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The association between food environment, diet quality and malnutrition in low- and middle-income adult populations across the rural—Urban gradient in Vietnam

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Abstract

Background: Economic reforms and trade liberalisation in Vietnam have transformed the food environment, influencing dietary patterns and malnutrition status. The present study focuses on the relationship between food environments (proximity and density of food outlets) and malnutrition (underweight, overweight, obesity) through diet quality in adult populations across urban, periurban and rural areas of Vietnam.

Methods: We evaluated food environment by geospatial mapping of food outlets through a transect walk across the "food ecosystem" from rural to urban areas. Diet quality was assessed using the Diet Quality Index–Vietnamese (DQI-V) comprising Variety, Adequacy, Moderation and Balance components. Malnutrition status was determined using body mass index. We performed a mediation analysis utilising mixed effect models to control for neighbourhood clustering effects. Confounders included age, education, income and nutrition knowledge score.

Results: Analysis of data from 595 adult participants (mean ± SD age: 31.2 ± 6.4 years; 50% female) found that longer distance to the nearest food outlet was associated with higher overall DQI-V ($\beta = 2.0$; 95% confidence interval = 0.2–3.8; $p = 0.036$) and the Moderation component ($\beta = 2.6$; 95% confidence interval = 1.2–4.0; $p = 0.001$). Outlet density shows a negative association with the odds of underweight among women (odds ratio = 0.62; 95% confidence interval = 0.37–0.96). However, we did not observe statistically significant relationships between diet quality and malnutrition. Education and nutrition knowledge scores were positively associated with diet diversity, while income was negatively associated with diet moderation.

Conclusions: The findings of the present study have important implications for nutrition and dietetics practice in Vietnam and globally. It emphasises the need to consider various dimensions of sustainable diets, including economic, health and socio-cultural/political factors. Longer distances to food outlets are associated with higher diet quality, whereas lower food outlet density increases the odds of underweight among women. This poses challenges in balancing modernisation and its adverse effects on sustainable food systems. Socio-economic status consistently correlated with diet quality and malnutrition, necessitating further research to promote healthy diets across socio-economic strata.

KEYWORDS
diet quality, food environments, low- and middle-income countries, malnutrition, sustainable diets

Key points

- Growing evidence supports the role of food environments in shaping diet quality and nutritional status based on body mass index, in both industrialised and industrialising countries.
- However, existing studies often focus on individual relationships between food environment and diet quality, diet quality and nutritional status, or food environment and nutritional status, leaving the full pathway from food environment to nutritional status via diet quality poorly understood, especially in industrialising countries.
- Although we did not have sufficient evidence to show the existence of a pathway from food environment to malnutrition through diet quality, we found intriguing associations:
- Longer distance to the nearest food outlet correlated with higher overall DQI-V, particularly the Moderation component (control of unhealthy food consumption).
- Outlet density was inversely related to the odds of underweight among women.
- Education and nutrition knowledge scores positively influenced diet diversity, whereas income showed a negative association with diet moderation.
- The study underscores the significance of considering multiple dimensions of sustainable diets, such as economic, human health, and socio-cultural/political aspects. This approach helps balance modernisation with healthy food environments, cultural preservation and social well-being, both in Vietnam and globally.
- Industrialising countries' food environments differ significantly from industrialised countries, necessitating innovative approaches beyond proximity and density to understand their impact on food access, consumption patterns, and nutrition. This includes accounting for natural food environments, seasonal cycles, infrastructure disparities, small-scale businesses, the informal sector, national culinary traditions and social fabric.
- Addressing the influence of socio-economic factors on diet quality and malnutrition is crucial in developing effective strategies to combat malnutrition and promote better health outcomes, particularly among diverse socio-economic groups.

INTRODUCTION

The launch of economic reforms in 1986 (termed Doi Moi) and rapid trade liberalisation in Vietnam have brought extensive transformations to the country's food system, from production, storage and distribution to wholesale, retail and consumption.[1] Fueled by these transformations, Vietnam has been witnessing significant changes in diet and ultimately an increasing burden of multiple forms of malnutrition.[2–5] A food systems approach was used to investigate the nuanced and complex relationships between food environment, a key element of food systems, diet quality and malnutrition (underweight, overweight, obesity) along an urban–rural transect in Vietnam.

In their study, Down et al.[6] defined food environments as the consumer interface with the food system that is composed of the availability, affordability, convenience, promotion and quality, and sustainability of foods and beverages in wild, cultivated and built spaces. According to their paper, food environment typology was divided into two overarching categories: natural and built environments. Natural food environments include wild (forests and jungles, disturbed habitat, open pastures, natural lakes, seas, ponds and rivers) and cultivated food environments (fields, orchards, pastures, gardens, aquaculture), whereas built environments comprise informal (wet markets, unlicensed street vendors, kiosks) and formal markets (super/hyper-markets, retailers, farmer's markets, restaurants, institutions and public procurement, licensed street vendors, online vendors). The present study focuses on the built food environments. Although traditional wet markets are still the dominant channel for food purchasing, modern retail outlets such as supermarkets and convenience stores have been introduced and rapidly

expanded in Vietnam, especially in urban areas, since the late 1990s and 2000s.[7] On the one hand, these modern outlets offer consumers more choices of where to shop for food, thus increasing diet diversity. On the other hand, supermarkets are also the main point of purchase for processed food with high content of added sugar, unhealthy fat and sodium.[8]

Parallel with the changing landscape of the built food environments, the general dietary pattern of Vietnamese people has shifted to eating less starchy staples, dark green vegetables and legumes, and more animal proteins, fat/oils, ripe fruits, and processed and pre-prepared foods and beverages.[9,10] Previous studies in Vietnam have observed a gap in expenditures on highly processed foods, fish, milk and beverages between urban households and rural households where the former spent significantly more.[11,12] To quantify dietary quality, studies in Vietnam usually evaluate diet diversity using diet diversity score[13,14] or nutrient adequacy by comparing actual nutrient intake with the individual recommended nutrient intakes.[15] These metrics can give a fairly good and low-cost assessment of diet quality. However, diet quality is a multi-faceted concept including food and/or nutrient variety, adequacy, moderation and balance. Thus, a more comprehensive diet quality indicator is needed to capture all these nuances.

Transition in dietary patterns is shown to be associated with changing patterns of nutrition-related diseases. There have been significant improvements regarding undernutrition over the past 20 years in Vietnam. According to the Global Nutrition Report,[2] the national prevalence of stunting in children under 5 years of age has decreased from 43% in 2000 to 24% in 2017. Underweight prevalence in adults aged 18 years and over has dropped from 24% in 2000 to 18% in 2017. Nevertheless, the prevalence of stunting among children under 5 years of age is higher than the average for the Asia region (22%). At the same time, the nationwide prevalence of overall overweight in adults has increased from 7.7% among males and 12.2% among females in 2000 to 15.8% among males and 20.5% among females in 2016.[2] Notably, the distribution of undernutrition and overnutrition is not equal between rural and urban areas. Undernutrition is more prevalent in rural areas, whereas overnutrition rate is higher in urban areas.[16]

The evidence on how food environment affects an individual's diet and ultimately their nutritional status continues to develop. The conceptual framework proposed by the High-Level Panel of Experts on Food Security and Nutrition[17] and the food environment typology[6] propose that food environments are among major drivers of diet quality. Prominent findings in the studies conducted in industrialised countries, dominated by the US, show that fast-food restaurants and convenience stores boost overconsumption of unhealthy foods and consequently higher body mass index (BMI), whereas the presence of supermarkets promotes increased intake of fruits and vegetables and thus lower levels of obesity.[18,19] Nevertheless, there have also been numerous null and mixed findings. Little evidence was found for the associations between proximity of participants' homes to food outlets and dietary intake or BMI among adults in Los Angeles County.[20] A study conducted in Seattle (WA, USA) found no evidence on the link between built environment and diet quality, but the association between diets and obesity prevalence was significant.[21]

The majority of the existing literature in industrialising countries primarily evaluates food outlet access through the share of food expenditure spent at a specific food outlet, rather than food outlet density or proximity.[22] Studies in Guatemala, Zambia and Kenya found that higher supermarket purchases were associated with lower consumption of fresh fruits and vegetables and increased consumption of processed foods high in fats and sugars.[23–25] A study conducted in South Africa did investigate household proximity to food outlets,[22] reporting that living closer to supermarket and fast-food restaurants increased individuals' BMI and their likelihood of being overweight or obese. One study conducted in Zambia suggested that modern retailers contribute to higher intake of protein and micronutrient intakes mainly through consumption of meat and dairy.[24] It is important to highlight that food environments in industrialising countries differ significantly from industrialised countries, necessitating different approaches beyond proximity and density to understand their impact on diet quality and nutrition status. Complex factors such as seasonal cycles, economic shocks, social biases and infrastructure disparities shape industrialising countries' food environments.[26] Diverse food sources, small-scale businesses and the informal sector add complexity.[26,27]

In rural areas of Vietnam, the high prevalence of child undernutrition is significantly influenced by factors such as limited retail diversity and households relying on their own production.[28] In a study conducted among urban households in Vietnam, modern market food expenditure was positively associated with consumption of foods rich in heme iron and protein, although there was no significant association with dietary diversity or diet quality.[13]

To our knowledge, there has been no research that examines the link from food environment to malnutrition via diet quality in Vietnam context. Therefore, we aim to fill that gap with the research question: Were food environments related to malnutrition (underweight, overweight/obesity) through diet quality? This research question has the following sub-questions: (1) Were food environments associated with malnutrition? (2) Were food environments associated with diet quality? (3) Was diet quality associated with malnutrition even after controlling for food environments? (4) Was the effect of food environments on malnutrition after controlling

for diet quality zero? We hypothesise that food environments have an impact on diet quality. Diet quality in turn was postulated to play an intermediary role between individual factors and food environments and malnutrition.

Furthermore, the present study provides significant insights into the intricate interplay of multiple dimensions inherent in sustainable diets. According to Downs et al.,[6] sustainable diets encompass four key dimensions: ecological, economic, human health and socio-cultural/political. The ecological dimension entails promoting production quality, conserving biodiversity, adopting sustainable agricultural practices, encouraging local and seasonal food consumption, utilising clean energy sources, and safeguarding vital resources. The economic dimension focuses on direct sales, minimising food waste and packaging, supporting livelihoods, and acknowledging local food systems. The human health dimension prioritises food safety, advocating for plant-based and nutrient-dense foods, and ensuring adequate nutrient intake. The socio-cultural/political dimension addresses equity, labour conditions and animal welfare. These dimensions collectively integrate environmental sustainability, economic viability, human health and social equity within the realms of food production and consumption. Specifically, the present study investigates the influence of the spatial distribution of food outlets on diet quality, encompassing the availability of nutrient-dense foods, the achievement of sufficient nutrient intake and the prevalence of malnutrition. Thus, it delves into the economic and human health dimensions. Moreover, it explores the socio-cultural dimension, where disparities in food access, dietary patterns and malnutrition status may arise among diverse socio-economic strata.

METHODS

Survey

Cross-sectional data were collected among individuals in the Northern part of Vietnam from July to September 2018, as part of a larger project named Partial Food Systems Baseline Assessment at the Vietnam Benchmark Sites.[29] This project collected data on diets, nutritional status (anthropometry), consumer behavior and food flows, comprising (i) ingredients used to prepare the meals consumed, and (ii) and frequency of food/dish consumption, of three members of each household: father, mother and child under 5 years. Our study only used data from adult household members. Specifically, 595 adults aged 18–66 years (298 women and 297 men) from three districts representing urban, peri-urban and rural populations were included in the study. The districts were Cau Giay (an urban site in Hanoi, $n = 217$; 109 women and 108 men), Dong Anh (a peri-urban site in Hanoi province, $n = 158$; 79 women and 79 men) and Moc Chau (a rural site in Son La province, $n = 220$; 110 women and 110 men).

Using a probability proportional to size procedure, 30 communes were randomly selected as primary sampling units (PSUs) within each district, where higher population communes had higher probabilities of being selected.[29] Once selected, a rapid enumeration of households and household members was obtained from district health centres. The number of households and/or individuals selected was determined according to a sample size calculation that assumed population-level representativeness. More details about the sampling frame are included in the Suppporting information (Doc. S1).

Assessment of food environments, diet quality and malnutrition

Assessment of food environments

Food environments in the present study were measured by food outlet density (availability) and proximity to food outlet (accessibility). There are many more dimensions of the food environment, such as vendor and product properties, marketing and regulation, affordability, and desirability,[27,30] as well as other elements impacting food systems, such as surrounding political, social and cultural norms[17] that are not investigated here.

To explore the built food environment of the 30 research communes, geospatial mapping of different food outlets was performed to identify and map different food outlets.[28] This mapping process involved a transect walk in the "food ecosystem" from rural to urban areas. In cases where formal maps and data were unavailable, transect walks were considered valuable for documenting community environments.[28,31] During the walk, the researcher, accompanied by a local guide, traversed (walked or drove) the 30 sampled communes within their administrative boundaries, identifying and recording all food retailers in the area. The resulting database (https://cal.maps.arcgis.com/apps/MapJournal/index.html?appid=75b4657a6a0243bc963fe5e0e3e48d92) encompasses various food retail stores, restaurants and direct producer-to-consumer marketing venues, such as farmers' markets and farm stands. The food outlets were originally classified into twelve distinct groups, with definitions provided in the Supporting information (Table S1). In the present study, we further aggregated those twelve groups into three categories: traditional outlets, modern outlets and restaurants (see Supporting information, Table S1). However, the limited number of each outlet type at the commune level, particularly in rural areas where modern outlets and restaurants were scarce, led to a lack of statistical power and reliability in drawing definitive conclusions. Therefore, although we acknowledge the significance of distinguishing between various types of food outlets, we made the decision

to aggregate all types together in our models. We acknowledge this as a limitation of our study.

Outlet density was measured by dividing the total number of food outlets by the total population in each commune. To assess the proximity of food outlets to households, we measured straight-line distances from the available household coordinates to the nearest specified type of food outlet using ArcGIS, version 3.6.1 (https://www.arcgis.com). These distances were employed as an indicator of a household's proximity to food stores. Because of the unavailability of roadway or sidewalk distance and travel time data across all districts, we opted for straight-line distance measurements. The coordinates of both the stores and participants' households were tracked using an iPhone (Apple Inc.) equipped with the maps.me app, which provides GPS support. However, because complete data on households' coordinates were not obtainable for all participants' residences, we determined the minimum distance among the available distances and assigned it to participants residing in that commune. In addition, differences in urbanicity, which refers to whether an individual resides in urban, peri-urban or rural areas, was also included in this domain. Food environment variables were treated at the commune level, such that people from the same commune were assigned the same value.

Assessment of BMI and malnutrition categories

Individual weight and height data were from the anthropometry component of the larger project. Body weight was measured and recorded to the nearest 0.01 kg with a calibrated electronic scale (SECA) after participants were asked to remove unnecessary clothing.[29] Body height was measured and recorded to the nearest 1 mm with a wooden stadiometer. The average of two independent measurements was recorded for each anthropometric variable.

BMI was calculated by dividing the weight in kilograms by the squared height in meters (kg/m^2). We defined underweight as $BMI < 18.5\ kg/m^2$ and overweight and obesity as $BMI \geq 25\ kg/m^2$.[32] Because few individuals in our study were obese (< 1% of total population), we combined overweight and obese individuals into a single category, denoted as overweight/obesity.

Assessment of dietary intake and diet quality

Individual dietary intakes were derived from the 24-h dietary survey of the larger project. Dietary data were collected on households from 10 randomly selected PSUs within each district (of the 30 total PSUs in each district).[29] Trained enumerators, using the 24-h dietary recall questionnaires, asked each participant about all the foods and beverages consumed in the last 24 h prior to the interview. Two non-consecutive recalls were conducted in this survey: The first recall was on a weekday and the second recall was on either a weekend or weekday. Weekend days accounted for 19.5% of the total second recalls. The 24-h diet recall questionnaire was based on the standard questionnaire from Vietnam National Institute of Nutrition (NIN) with slight modifications.

The enumerators collected detailed information on all foods consumed within the previous 24-h period, starting from the beginning of that time frame. When recording recipes, certain essential features were carefully documented. These included (i) a descriptive list of all ingredients, encompassing herbs and spices; (ii) the weight of raw ingredients as edible portions; (iii) the method of preparation and cooking, including the use of fats, oils, condiments and other relevant details; (iv) the final weight or volume of the cooked food; and (v) the weight of the amount consumed by each individual. Furthermore, any functional foods or supplements were also recorded as part of the data collection process. A food atlas from the NIN, electronic scales and local utensils were used to facilitate portion size estimation. Processed dietary data were converted into nutrient values using the 2017 Vietnamese Food Composition Table (FCT) constructed by NIN[33] and the updated FCT, which adds missing foods and missing nutrients constructed by Raneri.[34] For food items that still lack nutrient values in the Vietnamese FCT and the updated FCT, we took the value of nutrients of these or similar foods from other Asian FCTs and the USDA food database.[35] If the nutrient value could not be found in any databases, we averaged the value of that nutrient from the food items in the same food group. For mixed dishes, the researchers asked the respondents for information on ingredients. If the ingredients could not be determined, recipe information was obtained from other studies on diet assessments in Vietnam. When recipes could still not be found in these studies, the researchers obtained ingredient information for recipes from multiple sources.

The multiple source method (MSM)[36] was used to estimate usual intake from the 24-h diet recall information. It is composed of three steps. First, the probability of consumption of food on a day for every individual is estimated. Second, the usual amount of food consumption on days of consumption is approximated. Finally, the usual food intake on all days is computed by multiplying the probability of consumption of food with the usual amount of food intake on days of consumption. Covariates that are related to food intake are selected in advance and can be included within the estimation steps.[36] Data were entered into a web-based statistics package (https://msm.dife.de) for calculation. Total calorie intake was calculated for each participant by first converting quantity from grams to kcals and then summing them together. All dietary intakes were

expressed as energy density standards rather than leaving them as absolute amounts, that is, grams per 2000 kcal, calculated by dividing the number of grams of each food intake by the total kcal intake multiplied by 2000.[37] This method, similar to that of Mertens et al.[38] and Fisberg et al.,[37] calculates densities representing relative consumption quantities of food and food groups in the diet. By normalising the diet to 2000 kcal, the focus shifts to dietary composition rather than caloric differences, expressed as grams per 2000 kcal/day. Additionally, this method deals with the size and energy difference across different individuals, thus accounting for differences in food intake between big and small eaters. It also compensates for over- or underestimation of food intake.[38]

Diet quality was assessed by the Diet Quality Index – Vietnam (DQI-V), an adaptation from the Diet Quality Index – International (DQI-I). The DQI-I was chosen because it has been used in a range of cultural contexts and validated in a range of countries with different dietary patterns. Moreover, it is a combination of nutrient- and food/food group-based indicators and provides a more comprehensive picture of diet quality than nutrient or food/food groups alone. The DQI-V was computed using the method by Kim et al.[39] adapted to Vietnamese dietary guidelines composing the recommended dietary guidelines[40] and the Nutritional pyramid for Vietnamese people.[41] The DQI-I assesses four aspects of a diet: variety (the diversity of food), adequacy (the fulfillment of essential nutrient requirements), moderation (the control of consuming unhealthy food and nutrients) and balance (the balance among macronutrients and fatty acids), each of which has subcomponents. The construction method of DQI-I was as follows: scores of each of the four components were calculated separately, then the total DQI-I was calculated as the sum of these component scores, producing a score between 0 and 100, with 0 being the poorest, indicating a diet of the lowest quality, and 100 being the best, indicating a diet of the highest quality.[39]

The detailed DQI-V and its corresponding scoring criteria are described in the Supporting information (Doc. S2, and Table S2). Similar to the original DQI-I, a higher DQI-V score indicates a higher-quality diet with better variety, adequacy, moderation and overall balance.

Individual factors as confounders

Demographic factors

Gender and age were included as demographic factors.

Socio-economic status (SES)

Individual education and household income were included as SES indicators. Education was divided into three levels: low (completed secondary school or lower); middle (High school and vocational education); and high (University and postgraduate). Income was categorised as low (below or equal to 6.9 million VND/household/month ~300 USD); middle (larger than 6.9 million VND/household/month and smaller than or equal to 14.9 million VND/household/month ~650 USD); and high (more than VND 14.9 million/household/month). This categorisation was based on convenience for the present study. The number of individuals in the home, or household size, was also included.

Nutrition knowledge score

Household nutrition knowledge was measured through a series of 30 questions about diet and nutrition, similar to the Nutrition Knowledge, Attitudes, and Practices (KAP) manual published by FAO.[42] It includes many aspects: micronutrient attitudes, diet diversity knowledge, diet diversity attitudes, undernutrition knowledge, undernutrition attitudes, over-nutrition knowledge and over-nutrition attitudes. Nutrition knowledge data were collected at the household level. The survey of nutrition knowledge was conducted on the household member who was mainly responsible for household food purchase and preparation.

Statistical analysis

Descriptive analyses were conducted in this research to examine the central tendency, variations, and frequency of the variables. Continuous variables following normal distribution were expressed as mean ± SD and compared by one-way analysis of variance and post-hoc Tukey's range test for pairwise comparison. Those continuous variables with a skewed distribution were expressed as median (interquartile range) and compared using the Kruskal–Wallis H test and Kruskal–Wallis post-hoc Nemenyi test. The Shapiro–Wilk test, histograms and Q-Q plots were used to evaluate normality. Categorical variables were expressed as number and percentage, and Fisher's exact test was used for among-group comparison due to small sample size. $p < 0.05$ (two-tailed) was used to identify statistically significant differences.

The primary research question, "To what extent are food environments associated with malnutrition through diet quality?", was investigated using a mediation analysis. Following the guidelines of Baron and Kenny,[43] a four-step approach was employed, as depicted in Figure 1 and detailed in the the Supporting information (Doc. S3). The predictor variable was the food environment, the mediator variable was diet quality and the outcome variable was nutritional status.

Regression models were selected based on the nature and level of the variables. Multilevel regression models

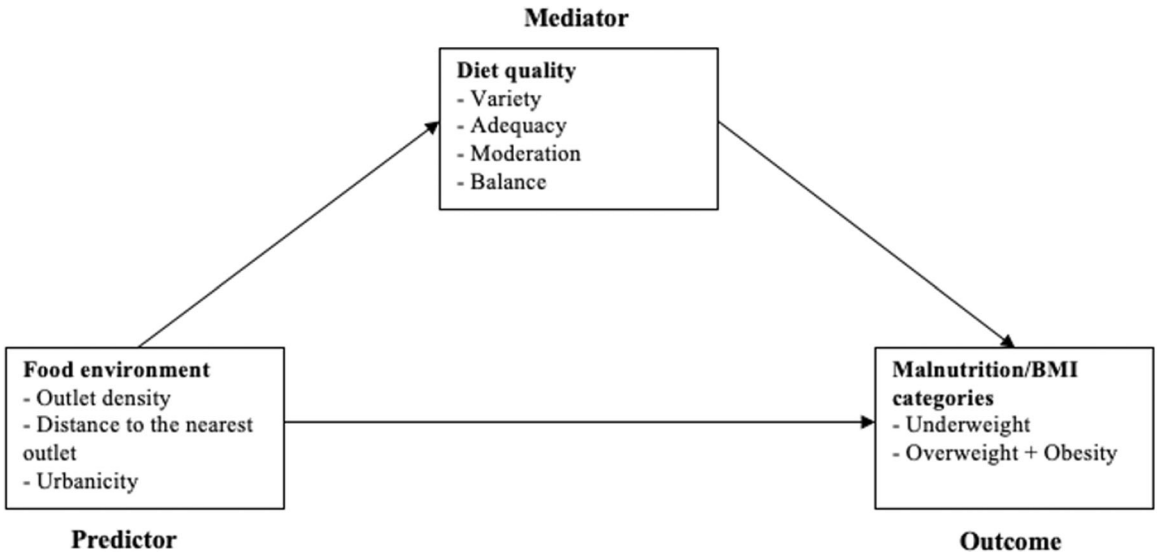

FIGURE 1 Research logical flow: the linkage between food environments, diet quality and malnutrition. BMI, body mass index.

(or mixed effects models), accounting for the hierarchical data structure at the commune, as well as household and individual levels, were utilised.[44,45] Linear regression was applied when both the independent variable and the moderator variable were continuous. In the analysis, the predictors included food outlet density or proximity, gender, age, education level, income level, household size and knowledge score. Random intercepts were incorporated for the neighbourhood variable to capture the clustering effect.

In the first step, regular binary logistic regression models were employed to examine the association between food environments and nutritional status, as minimal hierarchical effects were observed. The second step employed mixed-effects models to investigate the relationship between food environments and diet quality scores. Linear mixed models were employed for continuous scores, whereas Poisson mixed models were utilised for discrete scores.

Steps three and four focused on evaluating the association between diet quality and nutritional status using regular binary logistic regression models, given the negligible clustering effect. The reference category for each outcome was 'normal weight'. The food environment variables were included in the same equation as predictors.

Confounding variables were pre-determined based on prior literature and limited in number due to the small sample size. The full models were adjusted for age, education level, income level, household size and knowledge score. Separate models were developed for males and females. Variance inflation factors were examined to assess multicollinearity, and no significant issues were detected. All analyses were conducted using the R programming language (R Foundation), specifically the lme4 package. version 3.6.0, 2019-04-26.[46]

RESULTS

Participant characteristics

Table 1 displays the descriptive statistics of the study participants. The mean age of urban participants was larger than that of peri-urban and rural participants. Significantly more urban people were found to have attained higher educational status compared to peri-urban and rural participants, in descending order (the rate of university and postgraduate women was highest in the urban (66.1%), then the peri-urban (15.2%) and finally the rural site (0.9%). In the urban site, households from the highest income tercile (more than USD 650 per month) accounted for 67%; in contrast, in the rural site, households in the lowest income tercile (less than USD 300 per month) represented 72.7% of the population. Because nutrition knowledge was also evaluated at the household level, such that men and women from the same household had the same scores, there was no difference between men and women. The score in the urban site was higher than the rural site, at 0.7 and 0.5, respectively.

How did food environment, diet quality and malnutrition differ between the urban, peri-urban and rural districts?

How did food environments differ between the urban, peri-urban and rural districts?

Because the data on food environments were collected at the neighbourhood level, men and women in the same neighbourhood shared the same values for these variables. The total number of food outlets was highest in the urban district (262 outlets), followed by the peri-urban district (221 outlets) and, lastly, the rural district (49

TABLE 1 Summary of study participants' characteristics.

Characteristics	Women			Men		
	Urban ($n = 109$)	Periurban ($n = 79$)	Rural ($n = 110$)	Urban ($n = 108$)	Periurban ($n = 79$)	Rural ($n = 110$)
Individual factors						
Age	31.5 ± 4.6[a]	29 ± 5.2[b]	28.3 ± 6.3[b]	35 ± 6.2[a]	32.5 ± 6.2[b]	31 ± 7[b]
Education (%)						
< High school	4 (3.7%)[a]	19 (24.1%)[b]	74 (67.3%)[c]	8 (7.4%)[a]	22 (27.8%)[b]	81 (73.6%)[c]
High school and vocational education	33 (30.3%)[a]	48 (60.8%)[b]	35 (31.8%)[a]	25 (23.1%)[a]	41 (51.9%)[b]	28 (25.5%)[a]
University and postgraduate	72 (66.1%)[a]	12(15.2%)[b]	1 (0.9%)[c]	75 (69.4%)[a]	16 (20.3%)[b]	1 (0.9%)[c]
Income (%)						
< VND 6.9 million (M)	2 (1.8%)[a]	16 (20.3%)[b]	80 (72.7%)[c]	2 (1.8%)[a]	16 (20.3%)[b]	80 (72.7%)[c]
VND 6.9 M–VND 14.9 M	34 (31.2%)[ab]	34 (43%)[b]	27 (24.5%)[a]	33 (30.6%)[ab]	34 (43%)[b]	27 (24.5%)[a]
> VND 14.9 million	73 (67%)[a]	29 (36.7%)[b]	3 (2.7%)[c]	73 (67.6%)[a]	29 (36.7%)[b]	3 (2.7%)[c]
Nutrition knowledge score	0.7 ± 0.2[a]	0.6 ± 0.2[a]	0.5 ± 0.2[b]	0.7 ± 0.2[a]	0.6 ± 0.2[a]	0.5 ± 0.2[b]

Notes: The percentage is calculated for column; the denominator is column total for each category. Significant difference at 5% by one-way analysis of variance and post-hoc Tukey's range test for normal distributed continuous variables, Kruskal–Wallis H test and Kruskal–Wallis post-hoc Nemenyi test for non-normal distributed continuous variables and Fisher's exact test for categorical variables. Values with the same lowercase letter are not significantly different at $p < 0.05$. The mean ± SD was reported for normally distributed variables; the median (interquartile range) was reported for non-normally distributed variables.

outlets) (see Supporting information, Table S3). Traditional outlets accounted for the largest percentage in the outlet type composition, except for the urban site where restaurants slightly outnumbered traditional outlets. There are no modern food outlets in the rural districts, and the number of restaurants in this area was also very small. Distance to the closest food outlet was shortest in the urban site, followed by the peri-urban site and finally the rural site. The outlet density per 1000 residents in the urban district was three to four times higher than the outlet density in the rural and peri-urban districts.

How did diet quality vary between the urban, peri-urban and rural districts?

The original score of the overall DQI-V and its components were converted to the percentage of the maximum possible scores for a better comparison because each component score has a different score range (Figure 2). Rural participants had a significantly higher total DQI-V score compared to urban and peri-urban participants. The mean ± SD DQI-V in the rural district was 70.5 ± 8.3% of the maximum possible score, whereas the mean ± SD DQI-V in the peri-urban and urban district was 65.5 ± 8.6% and 64 ± 8.8%, respectively. This pattern persisted regardless of sex.

Mean scores of each DQI-V component were reported in Figure 2, also expressed as a percentage of the maximum possible scores. Variety was most fulfilled in all three districts although urban and peri-urban residents had significantly higher scores (93.2% and 92.9%, respectively) than their rural counterparts (81%). By contrast, moderation was significantly better fulfilled in the rural district (73%) than in the peri-urban (47.1%) and urban (39.7%) districts. Balance was the least fulfilled component in all three districts, at 39.1%, 39.2% and 35.5% for urban, peri-urban and rural districts, respectively. There was no significant difference in the Adequacy component along the urban-rural transect. These patterns persisted regardless of sex.

How did malnutrition vary between the urban, peri-urban and rural districts?

The overall prevalence of underweight and overweight/obesity of all study participants was 9.1% and 13.4%, respectively. The proportion of underweight women in the rural area was almost double the proportion of underweight women in the urban site (16.4% vs. 9.2%), whereas this trend was reversed for overweight and obesity (7.3% vs. 13.8%). For men, the same pattern was observed.

Were food environments related to malnutrition through diet quality?

The association between food environments and malnutrition (step 1 in the mediation analysis)

Our models in both females and males showed there are no associations between food environment variables (distance to

the nearest food outlet, food outlet density) and malnutrition (underweight, overweight/obesity). The odds ratios (ORs) in all models are 1.00–1.01 and their corresponding 95% confidence intervals (CI) include 1. Thus, the results are not clinically, nor statistically significant (Table 2).

The association between food environments and diet quality (step 2 in the mediation analysis)

Our models in both females and males showed that distance to the nearest food outlet was statistically positively correlated with the total DQI-V (females: $\beta = 2.02$; 95% CI = 0.22–3.82, males: $\beta = 2.06$; 95% CI = 0.2–3.93) and the Moderation component (females: $\beta = 2.63$; 95% CI = 1.23–4.04, males: $\beta = 2.53$; 95% CI = 0.99–4.07) (Table 3). This result indicated that the longer the distance to the nearest food outlet was, the higher the diet quality score was, especially the Moderation component. Food environment characteristics (both distance to the nearest food outlet and food outlet density) were not statistically associated with the other DQI-V components in both men and women models.

The association between diet quality and malnutrition (steps 3 in the mediation analysis)

Our models in both females and males showed there are no associations between diet quality variables (overall DQI-V, Variety, Adequacy, Moderation and Balance)

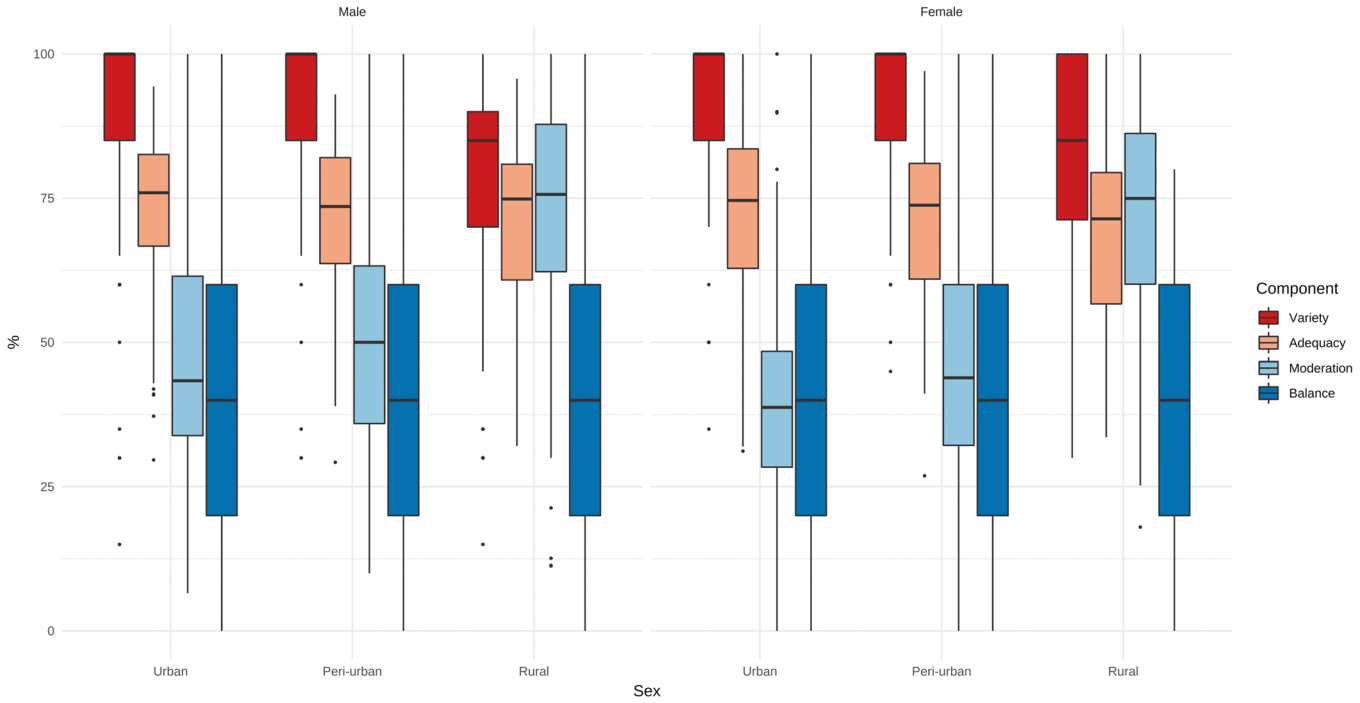

FIGURE 2 The mean percentage of attaining the maximum score of Diet Quality Index – Vietnamese (DQI-V) components stratified by gender and study sites.

TABLE 2 Association between malnutrition and food environment (steps 1, 3 and 4 of the mediation analysis).

	Without controlling for diet quality						Controlling for diet quality					
	Women			Men			Women			Men		
	OR	95% CI	*p*-value	OR	95% CI	*p*-value	OR	95% CI	*p*-value	OR	95% CI	*p*-value
Distance to the nearest food outlet												
Overweight	1.00	(1.00, 1.00)	0.253	1.00	(1.00, 1.00)	0.222	1.00	(1.00, 1.00)	0.206	1.00	(1.00, 1.00)	0.658
Underweight	1.00	(1.00, 1.00)	0.676	1.00	(1.00, 1.00)	0.322	1.00	(1.00, 1.00)	0.699	1.00	(1.00, 1.00)	0.556
Food outlet density												
Overweight	1.01	(0.97, 1.05)	0.672	1.01	(0.71, 1.4)	0.967	0.86	(0.53, 1.28)	0.246	0.85	(0.60, 1.15)	0.324
Underweight	0.64	(0.38, 0.97)	0.058	1.00	(0.94, 1.04)	0.860	0.62	(0.37, 0.96)	0.049	1.12	(0.62, 1.78)	0.673

Note: The results are from the adjusted model controlling with the following covariates and confounding variables: age, education, income, household size and knowledge score.
Abbreviations: CI, confidence interval; OR, odds ratio.

TABLE 3 Association between diet quality and food environment (step 2 of the mediation analysis).*

	Women				Men			
Overall DQI-V	**Beta/IRR**	**95% CI**		***p*-value**	**Beta/IRR**	**95% CI**		***p*-value**
Distance to the nearest food outlet	2.02	0.22	3.82	0.036	1.00	1.00	1.00	0.222
Food outlet density	1.01	0.97	1.05	0.672	1.01	0.97	1.05	0.672
Variety								
Distance to the nearest food outlet	1.00	0.96	1.05	0.882	1.00	1.00	1.00	0.322
Food outlet density	0.97	0.93	1.01	0.188	1.00	0.94	1.04	0.860
Adequacy								
Distance to the nearest food outlet	0.2	−1.4	1.8	0.786	0.43	−1.01	1.87	0.562
Food outlet density	0.26	−1.21	1.72	0.738	0.66	−0.63	1.93	0.328
Moderation								
Distance to the nearest food outlet	2.63	1.23	4.04	0.001	2.53	0.99	4.07	0.003
Food outlet density	−0.88	−2.36	0.57	0.254	−0.55	−2.1	0.97	0.492
Balance								
Distance to the nearest food outlet	0.91	0.82	1.02	0.1	0.85	0.76	0.95	0.004
Food outlet density	1.05	0.96	1.15	0.263	0.97	0.88	1.07	0.556

Notes: The results are from the adjusted model controlling with the following covariates and confounding variables: age, education, income, household size and knowledge score. Beta is for overall DQI-V, adequacy and moderation (estimated from the linear mixed effect models), whereas IRR is for variety and balance (estimated from the Poisson mixed effect models).

Abbreviations: CI, confidence interval; DQI-V, Diet Quality Index – Vietnamese; IRR, Incidence rate ratio; OR, odds ratio.

*The results are from the adjusted model controlling with the following covariates and confounding variables: age, education, income, household size and knowledge score.

and malnutrition (underweight, overweight/obesity). The ORs in all models are 1.00–1.01, and their corresponding 95% CI include 1. Thus, the results are not clinically, nor statistically significant.

The association between food environments and malnutrition controlling for diet quality (steps 4 in the mediation analysis)

Our model showed that food outlet density was negatively correlated with the odds of being underweight among women (OR = 0.62; 95% CI = 0.37–0.96) when controlling for diet quality (Table 2). This result suggested that the higher the outlet density, the lower the odds of being underweight.

Results beyond initial hypotheses

Individual factors and diet quality

Although we did not have initial hypotheses about the relationships between individual factors and diet quality, we observed the following. Income was negatively associated with the overall DQI-V and the Moderation component in both men and women, education in the women model and nutrition knowledge scores in the men model were positively associated with the Variety component. Specifically, people in the highest income tercile had lower overall DQI-V scores than people in the lowest income tercile (β = −0.31, 95% CI = −0.59 to −0.04) (see Supporting information, Table S4). On the other hand, the Variety scores were 7% higher among people who attended high school or vocational school (second education tercile) compared to those who completed secondary school or lower (lowest education tercile) (incidence rate ratio [IRR] = 1.07, 95% CI = 1.01–1.12). Also, the Variety scores increased by 3% for each additional SD of nutrition knowledge score (IRR = 1.03, 95% CI = 1.01–1.06). People in the second tercile education level had higher Adequacy scores than people in the lowest education level. Compared to those who were in the lowest income tercile, people in the second and third income tercile had lower Moderation scores (β = −0.23, 95% CI = −0.41 to −0.04; β = −0.49, 95% CI = −0.72 to −0.27 respectively) than those in the lowest income tercile.

Individual factors and malnutrition

Alhough we did not have initial hypotheses about the relationships between individual factors and diet quality, we observed the following. Men in the higher education

levels (second and third terciles) were more likely to be overweight (OR = 3.16, CI = 1.10–9.05, OR = 5.41, CI = 1.59–18.41 respectively) than those in the lowest education tercile (less than secondary education; see Supporting information, Table S5).

DISCUSSION

Overall, we found significant differences in the food environment, diet quality and malnutrition between urban and rural districts. The peri-urban is an intermediary site that captures both characteristics of the urban and the rural sites, although diet quality (Figure 2) mirrored the urban sites. When examining whether there was a pathway from food environment to malnutrition through diet quality, we did not have sufficient evidence to show the existence of that pathway. However, we found food environments, especially distance to the nearest outlet, to be positively correlated with the overall DQI-V and its Moderation component. We also found evidence of the relationship between food outlet density and underweight among women when adjusting for diet quality. Finally, we found consistent results regarding the association between socio-demographic factors and diet quality and malnutrition.

Were food environments related to malnutrition through diet quality?

Food environments were not statistically related to malnutrition in the model without diet quality, but became significant in the model controlling for diet quality

Studies about the relationship between food environments and malnutrition showed mixed results. The majority of studies in the USA have suggested that better access and higher presence of supermarkets were associated with a lower prevalence of overweight and obesity, whereas the presence of convenience stores was associated with a higher prevalence of overweight and obesity.[47–49] Unexpectedly, a study in Japan found a positive association between supermarket accessibility and BMI, and no significant associations between fast food outlets/convenient stores and BMI.[50] Another study in Japan found that perceived availability of food outlets was not significantly associated with underweight.[51]

The present study provided evidence for the relationship between food outlet density and underweight among women. The result is different from previous literature because, first, we did not disaggregate food outlets into different types like supermarkets, convenient stores or fast-food restaurants in our mediation analysis. Also, it should be noted that, in the US studies, supermarkets were defined as those provide high-quality and healthy food choices. This might not be the same in Vietnam context where supermarkets are the main source of processed foods. Another reason might be the difference in the association between food outlet exposure and malnutrition of particular subgroups (e.g., school-aged population might be different from adult populations).

It is important to acknowledge the multifaceted aspects that influence individuals' interactions with their food environments, which extend beyond food outlet density and proximity to their homes. Factors such as affordability (purchasing power), convenience (relative time and effort of preparing, cooking and consuming food product) and desirability (preferences, acceptability, tastes, desires, culture) play crucial roles in shaping individuals' decisions regarding which food outlets to choose.[26,27] Recognising the complexity of these interactions can provide valuable insights into understanding how individuals navigate their food environments and can help inform interventions that promote healthier food choices and improved diet quality.

Food environments were statistically correlated with diet quality

The models between diet quality and distance to the nearest food outlet showed that people living far away from food outlets had higher Moderation and overall DQI-V scores. A possible explanation for this association is that the proximity to food outlets was a proxy measure for the diversity of food outlets, including those provide unhealthy food options. When there are less food outlets in the area, such that there is a longer distance to food outlets, the chance of consuming unhealthy food decreases.

Studies about the relationship between food environments and diet quality have mixed results. A study by Laraia et al.[52] found that women in North Carolina (USA) living more than 4 miles from a supermarket had a higher chance of getting the lowest diet quality score compared to those women living nearer to a supermarket. It was reasoned that because supermarkets (in the USA) demonstrated the greatest variety of food at the lowest cost, thus people who live closest to a supermarket can take advantage of this resource and may have better diet quality.[52] Reidpath et al.[53] suggested that in Melbourne (Australia) the density of fast-food outlets interacted with the social economic status to create environments in which the poor had more exposure to energy-dense foods. Nakamura et al.[51] argued that low food access was associated with infrequent intake of fruits and vegetables, meat and fish among community-dwelling older Japanese. A study conducted in Hanoi, Vietnam, found that geographical proximity did not have an influence on diet quality.[54]

As explained earlier above, these mixed results may be a result of different definitions and the disaggregation

of food outlets, as well as different study subgroups. Another plausible reason mentioned above is the interaction between food environment characteristics and other socio-economic and demographic factors.

Additionally, it is essential to consider natural food environments alongside built environments in our findings. As highlighted by Dawns et al.,[6] approximately 475 million smallholder farms, primarily located in industrialising countries, play a significant role in food production, particularly in rural areas. Although some households in these regions still rely on purchasing food, many depend heavily on their own agricultural production to fulfill their energy and nutrient requirements. The natural food environments in these areas significantly influence the availability, diversity and quality of food options, which in turn impacts the overall diet quality of these populations. Therefore, integrating discussions on natural food environments alongside built environments allows us to gain a comprehensive understanding of the complex dynamics shaping food access and consumption patterns in industrialising countries, especially in rural and peri-urban areas.

Diet quality were not correlated with malnutrition

The literature about the relationship between diet quality indicators and malnutrition has shown mixed results. A study by Funtikova et al.[55] found a significant negative association between DQI and waist circumference, but not BMI. A multi-ethnic study found that diet quality, measured by the Healthy Eating Index, predicts obesity outcomes better in White than in Chinese, Hispanics and African Americans.[56] Other studies had conflicting associations based on sex and design of the study[57] The present study did not find a significant association between diet quality and malnutrition.

Results beyond the study's hypotheses: Individual factors were correlated with diet quality and malnutrition

Individual factors and diet quality

Without *a priori* hypotheses, the present study found that individual factors associated with diet quality included income, education and nutrition knowledge score, Education was positively associated with the Variety and the Adequacy components in women, whereas nutrition knowledge was positively associated with these two components in men.

Education in general and nutrition education are known to play an important role in food purchasing and consumption behavior. The positive impact that general education and nutrition education had on the overall diet quality[58–61] and on diet diversity in particular[62,63] of adults was shown in previous studies in both industrialised and industrialising countries. Also, previous studies have demonstrated that dietary diversity can provide a fairly good assessment of micronutrient adequacy,[64,65] as reflected in the Adequacy component in the present study. Therefore, it is reasonable to see the same positive association between education and nutrition literacy with Adequacy scores.

Nevertheless, the situation was different for the Moderation component. The present study presented an association between higher education and higher income level with lower Moderation scores. In industrialised countries, lower household income has been consistently associated with poorer diet quality,[66,67] namely fewer fruits and vegetables, more sugar-sweetened beverages and other empty calorie foods (containing solid fats, alcohol and added sugars).[66,68] The pattern appears to be different in industrialising countries, especially those countries that are earlier in the transition. Two studies investigating the effects of socio-economic and demographic factors on meat and milk consumption in Vietnam revealed that rising income and food availability are among the important determinants of increasing meat consumption, especially pork and poultry,[69] and dairy products in Vietnam,[70] which are known to contain fat in general and saturated fat in particular.[71,72] According to Huse et al.,[73] individuals with higher socio-economic status tend to have less healthy diets compared to those with lower socio-economic status. The study suggests that this trend may be attributed to the increasing income and urbanisation in these countries. As incomes rise, there is a shift away from traditional rice-based diets towards 'luxury' foods such as fruits, vegetables, meat, dairy and ultra-processed products. Urban areas offer easier access to modern foods promoted by the food industry, leading to unhealthy dietary shifts. Consequently, urban residents are more prone to consuming unhealthy diets and experiencing overweight or obesity. Moreover, the participation of empowered women in the workforce further drives the demand for convenience foods, underscoring the necessity for healthier alternatives.

Individual factors and malnutrition

Our logistic regression models revealed that education was positively correlated with male overweight/obesity. Other studies also confirmed that malnutrition were affected by a combination of many factors. For example, snacking habit and alcohol consumption (dietary factors) together with poverty and marital status (socio-economic factors) predicted the odds of being overweight or obese in Ethiopia.[74]

Previous studies examining the malnutrition of adults in Vietnam suggested that gender, age, income and

education were associated factors.[5,75,76] Regarding educational level, although a positive association was found between education and overweight in the bivariate model, the model adjusted for food expenditure, area, age and gender indicated that the higher the education that people attain, the lower the chance of becoming overweight.[5] The study explained that this situation occurred mainly as a result of the stronger association between food expenditure (a proxy for income) and nutritional status than education.[5] Another study examining obesity prevalence in Ho Chi Minh City reported that the overweight prevalence increased with higher economic status, as measured by the household wealth index, among men but not women.[75,77] Studies in industrialised countries found that the general trend is that obesity is negatively associated with income level[78] and education level.[79] It can be concluded that the relationship between different socio-economic status indicators and overweight/obesity prevalence is complex and varied between industrialised and industrialising countries, by gender and by race/ethnicity.[80]

Sustainable food systems in the context of nutrition and dietetics practice in Vietnam and globally

According to the National Nutrition Strategy for the 2011–2020 period,[81] Vietnam has made significant strides in improving the nutrition status of its population, including reducing maternal and child malnutrition, enhancing nutrition knowledge and diversifying dietary patterns. However, challenges stemming from globalisation, urbanisation, climate change, population growth and the double burden of nutrition persist. To tackle these issues, government agencies and non-profit organisations are actively implementing strategies and policies. The Ministry of Education and Training focuses on nutrition education in schools, whereas the Ministry of Labor, Invalids and Social Affairs targets disadvantaged areas. The Ministry of Information and Communication ensures proper nutrition information dissemination. Social organisations such as the Vietnam Women's Union play a role in promoting health and nutrition knowledge. International organisations such as HealthBridge, Scaling up Nutrition Civil Society Alliance Vietnam (SUN-CSA Vietnam), UNICEF and the World Health Organization collaborate to provide research-based evidence and technical inputs for the National Nutrition Strategy (NNS) from 2021 to 2030.[82] An important focus of the 2021–2030 NNS is the control of overweight and obesity, as well as the prevention of chronic non-communicable diseases, with key policy measures such as sugar-sweetened beverage taxes and front-of-package labelling being planned.[83]

Globally, nutrition and dietetics practice is guided by various frameworks and initiatives. The World Health Organization has developed guidelines and recommendations for nutrition interventions, such as the Global Nutrition Policy Review and the Global Action Plan for the Prevention and Control of Noncommunicable Diseases.[84] The United Nations Sustainable Development Goals (SDGs), particularly SDG 2 on Zero Hunger and SDG 3 on Good Health and Well-being, provide a global framework for addressing nutrition and health challenges.[85]

The findings of the present study have important implications for nutrition and dietetics practice in Vietnam and globally. The study highlights the relevance of considering multiple dimensions of sustainable diets, including economic, human health and socio-cultural/political aspects. It reveals that longer distance to food outlets is associated with higher diet quality, whereas lower food outlet density is linked to higher odds of underweight among women. This presents a challenge in balancing modernisation and its adverse effects on sustainable food systems. A notable example is the trade-offs between modern retails, especially hyper- and super-markets and fast-food restaurants and undesired effects such as the overconsumption of unhealthy food and nutrients,[23] the obesity pandemic and the increase in greenhouse gas emissions, as well as the degradation of land and water resources.[86,87] Vietnam's food systems offer a unique case study because local preferences still lean towards traditional cuisine over Westernised options. Traditional wet-markets remain the dominant retail landscape, serving as hubs for fresh food and social interaction.[73] To balance modernisation with public health and cultural preservation, policymakers should support traditional markets, enhancing their food safety practices and infrastructure. This ensures safe, fresh and affordable food for all. Additionally, curbing the aggressive marketing of ultra-processed foods can help reduce unhealthy nutrient consumption. These actions foster a healthier food environment at the same time as preserving Vietnam's culinary traditions and social fabric.[88] The findings about the association between education, nutrition knowledge and income with diet quality suggest key recommendations for nutrition practitioners and policy makers. First, prioritise nutrition education to improve knowledge of the drivers of the nutrition transition,[89] apply novel approaches to nutrition teaching in Vietnamese universities, and foster the learning and sharing experiences with professionals in other countries.[90] Second, address affordability and accessibility of healthier food options, particularly for individuals with lower incomes, through subsidies, incentives and food assistance programs. Third, collaborate with the food industry to regulate marketing of unhealthy foods, implement front-of-package labelling and restrict availability of ultra-processed foods. These actions can promote healthier food environments and support sustainable and healthy dietary patterns.

Limitations

We were able to conduct the present study as a result of the unique dataset that collected individual diets and malnutrition and neighbourhood food environment characteristics, which are all elements that could be linked together in the same dataset to undertake standard statistical analyses. However, our study also has several limitations. First, the cross-sectional nature of study design did not allow us to draw any causal inference between food environment indicators and diet quality, as well as nutritional status. Second, the dietary data was collected using the 24 h recall, which may not represent the long-term dietary habits of the participants. For example, episodically consumed food could be misrepresented, which might explain the insignificant relationship between diet quality and nutritional status. However, we attempted to estimate the usual intake by the MSM method to account for between- and within-person variability as much as possible. Third, because this is the first time that the DQI-I was applied to assess diet quality in Vietnam, we were unable to evaluate its validity and credibility; therefore, it may not accurately reflect the diet quality in Vietnamese adults. This said, we did customise the international indicator to adapt to the Vietnamese Dietary Guidelines. Fourth, when stratifying by gender, the sample size became smaller with small cell size; for example, there were less than 10 cases per predictor variable in the logistic regression, which may have made the logistic regression model unstable. This small sample size issue might also affect the study power with respect to detecting an effect when there is one to be detected. Fifth, as a result of data limitations, we did not disaggregate food environment characteristics into different types of food outlets (such as traditional, modern and restaurants). This might also affect the model results. Finally, although we adjusted for several common confounding factors, other more complex factors were not considered, such as lifestyle choices, exercise status, asset ownership and food choice behavior.

CONCLUSIONS

Vietnam is undergoing diet and nutrition transition as a result of complex interactions within the food systems shaped by changes in a range of drivers, including natural resources, climate, innovation, technology, infrastructure, political and economic drivers, and socio-cultural and demographic drivers. These transformations do not occur at the same pace across the country, resulting in both opportunities and challenges in balancing between modernisation and combating adverse effects from these changes to build sustainable food systems. Opportunities include lessons learnt from other countries that have experienced these transformations in their food systems, early interventions to avoid undesirable effects in diet quality and malnutrition, and advantages of the unique co-existence of local food systems and exporting food systems.[88]

We recommend the following future research improvements: testing the validity and credibility of the DQI-I in the Vietnam context; including the measurement of frequency and quantity of episodic food consumption to have a more accurate estimate of usual intake; including other potential factors such as physical activity, smoking history, health record, television and refrigerator ownership; increasing the sample size; and finally integrating both quantitative and qualitative research method to gain a broader and more accurate picture about the relationship of food environments, diet quality and malnutrition.

AUTHOR CONTRIBUTIONS

All authors contributed to the study and analytical design, interpretation, and writing. TTTH and KNT conceived, designed, and oversaw data collection for the baseline study. KJF, HTT, TTTH, ADJ, CKK and VTV designed the analysis. KTH and VTV performed data cleaning. VTV performed the primary statistical analysis. VTV, HTT, ADJ, CKK and KJF contributed to the original draft preparation. All authors have read and approved the final version of the manuscript submitted for publication.

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CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest.

DATA AVAILABILITY STATEMENT

The datasets that support the findings of this study are available from the from the Alliance of Bioversity and CIAT – Asia Office upon reasonable request. This study used cross-sectional data collected among individuals in the Northern part of Vietnam from July to September 2018, as part of the Partial Food Systems Baseline Assessment at the Vietnam Benchmark Sites project (Reference no. 26: Huynh TTT, Pham HTM, Trinh HT, Duong TT, Nguyen TM, Hernandez R, et al. Partial Food Systems Baseline Assessment at the Vietnam Benchmark Sites [Internet]. Hanoi; 2021. Available from: https://hdl.handle.net/10568/113122). The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available as a result of privacy or ethical restrictions.

ETHICS STATEMENT

The Medical Research Ethics Committee of the National Institute of Nutrition (NIN) in Vietnam approved the protocols of the "Partial Food Systems Baseline Assessment at the Vietnam Benchmark Sites" project (Number 223/VDD-QLKH). This study protocol has been granted exemption from Cornell Institutional Review Board for Human Participants (IRB) review according to Cornell IRB policy and under paragraph(s) 4 of the Department of Health and Human Services Code of Federal Regulations 45CFR 46.104(d). The researchers obtained written consent from all study participants prior to data collection.

TRANSPARENCY DECLARATION

The lead author affirms that this manuscript is an honest, accurate, and transparent account of the study being reported. The reporting of this work is compliant with STROBE guidelines. The lead author affirms that no important aspects of the study have been omitted and that any discrepancies from the study as planned have been explained.

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PEER REVIEW

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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