/month/person, ≥¥5000/month/person) and food intake (kcal/d)

carbohydrates and spent fewer on most of micronutrients. Although food prices affect most of people, cost was the key determinants of food choice among low-income households and the unemployed [30].

The participants who closely adhered to high-quality diets paid more for food consumption than those who weakly adhered to them. Moreover, increasing the daily energy-adjusted diet costs was associated with a positive change in diet quality. The present data confirm previous observations, based on a representative sample of the French population [31] and the United States of Americans [32], that lower-cost diets are energy-dense and nutrient-poor. In contrast, higher-quality diets cost more. Several studies have emphasized that the food budgets of people experiencing poverty are insufficient to maintain a balanced diet [33]. Even when low-income groups develop efficient purchasing strategies [34], the food budget may not be adequate to procure a reasonable diet.

Dietary energy density was one index of the overall quality of the diet [35]. Diets high in whole grains, lean meats, fish, fresh vegetables, and fruit have a low energy density and high contents of vitamins and minerals [35], which are more costly per kcal than energy-dense diets rich in fats and sweets [36]. This study found that energy density was negatively associated with diet cost, which was consistent with the published findings from large representative samples of adults in the United States [5, 32] and France [37, 38]. A study from China revealed that vegetables and fruits had the lowest energy density, but their food prices were the highest per unit of energy [28]. The affordability of healthy foods for residents can be viewed as an economic strategy for health promotion.

The concept of nutrient density is critical to better understanding the relationship between diet quality and diet cost. The daily energy-adjusted diet cost was inversely associated with NRF9.2 and MAR. Drewnowski et al. reported that nutrient density scores was positively associated with diet cost per 100 g [39]. Moreover, from a nutritional quality point of view, Drewnowski et al. reported that nutrient adequacy scores was positively associated with diet cost per 1000 kcal [39]. Matthieu et al. reported that for a given energy intake and energy density, each 10% increase in MAR led to a 13% increase in estimated diet costs per 10 MJ [6]. In general, economic forces may hold the key to dietary change, given that more nutrient-dense foods and higher-quality diets tend to be more expensive per calorie basis [40]. Moreover, there were also some examples where changing food prices can improve dietary quality or clinical outcomes. Beydoun et al. reported that an annual rate of change in the monetary value of the diet may have a more substantial impact on dietary quality among American urban women and above-poverty individuals [41]. Anne Magnus et al. reported that the cost-effectiveness of a 20% price discount on fruit, vegetables, diet drinks and water with or without consumer nutrition education can improve individual's health in remote Australia [42]. Thus, food prices might be a policy concern to ensure a nutritious food supply for future generations.

Arguably, not all healthier diets were necessarily associated with higher costs. Compared with other populations, Mexican–Americans were found to consume higher-quality diets at lower prices [43]. The more food ingredients are processed, the more nutrients are lost, and the higher the unit price is. These studies highlight the need to identify dietary patterns that are both healthful and affordable for residents, especially for the low-income households.

The present study was the first to provide evidence for an inverse relationship between dietary quality (from the dimensions of nutrient density, energy density, and nutrient adequacy) and daily energy-adjusted diet costs among Chinese adults. However, several limitations of our study should be mentioned. First, the participants' food records were only collected 2 days by the 24-hour dietary recall method. Thus, the data may not provide an accurate reflection of daily dietary behavior. Furthermore, seasonal and regional variations of food prices might introduce a potential bias for the assessment of the diet cost. However, the annual average price across multiple regions and seasons was used in this study, which may reduce this bias. However, considering the diverse demographics and regional variations within Henan province. The findings might not be applicable to other regions. Finally, considering the small sample size, we did not analyze the adjusted daily diet costs diet among different income levels subgroups. And more research from larger sample size and more diverse populations will be needed to conduct for analyzing the relationship of dietary cost and diet quality.

Conclusion

The present results showed that a higher daily energy-adjusted cost diet tends to intake a high proportion of beneficial foods or nutrients. The daily energy-adjusted diet costs increased with increasing adherence to a high quality diet (NRF9.2, MAR, and ED). Furthermore, an increase in the energy-adjusted diet cost per day was associated with positive changes in NRF9.2 and MAR, and with a negative change in ED. The findings from our study indicated that the monetary costs of foods or diets should be considered for promoting dietary quality among Chinese adults from Henan province.

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Author contributions

All authors had full access to all of the data and take responsibility for the integrity of the data and the accuracy of the data analysis. Baihui Ma, Lijun Guo, Yongxia Kong acquired the data. Junya Zhai, Baihui Ma, Fangfang Yao, Rui Liang analyzed and interpreted the data. Junya Zhai, Baihui Ma, Hongbo Wu, Pipasha Khatun drafted the manuscript, which was critically revised for important intellectual content by all authors. Quanjun Lyu and Minghua Cong were responsible for the statistical analysis and revised the manuscript. Junya Zhai supervised the study and is a guarantor.

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Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

The Committee on Human Subjects at The First Affiliated Hospital of Zhengzhou University approved the study design (Protocol 2020–KY-066). All the subjects signed a consent form to participate in the study.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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