Development and Application of Novel Indicators to Measure Diet Quality and Affordability of Healthy Diets in Vietnam

Van Thi Thuy Duong

Propositions

1. Making healthy diets affordable for all is not only a technical but also a political challenge.
   (this thesis)

2. Calcium deficiency among Vietnamese adults cannot be solved yet.
   (this thesis)

3. Research participants in low-and-middle-income countries should be included in all aspects of the research, and not just as research subjects.

4. Investing in research capacity in low-and-middle-income countries is critical to solving the burden of malnutrition.

5. Research publications do not fully reflect the capacity of a researcher.

6. Nourishing ourselves with righteous thoughts is as important as consuming healthy foods.

7. Being a PhD is not about conquering the title but discovering oneself.

Propositions belonging to the thesis, entitled
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Thesis

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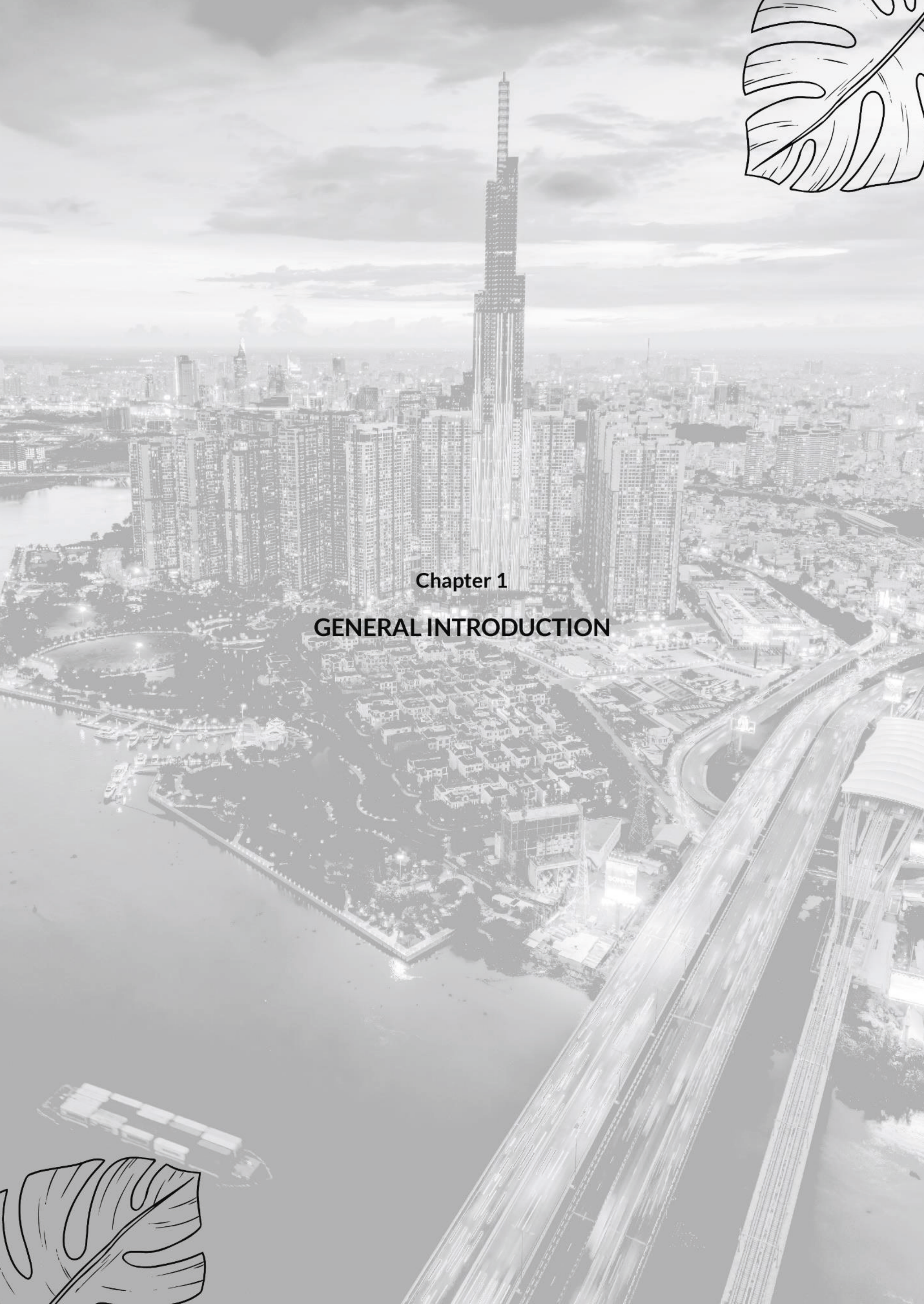
To Dad, Mom, Sister, Brothers, and Tin,

TABLE OF CONTENTS

ABBREVIATIONS

24HR	24-hour recall
24HR-CAPI	24-hour recall using the computer-assisted personal INDDEX24 platform
24HR-PAPI	24-hour recall using a pen-and-paper questionnaire
A4NH	CGIAR Research Program on Agriculture for Nutrition and Health
AME	Adult Male Equivalent
AFE	Adult Female Equivalent
AHEI-2010	Alternative Healthy Eating Index 2010
AI	Adequate Intake
aMED	alternate Mediterranean Diet Score
BMI	Body Mass Index
CI	Confidence Interval
CIAT	The International Center for Tropical Agriculture
CPI	Consumer Price Index
CPI_{Food}	Consumer Price Index for foods
CoHD	Cost of a Healthy Diet
CoNA	Cost of Nutrient Adequacy
CotD	Cost of the Diet
DASH	Dietary Approaches to Stop Hypertension
DHA	Docosahexaenoic Acid
DHD-index	Dutch Healthy Diet index
DHD15-index	Dutch Healthy Diet index 2015
FBDGs	Food-based dietary guidelines
E %	Energy Percentage
EARs	Estimated Average Requirements
EPA	Eicosapentaenoic Acid
FCT	Food Composition Table
FFQ	Food Frequency Questionnaire
GDP	Gross Domestic Product
GDQS	Global Diet Quality Score
GDR	Global Dietary Recommendations score
GHG	Greenhouse Gas
GNS	General Nutrition Survey
GSO	General Statistical Office

HEI	Healthy Eating Index
HEIC-2009	Canadian Healthy Eating Index
HEIFA-2013	Healthy Eating Index for Australian Adults
INDDEX	International Dietary Data Expansion
IMMANA	Innovative Methods and Metrics for Agriculture and Nutrition Actions
IFPRI	International Food Policy Research Institute
IPSARD	Institute for Policy and Strategy for Agriculture and Rural Development
IOM	The US Institute of Medicine
IQR	Interquartile Range
LMICs	Low- and middle-income countries
LOA	Limits of Agreement
MED	Mediterranean Diet Score
MDD-W	Minimum Dietary Diversity indicator for Women
MPA	Mean of Nutrient Adequacy
NHANES	National Health and Nutrition Examination Survey
NIN	National Institute of Nutrition
NCDs	Noncommunicable diseases
PA	Probability of Adequacy
PCA	Principal Component Analysis
PPP	Purchasing Power Parity
RAE	Retinol Activity Equivalents
RDA	Recommended Dietary Allowance
SD	Standard Deviation
SGD	Sustainable Development Goals
SHiFT	CGIAR Initiative on Sustainable and Healthy Diets through Food System Transformation
STL	Seasonal-trend Decomposition model
UN	United Nations
USDA	The United States Department of Agriculture
VASS	Vietnam Academy of Agriculture Sciences
VHEI	Vietnamese Healthy Eating Index
VHLSS	Vietnam Household Living Standard Survey
VND	Vietnamese Dong
WFR	Weighed Food Record
WHO	World Health Organization



Chapter 1

GENERAL INTRODUCTION

PROBLEM STATEMENT

Healthy diets play a crucial role in achieving adequate nutrition and better health(1); however, approximately three billion people cannot afford healthy diets worldwide, most of whom live in Africa and Asia(2). Consequently, sub-optimal diets are directly responsible for the burden of malnutrition in all its forms(3). The World Health Organization (WHO) estimates that 1.9 billion adults are overweight or obese, while 462 million are underweight(4). Undernutrition is still a major public health issue in low-and middle-income countries (LMICs), where it may be seen in its more severe forms(5), whereas in the same countries obesity and diet-related noncommunicable diseases (NCDs) have increased substantially(6). Deaths caused by low-quality diets have increased by 15% since 2010 and are estimated to attribute to more than 12 million NCD deaths in adults(7). Notably, over three-quarters of NCD deaths occurred in LMICs, according to the WHO NCDs mortality estimations in 2016(6).

These challenges call for more effective research and interventions in food systems to ensure access to and consumption of healthy diets for better nutrition and health outcomes in LMICs(8). Improving food systems for healthier diets requires monitoring the essential elements of the food systems, for example measuring diet quality and affordability of healthy diets(9; 10; 11). These indicators help fill in the knowledge gap to understand the causes of malnutrition, offer insights necessary to facilitate effective interventions, and inform policy options to support food security and nutrition(10; 12). However, they are still absent, especially in LMICs, leading to a lack of recent data on the quality of diets consumed by their populations and data on aspects of access to healthy diets, such as affordability(13; 14). Therefore, it is urgent to develop and apply these indicators in LMICs.

Vietnam is the local food system focused on in this thesis. Like most other LMICs, Vietnam has experienced a marked nutrition transition(15). The traditional Vietnamese diets are typically low in fat, with small amounts of meat and fish, and rich in vegetables(16; 17). However, in recent decades the Vietnamese dietary patterns have been changing towards diets with higher energy intake, processed foods (including instant noodles and sweetened non-alcoholic beverages), and animal source foods, as well as lower consumption of fresh fruit, vegetables and seafood[18; 19]. The increased consumption of animal source foods in Vietnam is striking, leading to a considerable increase in fat intake, especially saturated fats[20]. From 1985 to 2010, the percentage of food intake from animal sources rose from 12% to 21%, per capita daily meat consumption increased from 11g to 84g, and per capita oils and fats consumption increased 500%, while per capita daily vegetable consumption decreased from 214g to 190g[19; 20]. Vegetable and fruit consumption is still inadequate; approximately 80% of Vietnamese adults consume less than five portions of fruits and vegetables per day[19; 20]. These dietary changes have been driven in part by urbanization and changes in the food environment[21]. Vietnam has developed as a more market-oriented economy, with Gross Domestic Product (GDP) growth averaging 6.4% from 1985 to 2017 and a rapid rise in internal migration from rural to urban areas[22; 23]. The increasing availability of animal source food (i.e., pork) beginning in the early 1990s is also responsible for most of the increase in energy intake from animal sourced foods[21]. These dietary changes are also accompanied by changes in nutrition and health outcomes of the population. From 1980 to 2013, the prevalence of overweight and obesity doubled from 6.2% to 12.3% among adult women and tripled among adult men from 4.3% to 13.6% (aged ≥ 20 years), and these prevalence continue to rise[19]. NCDs such as cardiovascular diseases, cancers, chronic respiratory diseases, and diabetes are largely responsible for the country's disease burden[15; 19]. The diet quality of the population is clearly under threat, thus necessitating national food policies or nutritional programmes to improve outcomes through effective interventions.

LITERATURE REVIEW

Diet quality and studying the overall diet

A quality diet has been defined as a diet that is both adequate in nutrients and protective against diet-related NCDs(24; 25). Generally, there are two main strategies for assessing the overall diet and its quality(26). First, the *a priori* approach uses prior nutrition knowledge (i.e., guidelines for a healthy diet or evidence on diets known to be healthy) to construct diet quality indices(26). Second, the *a posteriori* approach derives dietary patterns from collected dietary intake data. These empirically derived dietary patterns provide insights into the current diets consumed by the population under study, which might not be the ideal diet from a health perspective, but can be used in public health interventions or in nutritional epidemiology research to explain the relationships between nutrition, health outcomes, and other related factors(26). There is also a *hybrid* approach, which combines the two previous approaches, but this approach is out of the scope of this thesis(26; 27).

Development of diet quality indices

Several diet quality indices have been developed following the *a priori* approach based on disease-specific dietary guidelines or evidence from epidemiological research. For example, the DASH score is developed based on Dietary Approaches to Stop Hypertension (DASH) diet, which consists of a set of recommendations including increased consumption of whole grains, fruits and vegetables, low-fat dairy products, and nuts and reduced consumption of sweets, sodium, and red and processed meats and emerged as a healthy eating guideline(28; 29). The Mediterranean Diet Score (MED) is based on the traditional Mediterranean diet, adherence to which has been associated with several beneficial health effects(30).

International or national dietary recommendations are also commonly used as standards for developing the *a priori* diet quality indicators. The Global Diet Quality Score (GDQS) is a validated global standard indicator of diet quality, allowing a simple way to measure diet quality in terms of both nutrient adequacy and diet-related NCDs and to compare diet quality between the countries(31; 32). The Global Dietary

Recommendations (GDR) score[33] is developed based on the WHO's global recommendations for a healthy diet[34]. The GDR score is calculated from food group consumption data using a low-burden survey questionnaire asking about foods consumed in the previous day, with "yes" or "no" questions for the intake of relevant food groups. This type of indicator enables an effective way to monitor diet quality in low-resource settings, such as LMICs, which still lack the financial and technical capacity for quantitative dietary intake surveys[33]. Recently, the EAT-Lancet index was developed based on the results of the EAT-Lancet Commission on healthy diets from sustainable food systems, the first global reference diet to consider both environmental sustainability and diet-related NCDs prevention[35].

In general, national dietary recommendations that consider the country's specific dietary habits are the so-called food-based dietary guidelines (FBDGs)[36]. They are official dietary guidelines published by governments in many countries' to serve their public health education and nutrition programmes[36]. A range of country-specific diet quality indicators is available, all developed from national FBDGs for assessing the overall diet quality of their population. For example, different versions of the Healthy Eating Index (HEI), including HEI[37]; HEI-2005[38]; HEI-2010[39]; HEI-2015[40], have been developed based on the Dietary Guidelines for Americans and are among the most well-known country-specific diet quality indices. Other examples include the Dutch Healthy Diet index (DHD-index), which was developed based on the Dutch Guidelines for a Healthy Diet[41], and the Japanese Food Guide Spinning Top score, which is based on the national Japanese Food Guide[42].

The Vietnamese FBDGs are developed by the National Institute of Nutrition (NIN), Ministry of Health, Vietnam, and serve as material to promote healthy diets and as a basis for guidance on developing food and agriculture policies[43; 44]. The first versions were published in 1995 and have been revised every five years since[43; 44]. The most recent versions of the Vietnamese FBDGs (2016-2020) were developed based on the 2016 Vietnamese recommended dietary allowances, the report '*Ten tips on proper nutrition for the period 2011-2020*' in Vietnam, and the results from studies on nutrition and health in the country, with adaptation from the international guidelines on nutrition and physical activity[45]. Different versions for different sub-groups of the population have been developed, including adults (aged ≥ 20 years), pregnant and lactating women, and children (two guidelines for children aged 3-5 years and 6-11 years) and adolescents (two guidelines for adolescents aged 12-14 years and 15-19 years). However, no indicator is currently in use that assesses the adherence to these FBDGs and the diet quality of Vietnamese populations.

Evaluation of diet quality indices

The development process of any diet quality index must incorporate a comprehensive evaluation strategy[26; 46]. This strategy should address validity (i.e., construct validity, content validity), reliability, comparability to other dietary assessment methods (known as relative validity), and validity against health outcomes (known as criterion validity). In the literature, the HEI is a perfect example of a well-evaluated diet quality index, of which different versions have been evaluated in terms of their content, construct, criterion validity, and reliability[47; 48; 49].

Reliability is the consistency of a measure, i.e., the extent to which the index measures similarly each time. Two methods are commonly used: test-retest reliability and internal consistency[50]. Test-retest reliability is determined by repeating the measure. Internal consistency can be evaluated by calculating the Cronbach's coefficient alpha, which represents the degree to which the multiple components within a diet quality index measure the same underlying, unidimensional, latent construct[50].

Construct validity is a quantitative examination on the extent to which the index measures what it is supposed to measure (i.e., adherence to the FBDGs)[49]. This type of validity can include evaluating whether the index can distinguish between subpopulations with known differences in the quality of their diets (for example, findings from other studies that men have poorer quality diets than women, young adults have poorer quality diets than older adults, and current smokers have poorer quality diets than non-smokers[49; 51]), assessing whether the index can measure diet quality independent of diet quantity, or evaluating whether the index can yield a wide range to end up with a score that is able to discriminate between individuals[47; 48; 49].

Criterion validity is the evaluation of the index's ability to predict health outcomes. Harmon and colleagues proved that the HEI-2010, the Alternative Healthy Eating Index 2010 (AHEI-2010), the alternate Mediterranean Diet Score (aMED), and the DASH score were all inversely associated with risk of mortality from all causes, cardiovascular disease, and cancer in US adults(52). Kurotani *et al.* showed that a higher Japanese Food Guide Spinning Top score was associated with a lower risk of total mortality and mortality from cardiovascular disease, particularly from cerebrovascular disease, in Japanese adults(42). These are a few examples of well-evaluated indices in terms of examining the predictive criterion validity; however, the remaining diet quality indicators have not been convincingly validated against health outcomes(25). These analyses require the use of cohort data, which are typically available in developed countries but are lacking in LMICs.

Relative validity is the comparability of a dietary index based on different dietary assessment methods. This analysis is important because measurement errors of the dietary assessment method will be reflected in the indices. For example, the Dutch Healthy Diet index 2015 (DHD15-index) derived from food frequency questionnaire (FFQ) data was compared with the DHD15-index derived from the 24HR(53), and the Healthy Eating Index for Australian Adults (HEIFA-2013) was applied and compared to the weighed food record (WFR) and FFQ data(54).

Derivation of dietary patterns

In order to follow the *a posteriori* approach, empirically derived dietary patterns are derived based on the existing dietary intake data using statistical techniques without prior assumptions. Two well-known methods can be distinguished, namely cluster analysis and factor analysis (principal component analysis, PCA, being the most widely adopted method)(55). Though other methods have also been used to obtain dietary patterns (i.e., reduced rank regression, treelet transform, and sparse latent factor models, amongst others)(56; 57; 58).

Dietary pattern analyses have been widely used in nutritional epidemiological research to examine the associations between empirically derived dietary patterns and nutrition and health outcomes, and to provide insights for further public health interventions[27]. For example, van Dam *et al.* used PCA to derive three dietary patterns (the cosmopolitan, traditional, and refined-foods patterns) among the general Dutch population[59]. These dietary patterns were found to be independently associated with blood pressure, plasma glucose, and cholesterol concentrations[59]. In the literature, research on the associations between empirically derived dietary patterns and nutrition-related outcomes includes diet-related NCDs[60] and nutritional status[61; 62; 63]. Studies have explored the relationships between derived dietary patterns with not only nutrition and health outcomes but also other factors such as the cost of diets. Lopez *et al.* used PCA to find that the healthy diet (Mediterranean pattern) is more expensive to follow than the less healthy one (Western pattern)[64]. The *a posteriori* approach has also been used recently to study the environmental impacts of dietary patterns in Vietnam[65].

Cost and affordability of healthy diets

Accomplishing the United Nations (UN) Sustainable Development Goal 2-Zero Hunger will only be achievable if people have enough foods to meet dietary needs and the diets they consume are healthy and affordable[1]. For the first time, the cost and affordability of healthy diets have now been included as a critical element of food security in the *'State of Food Security and Nutrition in the World 2020'* report[66]. Therefore, data for the cost and affordability of healthy diets are needed to fill in the knowledge gap of one of the core principles embedded in the definition of food security[11].

Following this demand, research on the cost and affordability of healthy diets has gained momentum in recent years. Global research across 170 countries in the *'Cost and affordability of healthy diets across and within countries'* published by the Food and Agriculture Organization (FAO) of the UN[2] showed the high cost of healthy diets, and indicated that an staggering number of people (three billion) cannot afford healthy diets[2]. Another global study using retail prices of 177 countries showed that nutrient adequacy is out of reach for the world's poorest populations (measured by the Cost of

Nutrient Adequacy, CoNA, a nutrient-based indicator)(67). The EAT-Lancet reference diet is also not affordable for many of the world's low-income populations(68). Together with these global analyses, country-specific analyses on the cost of healthy diets and affordability have been explicitly conducted for some countries, such as India(69), Nigeria(70), Myanmar(71), Tanzania(2), Malawi(2), using their own national food price databases. These national or local analyses are important to help inform local interventions and facilitate systemic innovations, as each local food system has faced unique challenges and resource constraints. So far, though, no such analyses have been conducted in Vietnam.

Various methods and indicators have been developed and applied to perform the cost of a healthy diet measurement. The oldest method was created by Stigler in 1945 and used linear programming to select a diet from a list of foods that minimizes the cost of meeting a set of nutrients(72). Following a similar concept, the Cost of Nutrient Adequacy (CoNA) indicator was recently developed by Masters *et al.* in 2018 to measure the least-cost diets based on nutrient requirements(73). The Cost of the Diet (CotD) was developed by Save the Children to apply linear programming to choose a combination of local foods that meet the average needs for energy and nutrients at the lowest cost(74). The Cost of a Healthy Diet (CoHD) indicator was developed by Herforth *et al.*(2; 11) and is a straightforward indicator for measuring the total lowest daily cost of consuming a healthy diet recommended by the country's FBDGs which sums the average cost of recommended quantities from each food group. The cost of each food group is measured by averaging the two lowest-cost foods (except for the vegetables group that uses three food items requiring leafy green vegetables as a third food item in the group) (2; 11).

The affordability of a healthy diet characterises economic access, indicating whether sufficient quantities of each food group could be acquired based on different standards (i.e., income, food expenditure)(11). Herforth *et al.* used multiple indicators to determine affordability, in which the cost of a healthy diet is calculated relative to a standard of the international poverty line, food expenditures, income, the number of people in each country who cannot afford a healthy diet, and rural wages(2; 11). The affordability indicators have been applied for the global analysis[2] or for several country's specific analyses in Africa[70] and Asia[69; 75].

OBJECTIVES AND OUTLINE OF THE THESIS

This thesis aims to fill in the data of diet quality and access to healthy diets gap by generating the essential tools for assessing the diet quality and the cost and affordability of healthy diets in Vietnam. Following the overall objective, the specific objectives are: 1) to develop, evaluate, and apply the Vietnamese Healthy Eating Index (VHEI) as a measure of diet quality assessing adherence to the 2016-2020 Vietnamese FBDGs for the general Vietnamese population; 2) to study Vietnam's empirically derived dietary patterns concerning diet quality and cost; 3) to estimate the cost and affordability of healthy diets recommended by FBDGs using the Cost of a Healthy Diet (CoHD) indicator. Based on these objectives, the chapters following this general introduction are organised as indicated below.

Chapter 2 follows the *a priori* approach to construct the Vietnamese Healthy Eating Index (VHEI) as a diet quality indicator for the general Vietnamese population. The VHEI quantifies healthiness based on the 2016-2020 Vietnamese FBDGs, defined by the National Institute of Nutrition (NIN), Ministry of Health, Vietnam. The study in this chapter uses dietary intake data of a large national representative sample, the Vietnamese General Nutrition Survey 2009-2010, where food consumption data of 8,225 households are converted to individual dietary intake data.

Chapter 3 focuses on the evaluation of the VHEI regarding its reliability and validity (including construct, criterion, and relative validity). The novelty in evaluating the VHEI is its relative validity when it is derived from different dietary assessment methods, including weighed food record as a benchmark and 24-hour individual dietary recalls using the computer-assisted personal INDDEX24 platform or a pen-and-paper questionnaire. This chapter also provides an application of the VHEI in a national representative sample and a sample of a validation study and studies how diet quality is related to nutritional outcomes. The study uses dietary intake data from the Vietnamese General Nutrition Survey 2019-2020 (n=3,528) and a sample (n=212 women) of a validation study conducted as part of the International Dietary Data Expansion (INDDEX) Project's validation of the INDDEX24 Dietary Assessment Platform.

Chapter 4 follows the *a posteriori* approach to study the empirically derived dietary patterns consumed by Vietnamese adults and their associations with sociodemographic characteristics, nutrient intakes, diet quality, and diet cost. The study in this chapter links the Consumer Price Index food price database to the most recent dietary intake data of a large national representative sample, the Vietnamese General Nutrition Survey 2019-2020 (n=3,528). Different indicators are used to assess and compare the overall diet quality of derived Vietnamese dietary patterns, including the global index (GDQS) and the national index (VHEI). The mean of nutrient adequacy using the probability approach, renowned for being the most accurate method to assess the adequacy of nutrient intakes(76), is also applied as another diet quality indicator in this chapter.

Chapter 5 aims to estimate the cost and affordability of the healthy diets recommended by the 2016-2020 Vietnamese FBDGs. The lowest cost of meeting the healthy diets is calculated using the CoHD indicator and is compared by food group, region, and seasonal variation. The affordability of healthy diets is assessed using standards of households' income and food expenditures. This study made use of the Consumer Price Index food price database from January 2016 to December 2020 for the calculation of the cost of healthy diets and the three latest Vietnamese Household Living Standard Surveys in 2016, 2018 and 2020 for the calculation of the households' income and food expenditures.

Finally, the last chapter of this thesis provides a general discussion of the thesis's main findings, the methodological considerations, the implementations of the results, the limitations and strengths, and recommendations for future research.

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Landmark 81 building in Ho Chi Minh City, together with Saigon bridge and other buildings along the Saigon River, cityscape at night.

Chapter 2

DEVELOPMENT OF THE VIETNAMESE HEALTHY EATING INDEX

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ABSTRACT

Poor diet quality is a major contributor to malnutrition and disease burden in Vietnam, necessitating the development of a tool for improving diet quality. Food-based dietary guidelines (FBDGs) have been proposed to do this by providing specific, culturally appropriate, and actionable recommendations. We developed the Vietnamese Healthy Eating Index (VHEI) to assess the adherence to the 2016-2020 Vietnamese FBDGs and the diet quality of the general Vietnamese population. This VHEI consists of eight component scores, “grains”, “protein-rich foods”, “vegetables”, “fruits”, “dairy”, “fats and oils”, “sugar and sweets”, and “salt and sauces”, representing the recommendations in the FBDGs. Each component score ranges from 0 to 10, resulting in a total VHEI score between 0 (lowest adherence) and 80 (highest adherence). The VHEI was calculated using dietary intake data from the Vietnamese GNS 2009-2010 (n=8,225 households). Associations of the VHEI with sociodemographic characteristics, energy and nutrient intakes, and food group consumptions were examined. The results showed that the mean ± standard deviation (SD) score of the VHEI was 43.3 ± 8.1. The component “sugar and sweets” scored the highest (9.8 ± 1.1), while the component “dairy” scored the lowest (0.6 ± 1.6). The intake of micronutrients was positively associated with the total VHEI, both before and after adjustment for energy intake. In conclusion, the VHEI is a valuable measure of diet quality for the Vietnamese population regarding their adherence to the FBDGs.

Key words: diet quality, food-based dietary guidelines, Healthy Eating Index, Vietnamese adults

INTRODUCTION

Focusing on dietary patterns rather than on single foods or nutrients has been recommended in the literature as a more appropriate approach for exploring the relationships between diets and noncommunicable diseases (NCDs)[1; 2]. In recent years, scientific evidence on the relationships between diets and health outcomes has been translated into specific, culturally appropriate, and actionable recommendations in the form of FBDGs[3]. These dietary guidelines are developed and regularly updated to influence the target population's nutritional behaviour and, in some countries, to inform a range of national food, nutrition, and health policies and programs[3].

Association between adherence to the recommendations mentioned in the FBDGs and the related health outcomes should be examined to evaluate the potential impact of such FBDGs. For this purpose, a diet quality index is needed to assess adherence to the FBDGs[4; 5; 6]. This type of index has been developed in many countries based on their current national FBDGs [6; 7; 8] and has been used for various purposes, such as measuring the diet quality of populations at one point in time or over a period of time[9]; assessing changes in dietary patterns in a nutritional intervention[10]; examining the associations between diets and diseases[11] as well as the risk of mortality[8]; and combining environmental and other factors to assess the sustainability of foods and diets[12].

Poor diet quality is the main contributor to the burden of malnutrition and is one of the fundamental causes of morbidity and mortality worldwide, including Vietnam[13; 14]. In Vietnam, NCDs such as cardiovascular diseases, cancers, chronic respiratory diseases, and diabetes are main contributors to the disease burden, demonstrating the ongoing nutrition transition[15; 16]. Also the prevalence of overweight and obesity and hypertension in Vietnamese adults is increasing and in 2015 amount to 15.0 % for overweight and 20.0 % for hypertension[15]. The traditional Vietnamese dietary pattern is considered to be low in fat, including small amounts of meat and fish, and rich in vegetables, high in salt, and low in dairy[17]. However, the diets are quickly changing towards more unhealthy dietary patterns, with an increase in fat intake and meat consumption together with a decrease in vegetable intake[16; 17]. This trend calls for national food policies and nutritional interventions, and the development of Vietnamese FBDGs with critical messages and visual representations as a tool for nutritional education and communication is among the key actions in achieving this goal[18].

The Vietnamese FBDGs were first published in 1995 and have been revised every five years, aiming to promote healthy diets and serving as a basis for guidance on developing food and agriculture policies [18; 19]. The 2016-2020 Vietnamese FBDGs are developed for different populations, including adults, pregnant and lactating women, and children[19; 20]. These current guidelines are developed based on the 2016 Vietnamese recommended dietary allowances[21], the report *'Ten tips on proper nutrition for the period 2011-2020'* in Vietnam[19], and the results from studies on nutrition and health in the country, with adaptation from the international guidelines on nutrition and physical activity[22]. However, no index is currently in use that measures the adherence to these FBDGs to assess the diet quality of Vietnamese adults. Thus, the present study aimed to develop the VHEI as a measure of diet quality in terms of adherence to the 2016-2020 Vietnamese FBDGs for adults and to examine the associations between the VHEI and socio-demographic characteristics, energy and nutrient intakes, and food group consumptions of the study population.

SUBJECTS AND METHODS

Study population

The research described in this paper was based on an analysis of the Vietnamese GNS 2009-2010. This survey aimed to determine the nutritional status and household food consumption of the Vietnamese population. The GNS 2009-2010 survey was conducted in accordance with the guidelines laid down in the Declaration of Helsinki and was approved by National Institute of Nutrition (NIN), Ministry of Health, Vietnam. Written informed consent was obtained from the participants prior to data collection[(23)]. NIN permitted access to the dataset for the analysis of this study.

In the original GNS 2009-2010 survey, targeted households were selected by a stratified multi-stage cluster design across the six ecological zones in Vietnam. The sampling procedure of this survey has been described in more detail elsewhere[(23)]. The households included were those willing to participate and consisted of at least three members with one available adult responsible for food preparation, resulting in 8,386 households.

Dietary assessment

The dietary intake data for the previous 24 hours was collected by trained interviewers for each household. Briefly, food consumption was described by a representative household member who was responsible for preparing meals and beverages that all household members consumed. The edible portions, yield factors, and conversion factors of the food items were applied[(23)]. To conduct the analysis and present results based on the intake of one person instead of the whole household, the Adult Male Equivalent (AME) concept was first introduced[(24)]. Although this approach does reflect individual intake, the AME represents a proxy for intra-household food distribution. It has been validated and used widely to convert household intake data to the intake of a reference individual based on energy requirements[(25; 26)]. Studies have used the AME with Household Consumption and Expenditures Surveys data and found values were comparable to individual 24-hour recall (24HR) intake data[(24)]. However, since target groups in nutritional programmes are usually not the adult men but women of reproductive age, as they are amongst the most vulnerable groups and thus a highly relevant group of interest to include in research, the Adult Female Equivalent (AFE) referring to an adult non-pregnant non-lactating woman, 20-30 years, was used as suggested previously(27). In this study, we followed the AFE strategy to transform household food consumption into intake of a reference individual(24), with a correction based on the recommendations of the Human Energy Requirements(28) for all individuals in the households, considering their age and gender. AFE values of other household members were calculated by dividing their energy requirement by the energy requirement of the reference AFE per day and they were then summed up to obtain the total household AFE. Because information about age and gender was missing for members of 145 households, these households were deleted. Outliers were identified based on a Z-score value of less than -2.58 or more than 2.58 derived from energy intake, resulting in the deletion of 16 extreme outliers and leaving 8,225 observations in our final analysis.

The 2019 Vietnamese Food Composition Table (FCT)(29) was used as the primary source to estimate energy and nutrient intakes. Approximately 20% of the energy and nutrient values of 613 food items in the GNS 2009-2010 were missing and complemented with data from the 2017 Indian FCT(30), the 2015 Standard FCT in Japan(31), and the 2020 Food Data Central, The US Department of Agriculture (USDA)(32) (mentioned in order of use).

Development of the Vietnamese Healthy Eating Index

We created the VHEI to measure adherence to the 2016-2020 FBDGs for Vietnamese adults aged 20 years and older, with a higher score demonstrating higher adherence and thus higher diet quality. The eight component scores were developed to reflect the recommendations relating to the eight food groups of the FBDGs, including grains, protein-rich foods, vegetables, fruits, dairy, fats and oils, sugar and sweets, and salt and sauces. The information regarding the definition of servings of each food group and the foods to be included in each food group were derived from the graphic presentation (Supplementary Figure 2.S1), the official background document of the

2016-2020 Vietnamese FBDGs (written and published in Vietnamese)[22], and information provided by NIN. The graphic presentation is translated from Vietnamese into English and gathered with additional information from the official background document of the FBDGs in Supplementary Table 2.S1. The eight components were divided into adequacy, moderation, and optimum categories, with a different scoring system for each category as further described below.

Adequacy category

"Vegetables" and "fruits" are classified as adequacy categories. These food groups are considered healthy; thus, participants earn higher scores if they consume more of them. We modified recommended serving for vegetables and fruits to remove the upper limit of intake (described clearly below) in conforming to other scoring systems [8; 33].

Vegetables

The component "vegetables" was formulated based on the recommendation in the FBDGs that a Vietnamese adult should consume three to four servings of vegetables per day but was adapted to be three servings or more, with eighty grams of raw edible vegetables constituting one serving. Food items for this component encompassed all types of vegetables, including frozen and canned vegetables, mushrooms, and peas, but not legumes or potatoes. Vegetable juices were not included in this component due to the low fibre content. In the case of vegetable soup, vegetable broth was not classified as a vegetable, and we only counted the proportion of vegetables.

Fruits

The component "fruits" was formulated based on the recommendation in the FBDGs that a Vietnamese adult should consume three servings of fruits per day but was adapted to be three servings or more, with eighty grams of edible fruit constituting one serving. Food items for this component encompassed all types of fruits, including frozen fruit. However, dried fruit, canned fruit, fruit juices and fruit smoothies were not included in this component due to the high sugar content.

Scoring system for adequacy category

A minimum score of 0 was assigned when participants did not consume any items in this category. A maximum score of 10 was assigned when participants consumed equal to or more than the recommended servings. When participants consumed less than the recommended servings, the score was calculated with the formula:

$$\mathbf{10} \times \frac{\text{the consumed amount of servings}}{\text{the recommended amount of servings}}$$

Optimum category

"Grains", "protein-rich foods", "fats and oils", and "dairy" are classified as optimum categories as the intake should be within an optimal range. Thus, participants score lower if their intake is above the upper limit or below the lower limit of the optimal range.

Grains

The component "grains" was formulated based on the recommendation that twelve to fifteen servings of grains should be consumed daily, with one serving of "grains" containing 20g carbohydrate. Examples of one serving described in the FBDGs are 55g cooked rice, 37g bread or 95g potato. Food items included in this component are rice (plain rice, fried rice, broken rice, glutinous rice, porridge rice), bread (white bread or whole grain bread), noodles (rice-based noodles, wheat-based noodles, instant noodles), potato (white potato, sweet potato, Chinese yam) and corn. No distinction was made for whole grains in this component.

Protein-rich foods

The component "protein-rich foods" was formulated based on the recommendation that five to six servings of protein-rich foods should be consumed daily, with one serving of "protein-rich foods" containing 7g protein. Examples of one serving described in the FBDGs are 31g cooked pork, 42g cooked chicken, or 35g cooked fish. Food items included in this component are all types of fresh, frozen, or canned meat (whereby no distinction between red or white meat was made), fish, seafood, eggs, soybean products and other legumes (excluding peas) but not dairy products.

Dairy

The component “dairy” was formulated based on the recommendations that three to four servings of dairy and dairy products should be consumed daily, with one serving of “dairy” containing 100mg calcium. Examples of one serving described in the FBDGs are 100ml milk, 100g yogurt, 15g cheese. Food items included in this component were milk, milk powder, yogurt, and cheese, whereas sugar-sweetened dairy (condensed milk) and soya milk were not included.

Fats and oils

The component “fats and oils” was formulated based on the recommendation that five to six servings of fats and oils should be consumed daily, with one serving of “fats and oils” containing 5g total fat. Food items included in this component were cooking oil, vegetable oil, animal fat, butter, margarine, nuts, and seeds.

Scoring system for optimum category

A maximum score of 10 points was assigned if participants consumed within the optimal range. When participants consumed less than the lower limit of the optimal range, the score was calculated with the formula:

$$\mathbf{10} \times \frac{\text{the consumed amount of servings}}{\text{the lower limit of the recommended range}}$$

When participants consumed more than the upper limit of the optimal range, the score was calculated with the formula:

$$\mathbf{10} - \frac{\mathbf{10}\ \times\ (\text{the consumed amount of servings}\ -\ \text{the upper limit of the recommended range})}{\text{the upper limit of the recommended range}}$$

Moderation category

“Sugar and sweets” and “salt and sauces” are classified as moderation categories. These food groups are considered unhealthy; thus, participants earn higher scores if they consume less of them.

Sugar and sweets

The component "sugar and sweets" was formulated based on the recommendation that less than five servings of sugar and sweets should be consumed daily, with one serving of "sugar and sweets" containing 5g sugar. Examples of one serving described in the FBDGs are 5g table sugar, 6g honey and 8g candy. Food items included in this component were added sugar, sugar-containing products such as candy, cakes, biscuits and desserts, sugar-sweetened dairy (condensed milk), and sugar-sweetened soft drinks. Instant drink powders (coffee, cocoa, orange flavour, etc.), dried or canned fruit, fruit juices and smoothies were also included due to their high sugar content.

Salt and sauces

The component "salt and sauces" was formulated based on the recommendation that less than one serving of salt and sauces should be consumed daily, with one serving of "salt and sauces" containing 5g of table salt (equal to 1,938mg of sodium in seasonings and sauces). Examples of one serving described in the FBDGs are 8g seasoning powder, 25g fish sauce or 35g soy sauce. Food items included in this component were table salt, salt-containing products such as seasoning powder, fish sauce, soy sauce and chilli sauce, added during cooking or at the table.

Scoring system for moderation category

A maximum score of 10 points was assigned when participants consumed less than the recommended servings. When participants consumed more than the recommended servings, the score was calculated with the formula:

$$\mathbf{10} - \frac{\mathbf{10} \times (\text{the consumed amount of servings} - \text{the recommended amount of servings})}{\text{the recommended amount of servings}}$$

The scores of the eight components would be rounded off to the nearest whole number and capped at 0 if the calculations provided a negative score. They were then summed up to obtain a total VHEI score ranging from 0 (the lowest adherence to the Vietnamese FBDGs) to 80 (the highest adherence to the Vietnamese FBDGs). An overview of eight component scores and their cut-off values (maximum score) and threshold values (minimum score) are summarised in **Table 2.1** and visually illustrated in **Figure 2.1,** which is adapted from the study by Looman *et al.*[34].

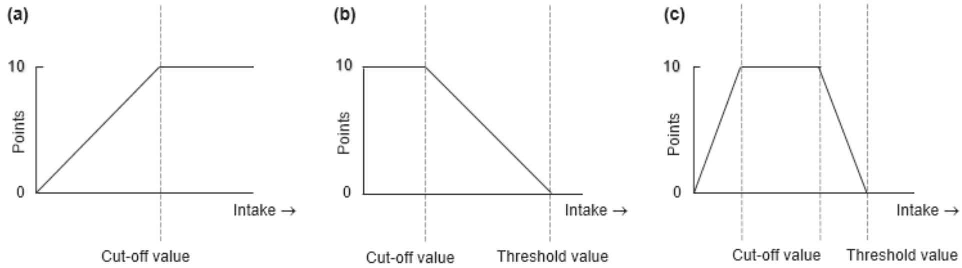

Figure 2.1. Graphic presentation of the Vietnamese Healthy Eating Index for (a) adequacy category, (b) moderation category, and (c) optimum category

Table 2.1. Operationalization of the Vietnamese Healthy Eating Index

Components of the VHEI*	Cut-off value (minimum score = 0 points)	Scoring between 0 and 10 points	Threshold value (maximum score = 10 points)
Adequacy category			
Vegetables	0	>0 – <3	≥3
Fruits	0	>0 – <3	≥3
Optimum category			
Grains	0 or ≥30	>0 – <12 or >15 – <30	12 – 15
Protein-rich foods	0 or ≥12	>0 – <5 or >6 – <12	5 – 6
Fats and oils	0 or ≥12	>0 – <5 or >6 – <12	5 – 6
Dairy	0 or ≥8	>0 – <3 or >4 – <8	3 – 4
Moderation category			
Sugar and sweets	≥10	≥5 – <10	<5
Salt and sauces	≥2	≥1 – <2	<1

VHEI, Vietnamese Healthy Eating Index, with a range from 0 to 80 points.
* Data is presented in serving.

Statistical analysis

Sample weights of primary sampling units in the survey design were applied as provided by NIN[23]. Data were presented as mean and standard deviation for continuous variables and as percentages of participants for categorical variables. Mean across tertiles of the VHEI score were compared using P-value for trend based on general linear models to examine the associations between the total VHEI score and the socio-demographic characteristics, energy intakes, nutrient intakes, and food group consumption. Concordance of ranking of participants based on their adherence using the VHEI was examined by calculating Spearman's rank correlation coefficients. Nutrient intake was reported with and without energy adjustment. Adjusted macronutrient intake was presented as energy percentage (E %), and adjusted micronutrient intake was presented as mean intake per 1,000 kcal. All statistical analyses were performed using the statistical software package Stata version 15, and a *P-value* of less than 0.05 was considered statistically significant.

RESULTS

The mean score of the VHEI was 43.3 ± 8.1 and ranged from 12.7 to 72.1 out of a possible total of 80. The highest mean score was observed for sugar and sweets (9.8 ± 1.1) followed by grains (8.1 ± 2.3), whereas the lowest mean score was found for dairy (0.6 ± 1.6) followed by fruits (1.8 ± 3.1). The mean score of fats and oils was also low, with a mean of 3.1 ± 2.9. The scores of protein-rich foods, vegetables, and salt and sauces were 6.0 ± 3.1, 6.9 ± 2.9, and 7.0 ± 3.8, respectively. The mean scores of each component across tertiles of the VHEI is presented in **Figure 2.2**. All the component scores showed significant positive trends across tertiles of the VHEI as examined by the general linear model (*P-value* for trend <0.001).

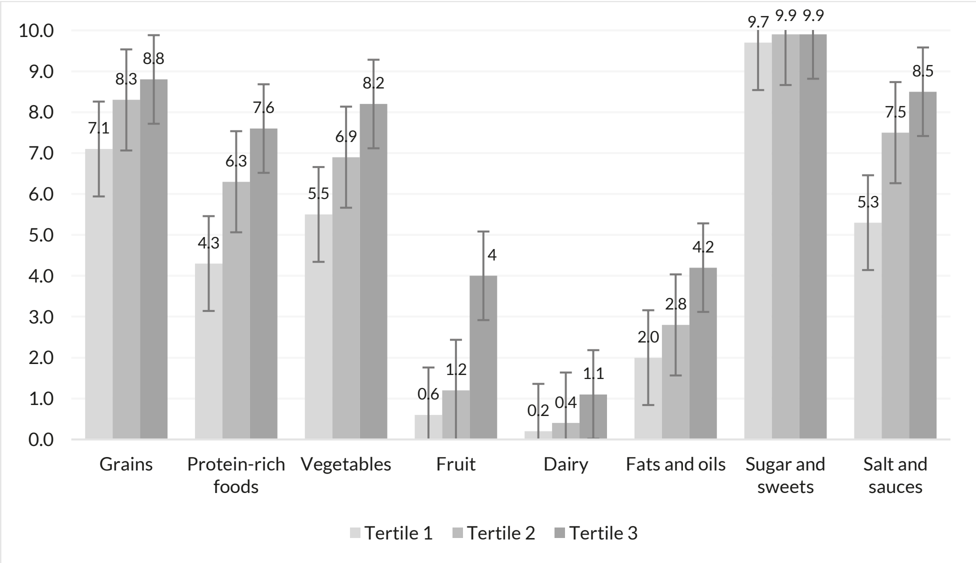

Figure 2.2. Mean component scores across tertiles of the Vietnamese Healthy Eating Index (Tertile 1 = lowest score = lowest adherence = lowest diet quality), means adjusted for sample weights

There was a significant association between the VHEI and region, as shown in **Table 2.2.** In the highest tertile of the VHEI large part of the households were from the Red River delta (28.8%), while in the lowest tertile of the VHEI more households were from the Northern and central coastal areas (33.2%), followed by Mekong River delta (25.0%). Approximately 50% of the participants in the first tertile were from the two lowest income groups, while more than 50% of the participants in the third tertile were from the two highest income groups.

Table 2.2. Sociodemographic characteristics of participants in the Vietnamese General Nutrition Survey 2009-2010 (n = 8,225) across tertiles of the Vietnamese Healthy Eating Index

Sociodemographic characteristics*	Tertiles of total VHEI score			*P-value*†
	T1 (n = 2742)	T2 (n = 2742)	T3 (n = 2741)	
Regions (%)				<0.001
Red River delta	13.5	19.7	28.8	
Northern midlands and mountain areas	13.6	19.3	18.0	
Northern and central coastal areas	33.2	25.3	17.0	
Central highland	7.1	4.9	4.1	
Southeast	7.6	11.6	18.4	
Mekong River delta	25.0	19.2	13.7	
Household income (%)				<0.001
Lowest	22.9	15.0	10.0	
Second	24.8	21.0	11.5	
Third	19.4	22.8	19.4	
Fourth	19.9	23.2	23.4	
Highest	13.0	18.0	35.7	

VHEI, Vietnamese Healthy Eating Index, with a range from 0 to 80 points. T, Tertile (T1 = lowest score = lowest adherence = lowest diet quality).
* Data is presented in percentage (%), adjusted for sample weights.
† *P-value* for trend analysed by general linear model.

Over the tertiles, no clear difference in energy intake was observed, as presented in **Table 2.3.** The VHEI was positively associated with the intake of protein, dietary fibre, total fat, and monounsaturated, polyunsaturated, and saturated fatty acids. These positive associations remained unchanged after adjustment for energy intake. For carbohydrate intake, an inverse trend across tertiles of the VHEI was observed both before and after adjusting for energy intake. There were moderate positive correlations between the VHEI and intake of protein, dietary fibre, total fat, and fatty acids, both before and after energy adjustment (r_s ranged from 0.23 to 0.36). There was a negative correlation between the VHEI and carbohydrate intake, with a poor correlation before energy adjustment and a moderate inverse correlation after energy adjustment (r_s -0.08 and r_s -0.35, respectively). The correlation between the VHEI and energy intake was weak, with $r_s = 0.06$.

Table 2.3. Daily macronutrient intake of participants in the Vietnamese General Nutrition Survey 2009-2010 (n = 8,225) across tertiles of the Vietnamese Healthy Eating Index

Macronutrients* (AFE/day)	Tertiles of total VHEI score						*P-value*†	r_s
	T1 (n = 2742)		T2 (n = 2742)		T3 (n = 2741)			
Energy intake (kcal)	1917	860.3	1814	563.4	1939	454.0	0.958	0.06‡
Macronutrient intake (g)								
Protein	67.1	36.6	68.8	26.9	74.9	20.2	<0.001	0.23‡
Carbohydrate	339.3	155.4	305.7	100.9	310.6	76.5	0.001	-0.08‡
Dietary fibre	5.2	3.9	5.6	3.8	7.3	3.8	<0.001	0.28‡
Total fat	30.5	32.8	33.2	23.7	41.7	23.4	<0.001	0.32‡
Saturated fat	9.4	13.1	10.0	8.1	12.3	8.2	0.001	0.29‡
Monounsaturated fat	12.7	15.2	13.9	10.7	17.7	11.0	<0.001	0.33‡
Polyunsaturated fat	6.7	8.7	7.2	6.1	9.5	5.9	<0.001	0.36‡
Energy percentage macronutrient intake (%)								
Protein	14.1	4.5	15.2	3.6	15.6	2.8	<0.001	0.28‡
Carbohydrate	71.4	12.8	67.7	10.0	64.4	8.1	<0.001	-0.35‡
Total fat	13.6	10.2	16.0	8.4	18.9	7.5	<0.001	0.33‡
Saturated fat	4.2	3.9	4.9	3.2	5.6	3.2	<0.001	0.27‡
Monounsaturated fat	5.7	5.3	6.7	4.3	8.1	4.4	<0.001	0.32‡
Polyunsaturated fat	3.0	3.0	3.5	2.5	4.4	2.5	<0.001	0.36‡

AFE, Adult Female Equivalent. VHEI, Vietnamese Healthy Eating Index, with a range from 0 to 80 points. T, Tertile (T1 = lowest score = lowest adherence = lowest diet quality).
* Data is presented in mean and standard deviation, adjusted for sample weights.
† *P-value* for trend analysed by general linear model.
‡ A statistical significance with a P-value of <0.001 calculated from Spearman's rank correlation.

Intake of calcium, potassium, magnesium, iron, zinc, folate, vitamin B1, vitamin B2, vitamin C, vitamin A RAE, vitamin B6 and vitamin B12 were positively associated with the VHEI, both before and after energy intake adjustments. The significant correlations between the VHEI and the micronutrient intake was confirmed by the Spearman's rank correlation coefficients (*P-value* <0.001). For each of the essential micronutrients (calcium, potassium, magnesium, iron, zinc, folate, vitamin B1, vitamin B2, vitamin A RAE, vitamin C, vitamin B6, and vitamin B12), there was a positive correlation between the VHEI and the intake of these nutrients, both before and after energy adjustment (with r_s ranging from 0.16 to 0.36). There was a negative correlation between the VHEI and sodium intake, both before and after energy adjustment (r_s -0.16 and r_s -0.20, respectively), as shown in **Table 2.4.**

Table 2.4. Daily micronutrient intake of participants in the Vietnamese General Nutrition Survey 2009-2010 (n = 8,225) across tertiles of the Vietnamese Healthy Eating Index

	Tertiles of total VHEI score							
Micronutrients* (AFE/day)	**T1 (n = 2742)**		**T2 (n = 2742)**		**T3 (n = 2741)**		***P-value*†**	r_s
Micronutrient intake								
Calcium (mg)	388.3	297.8	405.1	250.6	488.9	323.6	<0.001	0.24‡
Potassium (mg)	1938	988.3	1998	732.1	2362	660.4	<0.001	0.27‡
Sodium (mg)	3600	3240	2870	2409	2521	1564	<0.001	-0.16‡
Magnesium (mg)	200.3	139.1	204.7	126.5	233.1	96.9	<0.001	0.23‡
Iron (mg)	11.6	11.0	12.2	12.9	13.9	8.5	0.029	0.23‡
Zinc (mg)	9.8	4.9	9.8	3.8	10.9	3.7	0.002	0.16‡
Folate (µg)	186.7	151.7	221.1	150.3	274.4	150.6	<0.001	0.28‡
Vitamin B1 (mg)	0.8	0.5	0.8	0.4	1.0	0.4	<0.001	0.26‡
Vitamin B2 (mg)	0.6	0.4	0.7	0.4	0.8	0.5	<0.001	0.31‡
Vitamin A RAE (µg)	356.4	438.6	435.1	426.7	549.0	515.5	<0.001	0.22‡
Vitamin C (mg)	43.1	52.2	52.5	42.9	85.8	68.8	<0.001	0.36‡
Vitamin B6 (µg)	1.3	0.7	1.3	0.6	1.5	0.6	<0.001	0.25‡
Vitamin B12 (µg)	2.1	3.5	2.4	3.5	2.9	5.5	<0.001	0.25‡
Energy-adjusted micronutrient intake (per 1000kcal)								
Calcium (mg)	212.1	156.3	228.7	134.1	255.7	153.9	<0.001	0.24‡
Potassium (mg)	1038	355.6	1118	283.0	1236	276.3	<0.001	0.32‡
Sodium (mg)	2016	1737	1611	1254	1325	770.1	<0.001	-0.20‡
Magnesium (mg)	107.1	57.1	113.8	56.9	121.7	43.5	<0.001	0.22‡
Iron (mg)	6.1	3.3	6.7	4.1	7.2	3.2	<0.001	0.27‡
Zinc (mg)	5.2	1.2	5.4	1.1	5.6	1.4	<0.001	0.20‡
Folate (µg)	102.8	92.1	125.2	83.6	144.2	76.5	<0.001	0.27‡
Vitamin B1 (mg)	0.4	0.2	0.5	0.2	0.5	0.2	<0.001	0.29‡
Vitamin B2 (mg)	0.3	0.2	0.4	0.2	0.4	0.2	<0.001	0.32‡
Vitamin A (µg RAE)	197.8	264.2	245.0	243.3	287.2	256.0	<0.001	0.21‡
Vitamin C (mg)	24.3	29.9	30.1	25.7	45.2	35.5	<0.001	0.34‡
Vitamin B6 (µg)	0.7	0.2	0.7	0.2	0.8	0.2	<0.001	0.29‡
Vitamin B12 (µg)	1.1	1.8	1.3	1.9	1.5	3.0	0.001	0.22‡

AFE, Adult Female Equivalent. VHEI, Vietnamese Healthy Eating Index, with a range from 0 to 80 points. T, Tertile (T1 = lowest score = lowest adherence = lowest diet quality). RAE, Retinol Activity Equivalents.
* Data is presented in means and standard deviation, means adjusted for sample weights.
† *P-value* for trend analysed by general linear model.
‡ A statistical significance with a *P-value* of <0.001 calculated from Spearman's rank correlation.

Table 2.5. Daily food group consumption of participants in the Vietnamese General Nutrition Survey 2009-2010 (n = 8,225) across tertiles of the Vietnamese Healthy Eating Index

Food groups* (g/AFE/day)	**Tertiles of total VHEI score**						***P-value***†	r_s
	T1 (n = 2742)		**T2 (n = 2742)**		**T3 (n = 2741)**			
Grains	434.0	209.1	388.7	134.0	383.2	101.3	<0.001	-0.10‡
Rice	392.8	201.2	346.6	131.4	330.0	104.1	<0.001	-0.14‡
Noodles	28.0	70.1	34.1	63.3	44.3	67.7	<0.001	0.15‡
Bread	3.6	21.5	3.1	15.6	4.8	17.0	0.053	0.05‡
Protein-rich foods	159.2	167.5	186.8	128.4	218.8	100.6	<0.001	0.32‡
Red meat	54.3	91.7	66.1	82.1	84.9	75.8	<0.001	0.22‡
Poultry	13.2	58.3	14.2	66.8	14.6	45.9	0.882	0.05‡
Fish and seafood	64.4	99.5	71.0	86.3	68.5	73.0	0.084	0.09‡
Eggs	9.1	24.3	13.1	26.5	15.8	25.4	<0.001	0.15‡
Soya and legumes	17.3	76.5	21.1	54.4	33.4	68.8	0.001	0.16‡
Dairy	4.3	22.6	8.3	30.7	19.1	44.8	<0.001	0.22‡
Vegetables	153.9	131.1	191.2	115.7	237.5	110.9	<0.001	0.32‡
Fruits	17.3	64.7	33.0	79.3	119.1	139.3	<0.001	0.38‡
Sugar and sweets	7.7	24.7	6.1	32.0	5.7	14.4	0.133	0.02‡
Fats and oils	11.6	38.5	11.1	21.8	14.6	17.5	0.031	0.30‡
Salt and sauces	22.6	21.7	16.9	19.0	15.1	12.7	<0.001	-0.10‡

AFE, Adult Female Equivalent. VHEI, Vietnamese Healthy Eating Index, with a range from 0 to 80 points. T, Tertile (T1 = lowest score = lowest adherence = lowest diet quality).
* Data is presented in means and standard deviation, means adjusted for sample weights.
† *P-value* for trend analysed by general linear model.
‡ A statistical significance with a *P-value* of <0.001 calculated from Spearman's rank correlation.

There was an inverse association between rice consumption and the VHEI, whereas the consumption of noodles was positively associated with the VHEI. Within the protein-rich foods food group, no association between the VHEI and the consumption of white meat, fish, and seafood was observed. Positive associations were observed between the VHEI and the other protein-rich foods red meat, eggs, soybean, and legumes. Significant positive associations across tertiles of the VHEI were seen for dairy, vegetables, fruits, and fats and oils. A significant inverse association was observed for the food group salt and sauces. Low inverse correlations between the VHEI and grains, rice, and salt and sauces consumptions were observed (r_s -0.10, -0.14, and -0.10, respectively). Correlation coefficients between the VHEI and other food groups consumption were positive, ranging from 0.02 to 0.38 (**Table 2.5**).

DISCUSSION

We developed the VHEI as a measure of diet quality in terms of adherence to the 2016-2020 FBDGs Vietnamese for adults. The index proved to be a valuable tool for ranking participants based on their adherence to the FBDGs in our analysis. A positive association was observed between the VHEI and energy-adjusted intake of micronutrients calcium, potassium, magnesium, iron, zinc, folate, vitamin B1, Vitamin B2, vitamin A, vitamin C, vitamin B6 and vitamin B12, suggesting that a higher VHEI score was associated with higher diet quality. The total VHEI score was also positively associated with protein, total fat, and dietary fibre intake and inversely associated with sodium and sugar intake. There was a positive relationship between the total VHEI score and region and households' income.

The eight component scores of the VHEI, including grains, protein-rich foods, vegetables, fruits, dairy, fats and oils, sugar and sweets and salt and sauces, were developed based on the recommendations for the eight food groups in the 2016-2020 Vietnamese FBDGs. Each component was scored individually based on the absolute amount consumed estimated in servings, instead of using consumption as a dichotomous variable (i.e., "yes" or "no"). This is advantageous as it enables the possibility of grading within the score, however also it requires data about actual amounts consumed, which is challenging in low resource settings such as Vietnam[5]. Despite this short-coming, the flexibility of a graded system is still superior to a binary system that sheds no light on quantities of the foods consumed.

We gave a similar weight to the eight component scores in order to reflect the equal weighting seen in the Vietnamese FBDGs. This approach is applied widely in the literature[7; 8; 34] and is generally suggested when developing a diet quality index[5]. However, different components of a healthy eating index may affect the total diet quality score differently[35]. For example, the Chinese Healthy Eating Index applied unequal weighting factors for different individual components, in that cooking oils, sodium, and fruits were weighted twice as heavily as other components. They were considered important in Chinese dietary patterns and linked with various adverse health outcomes[35]. Future research may explore whether applying weighting factors for different components could improve the efficacy of a diet quality index in Vietnam.

The FBDGs also give recommendations on water consumption and physical activity, however these were not included in our methodology as the dietary intake dataset did not cover water consumption or physical activity information. Other indices did capture physical activity[7; 8; 36], while others did not [7; 34; 37]. Water intake and physical activity are integral parts of a healthy diet and lifestyle, and their incorporation could be expected to increase the efficacy of a diet quality index. Thus, it is advisable that these components are also included when collecting data or modifying the VHEI.

Participants who had a higher adherence to the Vietnamese FBDGs had higher absolute intake and higher energy-adjusted intake of micronutrients. This outcome demonstrates that a higher intake of micronutrients in the diet was observed among those who adhered more closely to the FBDGs regardless of their energy intake, which is in line with other studies[7; 34; 37]. The mean intake of micronutrients vitamin B2 and calcium was considerably lower than the recommended average intake for Vietnamese adults in all tertiles of the VHEI[21]. In Vietnam, calcium deficiency is still a severe problem affecting people of all ages and consumption of dairy and dairy products is still low[38; 39], as shown in our study where "dairy" scored the lowest among the eight component scores. The low intake of dairy and dairy products elsewhere in Asia was explained by the low per-capita supply and widespread lactose intolerance and lactase deficiency[35], though evidence is currently absent in Vietnam, preventing definitive conclusions from being made.

A higher total fat intake was observed for participants in the highest tertile of the VHEI, which differs from other studies that found higher diet quality scores associated with lower total fat intake[34; 35]. The low consumption of total fat in our study population could partly explain this result. The energy percentage of total fat intake ranged from 13.6% in the lowest tertile to 18.9% for participants in the highest tertile, which were lower than the recommended value for Vietnamese adults (20-25%)[21].

Similarly, the absolute intake was low, ranging from 11.6g to 14.6g, compared to the value of 25-30g as recommended in the FBDGs. As a result, those scoring higher on “fats and oils” component typically had values closer to the recommended value. In our study, saturated fat intake increased across tertiles of the VHEI, although it could be expected to decrease as unsaturated fat is preferable to saturated fat from a health perspective[40]. However, in the current Vietnamese FBDGs, no distinction is made between healthy and unhealthy fats, which are captured together in one “fats and oils” group, which is similar to that which is seen in the FBDGs of 35% of other countries[3]. Since we based our index on existing recommendations in the FBDGs, we also utilised only “fats and oils” component, although other diet quality indices separate total fat and saturated fat components[34; 41; 42]. New versions of the Vietnamese FBDGs should distinguish between different types of fat, as well as having a category for total overall fat in order to better reflect diet quality.

Although most participants were assigned a relatively high score for the “grains” component, almost none of them consumed whole grain products, indicating that the most significant proportion of the total grains consumed consisted of refined grains such as white rice, white noodle, and white bread. This is undesirable given evidence for the negative effects of refined grains on health, such as their association with an increased risk of type 2 diabetes[43]. Whole grains also contain a considerable amount of fibre, which partially explains our participants’ low dietary fibre intake. These health advantages of whole grain warrant its preference over refined grain in a healthy diet[44; 45]. In other FBDGs, a clear recommendation of whole grain intake was made that 90g of whole grain products should be consumed daily and they should replace refined grain products[34]. Thus, the Vietnamese FBDGs should consider updating the recommendation on grains to bias the intake of whole grains over refined grains.

Low intake of fruit and vegetables has been observed in another study in Vietnam, confirming that approximately 80% Vietnamese adults consume less than five servings of fruits and vegetables daily[46]. Our study found similar results, as reflected by the lower scores for the fruits. The mean daily intake of fruits of participants in the first tertile and the second tertile was very low, with 17.3g and 33.0g, respectively. Although participants in the third tertile had meaningfully higher fruits intake with the mean of 119.1g per day, this number only met approximately 50% of the recommendation that at least three servings (240g per day) should be consumed.

The mean daily consumption of vegetables of participants in the highest tertile (237.5g per day) was close to the recommendation of at least three servings (240g per day), whereas the mean intakes of participants in the other two tertiles were lower (153.9g per day in the first tertile and 191.2g in the second tertile). Despite this existing failure to meet vegetable intake recommendation, it is also possible that consumption of vegetables was overestimated in our study due to missing information on the proportions of water and vegetables in vegetable soups. We have tried to correct this by using the information given in standard recipes, but this strategy may not have fully recovered the vegetables intake. Thus, there is an obvious necessity to amend this low vegetable intake that is apparent in the Vietnamese population in order to improve diet quality.

The study participants scored reasonably highly for the component “salt and sauces” due to the low intake of salt and sauces, despite other studies showing that the dietary salt intake in Vietnam is higher than the recommended value(47). This discrepancy could be explained by the lack of clear information on salt or sauces added at the table or during cooking in our study. The majority (approximately 80%) of salt intake comes from table salt or salty condiments at home, and this is especially true in the Vietnamese situation(47). To resolve these differences, dietary intake studies in the future should estimate sodium intake more precisely and consider measuring sodium via 24hr collected urine samples, as this is the golden standard in research quantifying sodium intake(48).

Data on individual characteristics were missing in our analysis since the dietary intake data were derived from a household food consumption survey. Thus, we could only examine a relationship between characteristics at the household level and the VHEI. Here, we found a positive association between the VHEI and household wealth, which is in accordance with the results of another study in Vietnam[49]. The VHEI also varied by region as the largest percentage of participants with higher VHEI scores were from the Red River delta. Another study also showed regional variation in diet quality, where micronutrient (calcium and vitamin A) intake was higher in the Southeast and the Red River delta, and that the Red River delta had a more balanced dietary pattern than other regions in terms of macronutrient intake[50]. In contrast, participants with lower VHEI scores were more often from the Northern and central coastal areas and the Mekong River delta. Kim et al. also showed that inhabitants of the Mekong River delta had an excess energy intake from carbohydrates and a deficit of energy intake from other macronutrients[50]. Regional differences also exist in terms of income, and these differences align with the aforementioned findings on dietary index scores. The Southeast, which includes the largest city Ho Chi Minh, and the Red River delta, which consists of the capital Hanoi, have the highest average incomes in Vietnam[51]. Thus, taking the results of the present study and findings of others into account[49; 50], it is rational to further explore if households with higher income have access to healthier foods that may be unaffordable to households with lower income, which positively impacts their diet quality.

This present study has some limitations. First, the data we used were on the household level and needed to be converted to the individual level. This conversion might cause inaccuracy in estimating dietary intake since approximations were based on one reference household member's description of food consumption and the distribution among household members was not taken into account. This conversion had also prevented us from examining the VHEI and individual characteristics. Second, further work is needed to evaluate the VHEI regarding its reliability and validity. However, the VHEI is the first of its kind for Vietnam and was developed based on dietary intake data of a large national representative sample. This work was conducted in a low-and-middle-income country, where tools and indicators are still lacking to fill in the knowledge gap of the relation between diet quality and other aspects.

In conclusion, the VHEI proved it to be effective at measuring diet quality in terms of adherence to the Vietnamese FBDGs, confirming it as a valuable tool for future research to examine the associations between diet quality and health-related outcomes; relationships between diet quality and the environmental impacts of diets; and affordability of diets in Vietnam. Additionally, the index can also be used as a monitoring tool in nutrition interventions focusing on improving diet quality. Finally, and most importantly, the outcomes of our study provide recommendations for the improvement of the development of the new 2021-2025 Vietnamese FBDGs.

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SUPPLEMENTARY MATERIALS OF CHAPTER 2

THÁP DINH DƯỠNG DÀNH CHO NGƯỜI TRƯỞNG THÀNH (FOOD PYRAMID FOR ADULT)

Khuyến cáo mức tiêu thụ thực phẩm trung bình cho 1 người/1ngày (Recommendation an average food consumption per head/day)

Table 2.S1. Interpretation of the 2016-2020 Vietnamese food-based dietary guidelines for adults*

Food groups	Main food items	Definition of *one serving*	Examples of *servings*	Recommended servings daily
Grains	Rice, bread, noodles, potato, corn, casava	Provides 20g carbohydrate	1 serving: 55g cooked rice, 27g sliced bread, 95g potato, 84g sweet potato 2 servings: 110g cooked rice, 120g cooked rice noodles, 120g cooked corn, 35g bread	12 – 15
Protein-rich foods	Fish, meat, seafood, tofu and soybean products, egg	Provides 7g protein	1 serving: 31g cooked pork, 42g cooked chicken, 47g cooked egg, 35g cooked fish, 30g cooked shrimp, 58g cooked tofu	5 – 6
Fats and oils	Animal fat, oil, butter, nuts, and seeds	Provides 5g total fat	1 serving: 5g oils, 5g animal fat, 6g butter, 8g peanuts, 8g sesame seeds	5 – 6
Dairy	Milk, yogurt, cheese	Provides 100mg calcium	1 serving: 100ml milk, 100g yogurt, 15g cheese	3 – 4
Vegetables	All type of vegetables, mushroom	80g of edible vegetables (raw, cooked)	1 serving: 80g of water spinach, mustard green, Chinese cabbage, pumpkin, gourd	3 – 4
Fruits	All type of fruits	80g of edible fruits	1 serving: 80g of mango, lychee, grapefruits, longan, grape, watermelon	3
Sugar and sweets	Sugar, sweets, honey	Provides 5g free sugar	1 serving: 5g sugar, 8g peanut candy, 6g honey	< 5
Salt and sauces	Salt, seasoning, sauce	Provides 5g salt	1 serving: 5g salt, 8g seasoning powder, 25g fish sauce, 35g soy sauce	< 1
Water	Water	200ml plain water		8 – 12
Physical activity	At least 30 minutes of moderate physical activity every day.			

* The information in this table is the translation of the 2016-2020 food-based dietary guidelines pyramid with additional information derived from the 2016-2020 food-based dietary guidelines background document.

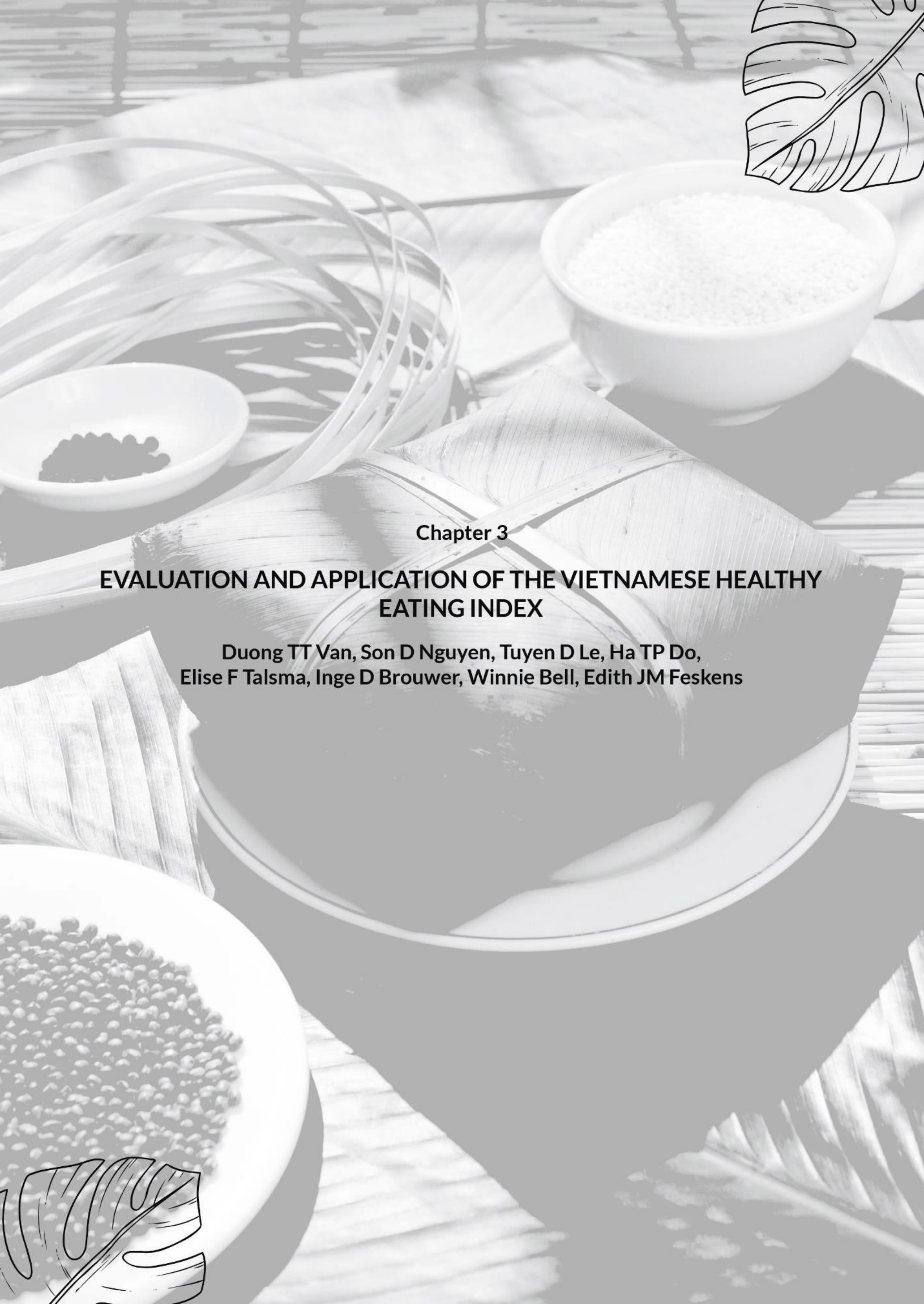
Table 2.S2. Daily energy and nutrient intakes of participants in the Vietnamese General Nutrition Survey 2009-2010 (n = 8,225)

Energy and nutrient intakes*	Absolute intake Mean ± SD	Adjusted intake† Mean ± SD
Energy intake (kcal)	1891 ± 636.5	-
Macronutrients (g)		
Protein	70.4 ± 28.3	15.0 ± 3.7
Carbohydrate	318.0 ± 113.8	67.7 ± 10.7
Dietary fibre	6.1 ± 3.9	-
Total fat	35.4 ± 27.1	16.3 ± 9.0
Saturated fat	10.6 ± 10.0	4.9 ± 3.5
Monounsaturated fat	14.9 ± 12.5	6.9 ± 4.7
Polyunsaturated fat	7.8 ± 7.0	3.7 ± 2.7
Micronutrients		
Calcium (mg)	429.7 ± 297.8	233.1 ± 149.9
Potassium (mg)	2109 ± 816.9	1135 ± 315.4
Sodium (mg)	2976 ± 2478	1637 ± 1309
Magnesium (mg)	213.4 ± 121.4	114.5 ± 52.7
Zinc (mg)	10.2 ± 4.2	5.4 ± 1.2
Iron (mg)	12.6 ± 10.9	6.7 ± 3.6
Folate (µg)	450.9 ± 473.2	124.9 ± 85.5
Vitamin B1 (mg)	0.9 ± 0.4	0.5 ± 0.2
Vitamin B2 (mg)	0.7 ± 0.4	0.4 ± 0.2
Vitamin A RAE (µg)	450.9 ± 473.2	245.2 ± 257.4
Vitamin C (mg)	61.4 ± 59.7	33.7 ± 32.3
Vitamin B6 (µg)	1.4 ± 0.6	0.7 ± 0.2
Vitamin B12 (µg)	2.5 ± 4.4	1.3 ± 2.4

* Data are presented in mean values and standard deviation, adjusted for sample weights.
† Energy percentage was presented for adjusted macronutrient intakes and mean intakes per 1,000 kcal was presented for adjusted micronutrient intakes.

Chapter 2

Bánh mì, a Vietnamese typical sandwich.



Chapter 3

EVALUATION AND APPLICATION OF THE VIETNAMESE HEALTHY EATING INDEX

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ABSTRACT

The Vietnamese Healthy Eating Index (VHEI) is a diet quality indicator that measures conformance with the 2016-2020 Vietnamese food-based dietary guidelines. In this study, we evaluated the VHEI regarding its reliability and validity (construct and criterion validity) and studied the comparability of the VHEI derived from different dietary assessment methods (relative validity). We also examined the correlation between the VHEI and nutrient intakes. Dietary intake data from the latest Vietnamese General Nutrition Survey (GNS 2019-2020; n=3,528) and a validation study (n=212) conducted in Northern Vietnam were used. The results showed positive correlations between diet quality measured by the VHEI and nutrient intakes. Higher VHEI was associated with a lower prevalence of overweight and obesity among Vietnamese adults. The mean total VHEI score was significantly lower in men (42.1 ± 6.0) than in women (45.1 ± 9.9), and significantly lower in smokers (41.0 ± 5.9) than in non-smokers (44.3 ± 8.8). The distribution of scores among the population was wide enough to detect differences in diet quality among Vietnamese adults. Principle component analysis (PCA) indicated multiple underlying dimensions of the VHEI. Correlations between the total VHEI score, its component scores, and energy intake were low. Cronbach's coefficient α was 0.41. The VHEI derived from different dietary assessment methods showed no difference in the total VHEI score between the dietary assessment methods. There was an indication of systematic bias comparing 24-hour recall (24HR) using a pen-and-paper questionnaire with weighed food record (WFR), but no bias comparing 24HR using the computer-assisted personal INDDEX24 mobile app with WFR. In conclusion, this study supports the validity of the VHEI regarding its construct and criterion validity. Differences in estimates produced by different dietary assessment methods may affect the performance of the VHEI.

Key words: diet quality, food-based dietary guidelines, Vietnamese Healthy Eating Index, evaluation, validation

INTRODUCTION

Ending malnutrition is the core of the United Nations Sustainable Development Goals (SDGs), motivated by the fact that poor diet quality is a primary cause of adverse nutrition and health outcomes worldwide[1]. However, the global effort has been insufficient, demanding further and stronger actions in order to reach the SDGs[2]. Diet quality assessment plays an essential role in facilitating promising nutritional strategies toward these goals. Many diet quality tools and indicators have been created to assess diet quality both globally and specific to a given country[3; 4], though the most optimal diet quality indicator for assessing malnutrition remains undetermined[5]. In addition, the analyses of diet quality and other related factors in low- and middle-income countries (LMICs), such as Vietnam, have been limited due to the lack of appropriate tools and databases[3; 6].

In Vietnam, a transition from traditional dietary patterns toward more unhealthy dietary patterns is ongoing, which has contributed to an increase in overweight, obesity, and diet-related noncommunicable diseases (NCDs)[7; 8]. Vietnam is experiencing a double burden of malnutrition where both undernutrition and overnutrition are common. This trend has called for more effective nutritional interventions in the country. The *'National Nutrition Strategy for 2011-2020, with a vision toward 2030'* report proposed the main objectives and instruments for nutritional policy in Vietnam[9]. Among these major objectives, improving the nutritional status of the general Vietnamese population is considered the most important. The GNS is conducted once every decade by National Institute of Nutrition, Ministry of Health to gather information on food consumption, nutrient intakes, and nutritional status of the Vietnamese population and serves as the basic foundation for nutritional intervention in the country[10]. In the previous GNS (i.e., GNS 2009-2010)[10], the dietary intake data were collected at the household level, whereas in the recent survey, the GNS 2019-2020[11], data were collected at the individual level, enabling more nuanced and effective ways to analyse and use the dietary intake data.

We recently developed the VHEI to measure diet quality relating to adherence to the 2016-2020 FBDGs for Vietnamese adults[12]. The index is a promising indicator to assess the overall diet quality of the Vietnamese diet or any foundational food groups that are critical to the diet quality recommendations of the FBDGs. It has been suggested for numerous research purposes, such as epidemiological study, population surveillance, and nutrition intervention, amongst others[13]. The VHEI can also be used to investigate whether the dietary recommendations protect against diet-related NCDs, and, if so, to what extent[14]. However, before using a new diet quality index such as VHEI in such investigations, an in-depth evaluation should be performed[14]. Several evaluation strategies for diet quality indices have been used, including examining the reliability, validity (content, construct, and criterion validity), and studying the comparability of the index derived from different dietary assessment methods (known as relative validity)[15; 16; 17]. However, the VHEI has not yet been evaluated in terms of both reliability and validity or applied elsewhere in the literature.

Therefore, the objectives of the present study were to 1) evaluate the reliability and validity (construct, criterion, and relative validity); 2) to apply the VHEI to the latest Vietnamese GNS and a subpopulation sample in examining the associations between diet quality and nutrient intakes; and 3) to discuss potential applications of the VHEI for future research.

SUBJECTS AND METHODS

To evaluate and apply the VHEI, we performed the analysis using the Vietnamese GNS 2019-2020 and a sample of a validation study conducted as part of the INDDEX Project's validation of the INDDEX24 Dietary Assessment Platform. These data were collected following the guidelines laid down in the Declaration of Helsinki. The Medical Research Ethics Committee of NIN approved the GNS 2019-2020 with decision number 441/VDD-QLKH. The institutional review boards approved the INDDEX24 validation study at Tufts University (#1904024) and NIN (45/VDD-QLKH). Written informed consent was obtained from all participants prior to data collection. NIN and Tufts University permitted this study access to the GNS 2019-2020 and INDDEX24 datasets.

Vietnamese General Nutrition Survey 2019-2020

The GNS 2019-2020 included sociodemographic data (age, gender, region, education, occupation, and smoking status), anthropometric data (body weight and height), and dietary intake data. Regarding dietary assessment, the multiple-pass quantitative 24HR was used to obtain the dietary intake data of 5,427 Vietnamese adults aged 15-49 years. A master database of standard recipes, retention factors, edible portions, and yield factors was developed during the pre-survey work at NIN and used to convert the dietary intake data(11). Adults < 20 years and pregnant and lactating women were excluded from our analysis. Outliers were identified based on a Z-score value of less than -2.58 or more than 2.58 derived from energy intake, resulting in the further deletion of 43 extreme outliers in GNS 2019-2020. To conclude, this study analysed a sample of 3,528 Vietnamese adults aged ≥ 20 years, including 880 men and 2,648 non-lactating, non-pregnant women (sociodemographic characteristics are described in Supplementary Table 3.S1). This sample is further weighted using sample weights provided by NIN to account for the complex survey structure. To evaluate the performance of the VHEI regarding its reliability and validity (construct and criterion validity), we scored 1-day dietary intakes obtained from this final sample.

INDDEX24

The INDDEX Project developed, tested, and deployed the INDDEX24 mobile app to collect and analyse quantitative 24HR data(18; 19). In the present study, we used the data from the INDDEX24 validation study in Vietnam, which was conducted among Vietnamese women aged 18-49 years from rural households in Thanh Oai District, Hanoi Province in 2019-2020(19). In this INDDEX24 validation study, the WFR was administered for each woman, and a 24HR was applied for the same woman on the next day. The INDDEX24 validation sample consists of 234 women with WFR and 24HR using the computer-assisted personal INDDEX24 platform (24HR-CAPI), or 24HR using a pen-and-paper questionnaire (24HR-PAPI). In addition, 60 women for whom the WFR was not conducted the day prior responded to a 24HR to evaluate the time per interview and assess the cost and cost-efficiency of using INDDEX24(18; 19). This additional sample was excluded from our analysis as it was not relevant for this

Chapter 3

paper. We further excluded women aged < 20 years and pregnant and lactating women, resulting in a final dataset of 212 women (sociodemographic characteristics are described in Supplementary Table 3.S2).

The 2019 Vietnamese Food Composition Table (FCT) was used to estimate energy and nutrient intakes. Missing nutrient values were complemented with data from the 2017 Indian FCT[20], the 2015 Standard FCT in Japan[21], and the 2020 Food Data Central, The US Department of Agriculture (USDA)[22] (mentioned in order of use).

Evaluation of the Vietnamese Healthy Eating Index

The VHEI was developed to measure diet quality in terms of adherence to the 2016-2020 FBDGs for Vietnamese adults aged ≥ 20 years. Briefly, VHEI is an 80-point scale, with a higher score demonstrating higher adherence to the FBDGs and thus higher diet quality. The eight component scores with a maximum score of 10 points each reflect the recommendations relating to the eight food groups of the FBDGs, including vegetables, fruits, grains, protein-rich foods, fats and oils, dairy, sugar and sweets, and salt and sauce. The scoring system of the VHEI is detailed elsewhere[12]. To evaluate whether the VHEI is a reliable and valid tool to measure the quality of diet consumed by Vietnamese adults in terms of alignment with the Vietnamese FBDGs, we examined its reliability, construct validity, criterion validity, and relative validity. The complete evaluation strategy of the VHEI is described in **Table 3.1** below, which is adapted from Reedy *et al.*[16] and Gleason *et al.*[23].

Statistical analysis

The statistical software package Stata version 15.0 was used to perform all statistical analyses. Descriptive statistics were presented as mean and standard deviation (SD) for continuous variables and percentages for categorical variables. The GNS 2019-2020 was used for the reliability, construct validity, and criterion validity evaluation and INDDEX24 was used for relative validity evaluation. All analyses related to the GNS 2019-2020 appropriately applied sample weights. A *P-value* of less than 0.05 was considered statistically significant.

For construct validity, we first compared the scores using multivariable-adjusted linear regression between gender groups (men and women), age groups (younger and older adults), and smoking status (smokers and non-smokers) to test the ability of the VHEI in detecting the differences in subpopulations with known differences in diet quality. Second, we described the distributions of the total VHEI score and its component scores according to their percentiles to evaluate if the distribution was wide enough to distinguish significant differences. Third, Pearson correlations between total VHEI scores and its component scores and energy intake was examined to check if the VHEI is able to measure diet quality independent of dietary quantity. Finally, the number of dimensions that emerged from the data was calculated to determine whether there was one or more than one factor that accounted for the systematic variation observed in the data based on the general patterns of the scree plot calculated from PCA.

Criterion validity was evaluated by conducting multivariate logistic regression analyses to test the association between the VHEI and overweight and obesity. The overweight and obesity variable was classified as Body Mass Index (BMI) ≥ 23.0 (kg/m^2) according to the World Health Organization (WHO) BMI cut-off point for the Asian population[(24)]. We ran the crude model and two adjusted models considering the following confounding variables: age (years, continuous variable), gender (men or women), region (categorical variable), current smoker (yes or no), education (categorical variable), occupation (categorical variable).

Relative validity was evaluated by examining the differences in scores, the correlation coefficients, and the agreement between scores of the total VHEI score and its component scores derived from different dietary assessment methods, including WFR as a benchmark, 24HR-CAPI, and 24HR-PAPI. In detail, the paired t-test was used to check the differences between the total VHEI scores and between its component scores derived from WFR and 24HR-CAPI, and WFR and 24HR-PAPI. The partial correlation coefficients were calculated for the total VHEI score and its component scores between WFR and 24HR-CAPI and between WFR and 24HR-PAPI, adjusted for energy intake from WFR. The agreement for the total VHEI scores between the

24HR-CAPI or 24HR-PAPI versus WFR was assessed using the Bland and Altman method by plotting the difference in the total VHEI scores between methods (24HR-CAPI/24HR-PAPI – WFR) against the average of both scores estimated from 24HR-CAPI or 24HR-PAPI plus that from WFR divided by 2 ([WFR + 24HR-CAPI/24HR-PAPI]/2). The upper and lower limits of agreement (LOA) were calculated as the mean difference ± 1.96 SD. The presence of proportional bias was assessed using linear regression. The LOA between the component scores was compared using Cohen's weighted kappa analysis.

The Cronbach's coefficient α was calculated to test the internal consistency. The reliability was also evaluated by estimating the Pearson correlations among the component scores and the correlations between each component score and the total VHEI score to test how each component score influenced the total VHEI score.

The correlation between total VHEI score and nutrient intakes was examined using Spearman's rank correlation coefficients. Nutrient intakes were presented with and without energy adjustment. Energy percentage and mean intakes per 1,000 kcal were presented for adjusted macronutrient intakes and adjusted micronutrient intakes, respectively.

Table 3.1. Evaluation of the Vietnamese Healthy Eating Index*

Question	Strategy	Applied to VHEI
Construct validity		
Does the index differentiate between groups with known differences in diet quality?	Conduct multivariable-adjusted linear regression to compare the scores of men and women, younger and older adults, smokers and non-smokers.	GNS 2019-2020
Does the index allow for sufficient variation in scores among individuals?	Estimate the mean of total score and component scores across the percentiles of the total score.	GNS 2019-2020
Does the index assess diet quality independent of diet quantity?	Estimate correlations between component scores and energy intake.	GNS 2019-2020
Is the index multidimensional?	Conduct a principal component analysis.	GNS 2019-2020
Criterion validity		
Can the index predict a health outcome?	Estimate hazard of health outcomes.	GNS 2019-2020
Relative validity		
Does the index yield different scores when calculating from different dietary assessment methods?	Examine the differences, the correlations, and the levels of agreement of the total score and its component scores derived from different dietary assessment methods with one method as a benchmark.	INDDEX24
Reliability		
How internally consistent is the score?	Calculate Cronbach's coefficient α.	GNS 2019-2020
What are the relationships between the component scores? Between total score and component scores?	Estimate correlations between component scores, and component score-total score correlations.	GNS 2019-2020

Q, Question. VHEI, Vietnamese Healthy Eating Index. GNS 2019-2020, Vietnamese General Nutrition Survey 2019-2020.
* Adapted from Reedy *et al.*[16] and Gleason *et al.*[23]

RESULTS

As shown in **Table 3.2**, the mean total VHEI score of 3,528 Vietnamese adults aged ≥ 20 years of the GNS 2019-2020 was 43.7 ± 8.5. The highest mean score was observed for sugar and sweets (9.5 ± 1.9), whereas the lowest mean score was observed for dairy (0.4 ± 1.8).

Construct validity

The mean total VHEI score for men (42.1 ± 6.0) was significantly lower than for women (45.1 ± 9.9), and four of the eight component scores were significantly lower for men. The mean total VHEI score of the younger adults aged 20-30 years (43.1 ± 8.9) was lower than of the older adults aged > 30 years (44.0 ± 8.2, *P-value* >0.05), two of the eight component scores (fruits and sugar and sweets) were significantly higher, and two (fats and oils and dairy) were significant lower for younger adults. The mean total VHEI total score for current smokers (41.0 ± 5.9) was significantly lower than for non-smokers (44.3 ± 8.8) **(Table 3.2).**

Table 3.2. Mean total Vietnamese Healthy Eating Index score and its component scores, grouped by gender, age, and smoking status of participants in the Vietnamese General Nutrition Survey 2019-2020 (n=3,528)

Components of the VHEI*	Total (n=3,528)	Men (n=880)	Women (n=2,648)	Aged 20-30 years (n=1,127)	Aged > 30 years (n=2,398)	Smokers (n=333)	Non-smokers (n=3,193)
Vegetables	6.7 ± 3.4	6.7 ± 2.5	6.6 ± 4.0	6.4 ± 3.5	6.8 ± 3.3	6.4 ± 2.6	6.7 ± 3.5
Fruits	3.5 ± 3.9	2.9 ± 2.7	4.1 ± 4.8†	3.2 ± 3.9	3.7 ± 3.9‡	2.6 ± 2.6	3.7 ± 4.2
Grains	7.0 ± 2.6	7.1 ± 2.1	6.9 ± 2.9	6.9 ± 2.7	7.0 ± 2.6	6.8 ± 2.2	7.0 ± 2.7
Protein-rich foods	5.5 ± 3.5	4.9 ± 2.7	6.0 ± 3.8†	5.4 ± 3.6	5.6 ± 3.4	4.7 ± 2.7	5.7 ± 3.6
Fats and oils	4.7 ± 3.0	5.2 ± 2.2	4.4 ± 3.5†	5.1 ± 3.1	4.6 ± 2.9‡	5.2 ± 2.2	4.7 ± 3.1
Dairy	0.4 ± 1.8	0.3 ± 1.1	0.6 ± 2.3†	0.6 ± 2.1	0.4 ± 1.6‡	0.2 ± 1.0	0.5 ± 1.9
Sugar and sweets	9.5 ± 1.9	9.5 ± 1.3	9.5 ± 2.3	9.3 ± 2.2	9.6 ± 1.7‡	9.5 ± 1.3	9.5 ± 2.0
Salt and sauces	6.3 ± 4.0	5.5 ± 3.0	7.1 ± 4.4†	6.2 ± 4.1	6.4 ± 3.9	5.5 ± 3.0	6.5 ± 4.1
Total VHEI score	**43.7 ± 8.5**	**42.1 ± 6.0**	**45.1 ± 9.9†**	**43.1 ± 8.9**	**44.0 ± 8.2**	**41.0 ± 5.9**	**44.3 ± 8.8§**

VHEI, Vietnamese Healthy Eating Index, with a range from 0 to 80 points.
* Data are presented in mean and standard deviation, adjusted for sample weights.
† Significantly different from men with a *P-value* of <0.05 calculated from a linear regression, adjusted for age and smoking status.
‡ Significantly different from adults aged 20-30 years with a *P-value* of <0.05 calculated from a linear regression, adjusted for gender and smoking status.
§ Significantly different from smokers with a *P-value* of <0.05 calculated from a linear regression, adjusted for gender and age.

The distribution of total VHEI scores among the general population was wide enough to distinguish the differences in diet quality among Vietnamese adults (Supplementary Table 3.S3). The correlation between total VHEI score and energy intake was very low (-0.09). Most correlations between VHEI component scores and energy were also low, except salt and sauces (r -0.47) (Supplementary Table 3.S4).

The VHEI scree plot examined from the PCA using GNS 2019-2020 **(Figure 3.1)** shows that the curve connecting the dots presented to generate at least four dimensions, indicating the multidimensionality underlies the VHEI. This result explained that no single linear combination of the VHEI component scores accounts for a significant proportion of the covariation in dietary patterns.

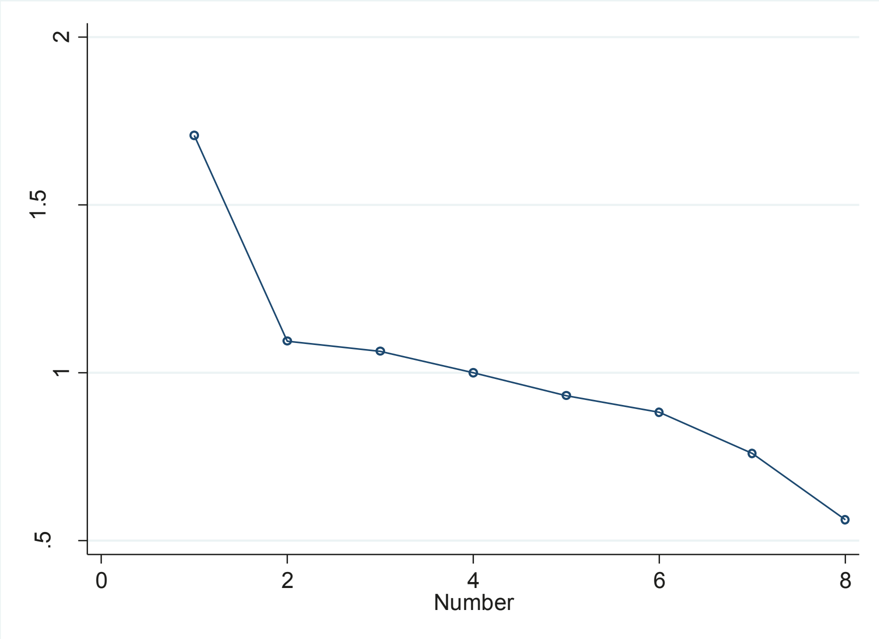

Figure 3.1. Scree plot from principal components analysis in a sample of 3,528 Vietnamese adults aged ≥ 20 years of the Vietnamese General Nutrition Survey 2019-2020

Criterion validity

The prevalence of overweight and obesity among Vietnamese adults aged ≥ 20 years in the GNS 2019-2020 was 38.9% (Supplementary Table 3.S3). The association between diet quality measured by the VHEI and overweight and obesity is showed in **Table 3.3**. The prevalence of overweight and obesity were 40.9% in T1, 39.8% in T2, and 35.8% in T3. After adjustment for confounding variables, higher VHEI scores were found to be associated with lower prevalence of overweight and obesity, where the multivariate adjusted hazard ratio of total overweight and obesity for a 10-point increment in the total VHEI score was 0.88 (0.78 - 0.99) with a *P-value* of 0.045.

Table 3.3. Multivariate adjusted hazard ratios and 95% confidence intervals of overweight and obesity according to the Vietnamese Healthy Eating Index of participants in the Vietnamese General Nutrition Survey 2019-2020 (n=3,528)

	Tertiles of total VHEI score				
	T1	**T2**	**T3**	**10-point increment**	***P-value***
Overweight and obesity*					
Percentage, %	40.9	39.8	35.8	-	-
Crude	1.0 (ref)	0.96 (0.75 - 1.23)	0.81 (0.62 - 1.06)	0.89 (0.79 - 1.00)	0.051
Model 1†	1.0 (ref)	0.96 (0.75 - 1.23)	0.82 (0.63 - 1.07)	0.89 (0.79 - 1.01)	0.075
Model 2‡	1.0 (ref)	0.95 (0.74 - 1.22)	0.80 (0.62 - 1.05)	0.88 (0.78 - 0.99)	0.045

VHEI, Vietnamese Healthy Eating Index, with a range from 0 to 80 points. T, Tertile (T1 = lowest score = lowest adherence = lowest diet quality).
* Data are presented in percentage, adjusted for sample weights.
† Adjusted for age and gender.
‡ Adjusted for age, gender, region, education, occupation, and smoking status.

Chapter 3

Reliability

Correlations between the eight component scores and total VHEI score varied across the components. The fruits and protein-rich foods components had the highest correlation, despite being only moderate correlated with the total VHEI score (r 0.51 and r 0.50, respectively). In contrast, the components salt and sauces and sugar and sweets had the lowest correlations with the total VHEI score (r 0.23), as shown in Supplementary Table 3.S4. The Cronbach's coefficient α of the VHEI calculated from the GNS 2019-2020 was 0.41 (data not shown).

Relative validity

As shown in **Table 3.4**, there was no difference between the mean total VHEI score calculated from 24HR-CAPI compared to WFR (48.4 vs 48.2). In contrast, there was a significant difference between the mean total VHEI score calculated from 24HR-PAPI compared to WFR (49.1 vs 50.5). The score of vegetables was significantly different between 24HR-CAPI and WFR, and two of the eight component scores (vegetables and fruits) were significantly different between 24HR-PAPI and WFR. Total VHEI scores calculated from 24-CAPI and 24-PAPI were moderately correlated with the total VHEI score derived from WFR (r 0.55 and r 0.58, respectively). The correlations between the component scores ranged from 0.16 to 0.87 for 24HR-CAPI and WFR and from 0.21 to 0.81 for 24HR-PAPI and WFR. The lowest correlation was observed for the component salt and sauces, while the highest correlation were observed for dairy and fruits. Weighted Cohen's kappa agreement between the component scores from WFR and 24HR-CAPI showed the lowest for salt and sauces and protein-rich foods (poor agreement with κ 0.13, k 0.16) and highest for dairy (good agreement with κ 0.80). Between WFR and 24HR-PAPI, the lowest agreement was also observed for sugar and sauces and protein-rich foods (poor agreement with κ 0.18 and κ 0.24, respectively) and the highest for dairy (good agreement with k 0.70).

Bland and Altman's plots analysed for the 24HR-CAPI against WFR showed a positive mean difference of 0.2 (LOA -16.2, 16.5), and the regression line (y= 0.1x – 6.2 with 95% CI -0.1, -0.3, *P-value* =0.208) showed no indication of systematic bias between the two methods **(Figure 3.2a).** A similar analysis for 24HR-PAPI against WFR showed a negative mean difference of -1.4 (LOA -16.5, 13.7), and the regression line (y=0.3x – 15.5 with 95% CI 0.1, 0.5, *P-value* = 0.006) indicated a systematic bias between the two methods **(Figure 3.2b).**

(a)

(b)

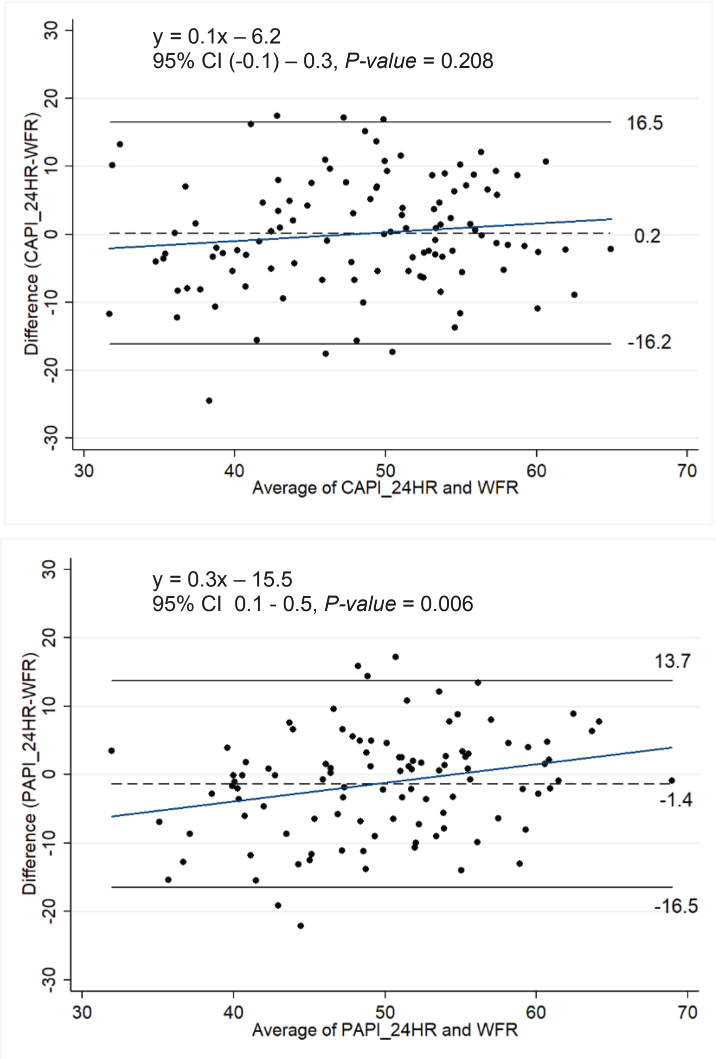

Figure 3.2. Bland and Altman's plots examine the agreement between total Vietnamese Healthy Eating Index scores measured by (a) 24HR-CAPI against WFR (n=109) and (b) 24HR-PAPI against WFR (n=103). In each figure, the dotted middle line represents the mean difference between scores. The black straight lines present the upper and lower LOA ± 1.96SD. The fitted regression line in dark blue indicates whether there is a systematic bias between the methods.

Table 3.4. Mean and standard deviation of the total Vietnamese Healthy Eating Index score and its component scores, partial Pearson correlation coefficients*, and weighted Cohen's kappa between the component scores derived from different dietary assessment methods of participants in the INDDEX24 validation study (n=212)

Components of the VHEI	24HR-CAPI Mean ± SD	WFR Mean ± SD	24HR-PAPI Mean ± SD	WFR Mean ± SD	Correlation coefficient†		Correlation coefficient‡		Weighted kappa† (95% CI)		Weighted kappa‡ (95% CI)	
Vegetables	7.7 ± 2.7	8.2 ± 2.6[a]	7.8 ± 2.7	8.4 ± 2.3[b]	0.47	<0.001	0.60	<0.001	0.34^{β}	0.20 - 0.48	0.46^{γ}	0.34 - 0.58
Fruits	4.5 ± 4.0	4.2 ± 3.9	5.3 ± 4.1	4.6 ± 3.9[b]	0.81	<0.001	0.81	<0.001	0.69^{δ}	0.57 - 0.82	0.69^{δ}	0.56 - 0.81
Grains	7.8 ± 2.2	7.7 ± 2.2	7.8 ± 2.1	8.0 ± 2.0	0.59	<0.001	0.71	<0.001	0.49^{γ}	0.37 - 0.62	0.43^{γ}	0.30 - 0.55
Protein-rich foods	7.2 ± 2.7	6.6 ± 2.9	6.5 ± 3.0	7.0 ± 2.7	0.22	0.020	0.40	<0.001	0.13^{α}	0.01 - 0.26	0.24^{β}	0.12 - 0.37
Fats and oils	4.1 ± 3.2	4.4 ± 2.9	4.8 ± 3.1	5.1 ± 3.0	0.60	<0.001	0.39	<0.001	0.44^{γ}	0.33 - 0.55	0.32^{β}	0.19 - 0.46
Dairy	0.8 ± 2.4	0.8 ± 2.3	1.1 ± 2.3	1.0 ± 2.4	0.87	<0.001	0.80	<0.001	0.80^{δ}	0.63 - 0.97	0.70^{δ}	0.53 - 0.87
Sugar and sweets	9.2 ± 2.8	9.5 ± 2.1	9.4 ± 2.2	9.4 ± 2.2	0.26	0.007	0.64	<0.001	0.32^{β}	0.04 - 0.60	0.59^{γ}	0.33 - 0.86
Salt and sauces	7.0 ± 3.7	6.9 ± 3.7	6.4 ± 3.8	6.9 ± 3.7	0.16	0.105	0.21	0.032	0.16^{α}	0.02 - 0.31	0.18^{α}	0.03 - 0.32
Total VHEI score	**48.4 ± 9.2**	**48.2 ± 8.3**	**49.1 ± 9.1**	**50.5 ± 7.3**	**0.55**	**<0.001**	**0.58**	**<0.001**	-	-	-	-

VHEI, Vietnamese Healthy Eating Index, with a range from 0 to 80 points. WFR, weighed food record. 24HR-CAPI, 24-hour individual dietary recalls using the computer-assisted personal INDDEX24 platform. 24HR-PAPI, 24-hour individual dietary recalls using a pen-and-paper questionnaire. SD, standard deviation. CI, confidence interval.
a Significantly difference between the scores derived from 24HR-CAPI compared to WFR with a *P-value* of <0.05 calculated from paired t-test.
b Significantly difference between the scores derived from 24HR-PAPI compared to WFR with a *P-value* of <0.05 calculated from paired t-test.
* Adjusted for energy intake from WFR.
† Tested between WFR and 24HR-CAPI (n=109).
‡ Tested between WFR and 24HR-PAPI (n=103).
α Poor agreement. β Fair agreement. γ Moderate agreement. δ Good agreement.

Table 3.5. The association between the Vietnamese Healthy Eating Index and energy and nutrient intakes of participants in the Vietnamese General Nutrition Survey 2019-2020 (n=3,528) and participants in the INDDEX24 validation study (n=212)

	GNS 2019-2020 (n=3,258)				INDDEX24-WFR (n=212)			
	Absolute intake*		Adjusted intake*,‡		Absolute intake		Adjusted intake‡	
	Mean ± SD	r_s	Mean† ± SD	r_s	Mean ± SD	r_s	Mean ± SD	r_s
Energy intake (kcal)	1998 ± 863.9	0.11†	-	-	1755 ± 476.3	0.10	-	-
Macronutrients (g)								
Protein	82.8 ± 41.7	0.05†	16.7 ± 4.7	-0.03	78.3 ± 35.7	0.04	17.8 ± 5.9	-0.11
Carbohydrate	289.7 ± 139.8	0.15†	58.8 ± 13.8	-0.03	255.7 ± 81.9	0.22†	58.5 ± 10.2	0.06
Dietary fibre	8.7 ± 7.5	0.36†	-	-	8.7 ± 4.9	0.25†	-	-
Total fat	49.8 ± 34.3	0.15†	22.1 ± 10.1	0.09†	44.5 ± 21.7	0.13	22.6 ± 8.0	0.03
Saturated fat	15.0 ± 11.6	0.11†	6.6 ± 3.5	0.06†	13.4 ± 7.3	0.09	6.8 ± 2.8	-0.01
Monounsaturated fat	21.8 ± 15.8	0.15†	9.6 ± 4.8	0.09†	17.9 ± 9.6	0.08	9.1 ± 3.6	-0.03
Polyunsaturated fat	13.0 ± 9.2	0.19†	5.8 ± 2.9	0.16†	13.1 ± 7.8	0.17†	6.7 ± 3.4	0.14†
Micronutrients								
Calcium (mg)	490.3 ± 423.7	0.24†	259.4 ± 220.6	0.20†	534.6 ± 316.2	0.23†	313.8 ± 171.9	0.11
Potassium (mg)	2628 ± 1244	0.25†	1357 ± 434.4	0.26†	2503 ± 794.5	0.19†	1457 ± 386.8	0.11
Sodium (mg)	3570 ± 3452	-0.01	1874 ± 1435	-0.08†	4461 ± 6788	-0.23†	2510 ± 3288	-0.32†
Magnesium (mg)	271.6 ± 188.3	0.18†	139.6 ± 80.1	0.14†	301.2 ± 209.9	0.15†	173.4 ± 107.7	0.03
Zinc (mg)	12.8 ± 11.8	0.15†	6.4 ± 4.3	0.13†	10.9 ± 3.5	0.10	6.3 ± 1.6	-0.001
Iron (mg)	14.3 ± 9.5	0.20†	7.3 ± 4.1	0.20†	14.2 ± 5.4	0.12	8.2 ± 2.6	0.01
Folate (μg)	293.8 ± 219.2	0.32†	155.5 ± 116.7	0.30†	287.4 ± 151.2	0.08	172.8 ± 108.2	0.01
Vitamin B1 (mg)	1.3 ± 0.8	0.17†	0.7 ± 0.3	0.15†	1.1 ± 0.8	0.12	0.6 ± 0.3	0.06
Vitamin B2 (mg)	0.9 ± 0.6	0.16†	0.5 ± 0.3	0.12†	1 ± 0.9	0.18†	0.5 ± 0.4	0.10
Vitamin A (μg RAE)	484.8 ± 609.6	0.18†	256 ± 339.1	0.14†	446.2 ± 368.7	0.07	256.6 ± 176.8	0.002
Vitamin C (mg)	119.7 ± 136.8	0.39†	64.7 ± 76.9	0.35†	101.6 ± 71.4	0.27†	59.5 ± 40.7	0.21†
Vitamin B6 (μg)	1.9 ± 1.2	0.15†	1.0 ± 0.4	0.11†	1.8 ± 1.4	0.13	1 ± 0.5	0.02
Vitamin B12 (μg)	5.2 ± 8.3	0.06†	2.6 ± 3.8	0.03	2.7 ± 2.6	0.12	1.5 ± 1.3	0.09

GNS 2019-2020, General Nutrition Survey 2019-2020. WFR, weighed food record. RAE, Retinol Activity Equivalents. SD, standard deviation.
* Data are presented in mean and standard deviation, adjusted for sample weights.
† A statistical significance with a *P-value* of <0.05 calculated from Spearman's correlation coefficients.
‡ Energy percentage was presented for adjusted macronutrient intakes and mean intakes per 1,000 kcal was presented for adjusted micronutrient intakes.

The relationship between the VHEI and nutrient intakes is shown in **Table 3.5.** In the GNS 2019-2020, for each of the essential micronutrients (calcium, potassium,

Chapter 3

magnesium, zinc, iron, folate, Vitamin B2, vitamin B1, vitamin A, vitamin C, vitamin B6, vitamin B12), there was a positive correlation between the VHEI and the intake, both before and after energy adjustment. For the INDDEX24-WFR, positive correlations were observed for micronutrient calcium, potassium, magnesium, Vitamin B2, and vitamin C before energy adjustment and only micronutrient vitamin C after energy adjustment. There was inverse correlation between the VHEI and sodium intake in both datasets, before and after energy adjustment. In contrast, higher VHEI was positively associated with higher dietary fibre intake (GNS 2019-2020 & INDDEX24-WFR).

DISCUSSION

This study provided evidence of the evaluation of the VHEI regarding its reliability and validity, including construct, criterion, and relative validity. We also applied the VHEI to the latest nationally representative survey and a subpopulation survey to examine the association between diet quality and nutrient intakes. The VHEI is proved a valid measure of diet quality in alignment with the 2016-2020 Vietnamese FBDGs based on the construct and criterion validity results.

The construct validity of the VHEI is supported by the results of the GNS 2019-2020 analyses. Firstly, the VHEI successfully captured the difference in diet quality between subpopulations with known differences in diet quality. The total VHEI scores were significantly higher in women and non-smokers, following our expected direction. These results align with other studies in both Western and Asian populations(16; 25). A body of literature on diet quality studies has also found that individuals who adhered to diet quality indices mostly had favourable health behaviours associated with being older, married, higher education, higher physical activity levels and non-smoking(26; 27; 28). Secondly, the distribution of the VHEI was wide enough to show the significant variances in diet quality among participants in our study population. Thirdly, there were low correlations between the total VHEI score and its component scores and energy intake, indicating its ability to assess diet quality independent of dietary quantity. This feature of a diet quality index such as VHEI is considered necessary because if the score was dependent on the quantities of foods consumed, higher scores might be due to eating higher quantities of food rather than the higher quality of foods consumed in such circumstances [16]. Lastly, the PCA analysis highlighted the multidimensional nature of the VHEI as the underlying construct of diet quality is multifaceted[29], suggesting that the VHEI component scores are equally as important as the total VHEI score.

Validating the association with health outcomes is the most significant criterion in choosing a specific *a priori* diet quality index[4]. The VHEI has proved its predictive criterion validity for overweight and obesity in the present study. A higher VHEI score was associated with a lower prevalence of overweight and obesity among Vietnamese adults. An existing body of evidence from prospective observational studies has also found the inverse relationship between diet quality and the risk of overweight and obesity[30; 31; 32]. However, the associations between diet quality indices and overweight and obesity were inconsistent among studies[33]. For example, a systematic review by Asghari *et al.* has discussed that the original Healthy Eating Index (HEI), a well-known index, reflected a reduced risk of obesity in studies conducted only in high-income countries but not LMICs[27]. Also, in this review, diet quality indices lacked efficiency in measuring overall diet quality and showed no significant findings in LMICs countries. This finding is predictable as the HEI was developed for Americans based on the US dietary guidelines, though it has been used widely in LMICs due to the lack of other tools and indicators. Therefore, a diet quality index tailored to the Vietnamese diet such as the VHEI becomes a promising tool for future research examining the relationship between diet quality and nutritional status in the country. Other studies also found the predictive criterion validity of other diet quality indices using prospective cohort data[16; 17; 34]. Here, higher diet quality scores were associated with decreased risk of total mortality and mortality from cardiovascular diseases and cancer in adult men and women[17; 35]. These analyses require using cohort data, typically available in high-income countries but lacking in LMICs. However, based on our criterion validity results, the VHEI can be a capable tool for measuring diet quality in future cohorts in Vietnam.

The VHEI total score did not reach the accepted standard of 0.70 for reliability in terms of internal consistency measured by the Cronbach's coefficient α, showing a lack of association between component scores. However, the size of the reliability coefficient can be influenced by the index and the study sample[36]. The coefficient α is also low in other diet quality indices because diet quality is considered to be a complex and multidimensional construct[37; 38]. For example, the Cronbach's coefficient α was 0.43 measured for the HEI-2005 or 0.40 measured for the Healthy Eating Index for Australian Adults (HEIFA-2013). As mentioned earlier, the PCA analysis confirmed the multidimensional character of the VHEI. Furthermore, internal consistency is also not a compulsory feature of a diet quality index such as VHEI since it is not easy for people to consistently meet all the recommendations used to assess diet quality[37]. However, internal consistency may have implications for its interpretation in different research applications; it should be therefore considered in future research when applying the VHEI.

The novelty of this paper is in evaluating the relative validity of the VHEI using different dietary assessment methods. In this context, the comparison refers to the extent to which the test method (i.e., 24HR-CAPI or 24HR-PAPI) agrees with the reference method (i.e., WFR) when applying to the same fundamental concept (i.e., VHEI)[23; 39]. We found that there was no difference in the mean VHEI scores derived from 24HR-CAPI compared to WFR (48.4 vs 48.2) or between the 24HR-PAPI and WFR (49.1 vs 50.5), although the difference in score between the 24HR-PAPI and WFR was larger. The component scores for vegetables and fruits also showed significant differences between 24HR-PAPI and WFR, and only for vegetables between the 24HR-CAPI and WFR. The Bland-Altman plots indicated there was no systematic bias between the VHEI derived from 24HR-CAPI compared to WFR, but there was a bias comparing 24HR-PAPI to WFR. These results show that the differences in VHEI scores produced by these two methods could be large at an individual level. In the INDDEX24 validation study, the 24HR-CAPI performed slightly better than the 24HR-PAPI across several accuracy measures, though they were not significantly different from one another on most measures [19]. The authors also discussed that the 24HR-CAPI sample was somewhat more educated than the 2HR-PAPI sample, which might have affected the ability of 24HR-CAPI respondents to better recall foods relative to 24HR-PAPI respondents[19]. The difference in the scores between the methods can also be partially explained by the day-to-day variation of dietary intake among participants since we scored them based on 1-day dietary intakes as discussed in other studies[40; 41]. Additionally, measurement errors of the dietary assessment methods and differences in estimates produced by the methods may affect the diet quality index[42].

Although the component scores of the VHEI are developed in terms of food groups, not nutrients, the positive correlations between the VHEI and the nutrient intakes proved that the VHEI reflects the fulfilment of nutrient requirements. A higher VHEI was shown to be associated with higher diet quality in general, including low intake of saturated fat and sodium and a high intake of various vitamins and minerals, similar to the results of our previous study[12].

Future research should consider the following when using the VHEI. First, the VHEI scoring system allows the calculation of scores at the individual level using dietary intake data derived from 24HRs, FFQs, and food diaries. The quantity of the following food groups (vegetables and fruits) and nutrients (protein, carbohydrate, calcium, sugar, and sodium) is needed to calculate the serving of each component to compute the scores. The investigation of different combinations of point values assigned to categories of components and computing sub-metric scores using subsets of components instead of all components is allowed since we developed three categories (adequacy, moderation, and optimum) in scoring the VHEI. Second, the VHEI is appropriate for assessing diet quality among populations to which the 2016-2020 Vietnamese FBDGs apply; it does not apply to other populations (i.e., pregnant and lactating women, children, and adolescents). Lastly, the application of the VHEI for assessing and analysing diet quality in surveillance, epidemiologic, and intervention research, especially prospective cohort studies, is promising.

In practice, an individual's usual intake is not easy to measure, especially in low-resource settings such as Vietnam. Typically, a single day of food consumption collected via a 24HR has been available. In such conditions, the VHEI can be calculated from 1-day dietary intake data, similar to what we performed in this study, but this might lead to a biased measure of the individual's VHEI score. In other diet quality indices, such as the HEI, calculating the scores using 1-day dietary intake data has resulted in a lower score than using usual dietary intake data[40; 41]. This issue is considered a limitation of this study and should be addressed in future studies when applying the VHEI.

Measuring diet quality in LMICs is more complicated to operate and interpret as it is also complex in such countries to assess diet quality in terms of reaching nutrient adequacy and prevention of overweight and obesity and diet-related NCDs simultaneously. This study proved that the VHEI is a valid tool for diet quality assessment in Vietnam. This scientific evidence may serve as a reference for future research and a foundation for developing and improving the FBDGs in Vietnam.

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Chapter 3

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SUPPLEMENTARY MATERIALS OF CHAPTER 3

Table 3.S1. Sociodemographic characteristics of participants in the Vietnamese General Nutrition Survey 2019-2020 (n=3,528)

Sociodemographic characteristics*	Total (n=3,528)	Male (n=880)	Female (n=2,648)
Age, years (Mean ± SD)	34.5 ± 7.5	34.2 ± 5.6	35.2 ± 8.9
BMI, kg/m^2 (Mean ± SD)	22.5 ± 3.4	22.6 ± 2.3	22.5 ± 4.3
Smoker (%)	17.8	37.5	0.2
Weight status† (%)			
Underweight	7.1	7.9	6.5
Normal weight	54.0	50.1	57.4
Overweight	32.3	34.9	30.0
Obesity	6.6	7.1	6.1
Region (%)			
Northern midlands and mountain areas	12.9	13.3	12.5
Red River delta	19.8	19.6	20.0
Northern and central coastal areas	22.4	23.1	21.8
Central highland	5.8	5.4	6.2
Southeast	20.0	19.0	20.9
Mekong River delta	19.1	19.6	18.6
Education (%)			
No education	9.3	7.2	11.2
Primary	13.7	12.5	14.7
Secondary	28.5	26.2	30.6
High school	21.4	24.3	18.7
Vocational training	7.7	9.0	6.6
College, university or postgraduate	19.4	20.8	18.2
Occupation (%)			
Farmer	19.6	20.0	19.3
Employee	28.2	31.9	25.0
Business or services	13.6	15.0	12.3
Freelance	19.6	24.2	15.4
Housewife	12.7	0.6	23.5
Others‡	6.3	8.3	4.5

SD, standard deviation. BMI, Body Max Index.
* Data are presented in mean and standard deviation or percentage (%), adjusted for sample weights.
† Weight status is defined based on BMI cut-off point for the Asian population[24].

Chapter 3

Table 3.S2. Sociodemographic characteristics of participants in the INDDEX24 validation study (n=212)

Sociodemographic characteristics	**WFR & 24HR-CAPI (n=109)**	**WFR & 24HR-PAPI (n=103)**
Age, years (Mean ± SD)	35.9 ± 7.2	37.3 ± 7.4
Education (%)		
No education	0.9	1.0
Primary	0.0	1.0
Secondary	18.3	25.2
High school	31.2	30.1
Vocational training	3.7	3.9
College or university	45.9	38.8
Weekly frequency of food preparation (%)		
All or most of the time	74.3	79.6
Sometimes (3-6 meals)	19.3	11.7
Rarely (1-2 meals)	6.4	8.7
Main mode of transportation to buy food (%)		
Walking	10.1	13.6
Bicycle	20.2	27.2
Motorbike	67.9	57.3
Other	1.8	1.9

SD, standard deviation. WFR, weighed food record. 24HR-CAPI, 24-hour individual dietary recalls using the computer-assisted personal INDDEX24 platform. 24HR-PAPI, 24-hour individual dietary recalls using a pen-and-paper questionnaire.

Table 3.S3. Means (standard deviation) in percentiles of total Vietnamese Healthy Eating Index score and its component scores of participants in the Vietnamese General Nutrition Survey 2019-2020 (n=3,528)

Components of the VHEI*	Mean ± SD	Percentiles								
		1st	5th	10th	25th	50th	75th	90th	95th	99th
Vegetables	6.7 ± 3.4	0.0 ± 0.0	0.4 ± 0.1	1.5 ± 0.04	3.6 ± 0.03	7.4 ± 0.04	10 ± 0.0	10 ± 0.0	10 ± 0.0	10 ± 0.0
Fruits	3.5 ± 3.9	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.8 ± 0.1	6.9 ± 0.1	10 ± 0.0	10 ± 0.0	10 ± 0.0
Grains	7.0 ± 2.6	0.0 ± 0.0	1.9 ± 0.1	3.2 ± 0.04	5.1 ± 0.02	7.4 ± 0.02	9.3 ± 0.01	10 ± 0.0	10 ± 0.0	10 ± 0.0
Protein-rich foods	5.5 ± 3.5	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	2.4 ± 0.04	6 ± 0.03	8.6 ± 0.03	9.9 ± 0.01	10 ± 0.0	10 ± 0.0
Fats and oils	4.7 ± 3.0	0.0 ± 0.0	0.1 ± 0.07	0.9 ± 0.05	2.3 ± 0.02	4.3 ± 0.04	7.2 ± 0.02	9.2 ± 0.1	9.9 ± 0.03	10 ± 0.0
Dairy	0.4 ± 1.8	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	3.9 ± 0.7	8.9 ± 0.3
Sugar and sweets	9.5 ± 1.9	0.0 ± 0.0	4.9 ± 0.6	10 ± 0.0	10 ± 0.0	10 ± 0.0	10 ± 0.0	10 ± 0.0	10 ± 0.0	10 ± 0.0
Salt and sauces	6.3 ± 4.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	2.3 ± 0.04	7.8 ± 0.02	10 ± 0.0	10 ± 0.0	10 ± 0.0	10 ± 0.0
Total VHEI score	**43.7 ± 8.5**	**21 ± 2.7**	**29.2 ± 0.2**	**32.2 ± 0.2**	**38.1 ± 0.1**	**43.6 ± 0.1**	**49.4 ± 0.1**	**54.2 ± 0.1**	**56.9 ± 0.3**	**61.3 ± 0.6**

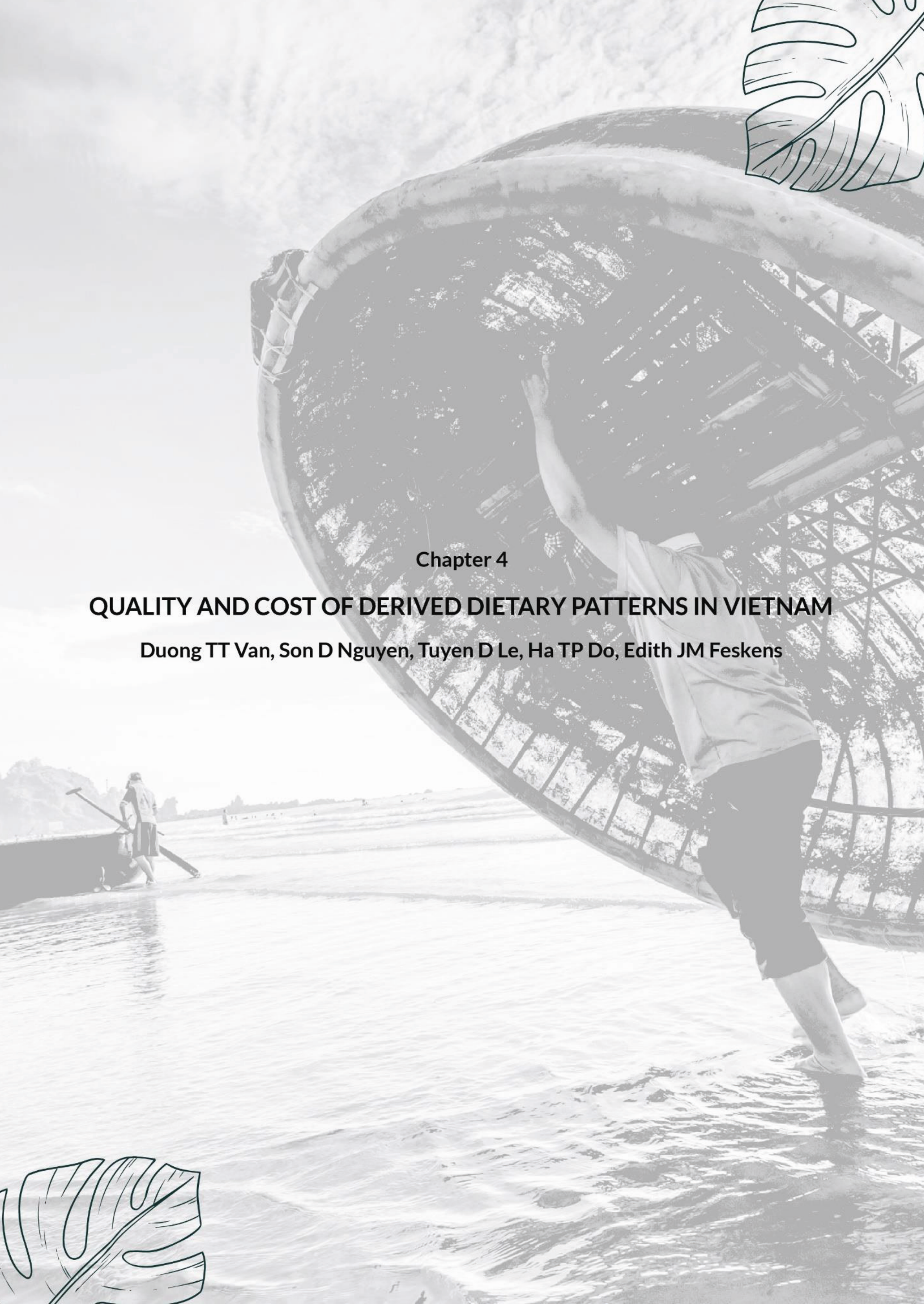
VHEI, Vietnamese Healthy Eating Index, with a range from 0 to 80 points. SD, standard deviation.
* Data are presented in mean and standard deviation, adjusted for sample weights.

Table 3.S4. Estimated Pearson correlations between eight component scores and the correlations between each component score and total Vietnamese Healthy Eating Index score, and energy intake of participants in the Vietnamese General Nutrition Survey 2019-2020 (n=3,528)

Components of the VHEI	Grains	Protein-rich foods	Vegetables	Fruits	Dairy	Fats and oils	Sugar and sweets	Salt and sauces	Total VHEI score
Grains	1.00								
Protein-rich foods	0.05*	1.00							
Vegetables	0.03	-0.07*	1.00						
Fruits	0.02	0.03	0.11*	1.00					
Dairy	-0.01	-0.02	0.005	0.08*	1.00				
Fats and oils	0.04	-0.07*	0.22*	0.05*	0.03	1.00			
Sugar and sweets	0.003	0.03	0.04	0.01	-0.06*	-0.004	1.00		
Salt and sauces	-0.03	0.24*	-0.38*	-0.11*	-0.04	-0.33*	-0.014	1.00	
Total VHEI score	0.35*	0.50*	0.34*	0.51*	0.22*	0.30*	0.23*	0.23*	1.00
Energy intake	-0.02	-0.25*	0.25*	0.12*	0.04	0.25*	-0.06*	-0.47*	-0.09*

VHEI, Vietnamese Healthy Eating Index, with a range from 0 to 80 points.
* A statistical significance with a *P-value* of <0.05 calculated from Pearson correlation coefficients.

Bánh chưng, a traditional Vietnamese food during the Tet Holiday.



Chapter 4

QUALITY AND COST OF DERIVED DIETARY PATTERNS IN VIETNAM

Duong TT Van, Son D Nguyen, Tuyen D Le, Ha TP Do, Edith JM Feskens

ABSTRACT

Few studies have analysed dietary patterns concerning diet quality and cost, especially in low- and middle-income countries (LMICs) such as Vietnam. This study aims to analyse the general Vietnamese population's most common dietary patterns and assess their diet quality and cost. The participants were 3,528 Vietnamese adults aged ≥ 20 participating in the Vietnamese General Nutrition Survey 2019-2020 (GNS 2019-2020). Dietary intake was measured by 24-hour recalls (24HR), from which 21 food groups were formed and analysed with principal component analysis (PCA). The mean probability of adequacy (MPA) for micronutrients, the Global Diet Quality Score (GDQS), and the Vietnamese Healthy Eating Index (VHEI) were applied to measure and compare diet quality. We linked the prices of food items in the list of foods collected for the monthly Consumer Price Index (CPI) and dietary intake data to estimate the cost of the derived dietary patterns. We identified three dietary patterns: meat, pescatarian, and healthy. Overall, the MPA was high in all the highest quintiles of the three dietary patterns (0.70 ± 0.19 for the meat and pescatarian patterns and 0.72 ± 0.22 for the healthy pattern). Higher adherence to the meat pattern was associated with lower total VHEI scores and higher diet cost (both before and after energy adjustment). Higher adherence to the healthy pattern was associated with higher both GDQS and total VHEI score, but also higher diet cost (both before and after energy adjustment). Higher adherence to the pescatarian pattern was associated with higher GDQS and lower diet cost (after energy adjustment). In conclusion, higher adherence to a healthy dietary pattern derived from recent dietary intake data was associated with both higher diet quality and cost. Therefore, higher costs might present a valid challenge to individuals who are in consideration of adopting a healthy diet in Vietnam.

Key words: dietary patterns, diet quality, diet cost, Vietnamese Healthy Eating Index, Global Diet Quality Score, mean probability of adequacy

INTRODUCTION

Studying the overall diet has been proposed as an integral approach in nutritional epidemiology research to better explain the linkages between nutrition, health outcomes, and other related factors due to the complex interactions and cumulative effects of dietary exposure and other reasons[1; 2]. Different approaches can be applied to study overall dietary patterns, commonly classified as *a priori* and *a posteriori* methods[3]. The *a priori* approach defines an index or indicator of overall diet quality, usually based on official dietary guidelines or well-known healthy diets[4]. In contrast, in the *a posteriori* approach, empirically derived dietary patterns are driven by the underlying dietary intake data using statistical techniques such as cluster or factor analyses[5].

In the literature, the *a posteriori* approach has been applied widely to explore the relationship between empirically derived dietary patterns and health outcomes such as diet-related NCDs[6; 7] or body mass index (BMI) and waist circumferences[8; 9], or overweight and obesity[10]. However, this approach has not been used broadly to investigate the linkages between dietary patterns and other related factors, while they are strongly shaped by many drivers such as food prices, incomes, food preferences, cultural traditions and beliefs, as well as geographical, environmental, social and economic factors[11]. Among these factors, food prices are among the essential determinants influencing people's choices in dietary consumption[12].

Approximately three billion people cannot afford healthy diets worldwide, the majority located in Africa and Asia[13]. Therefore, more effective interventions in food systems are needed to ensure access to healthy foods and diets and increase the opportunities to achieve higher diet quality and thus better nutrition outcomes for the population. These interventions should be highly focused on LMICs such as Vietnam. The country has been experiencing a marked nutritional transition in recent decades, which resulted in a dramatic increase in poor nutrition and health outcomes, especially overweight and obesity and diet-related noncommunicable diseases (NCDs)[14; 15].

The recent study by Nguyen *et al.* showed that the derived dietary patterns in Vietnam were low in diet quality in terms of nutritional adequacy and dietary diversity[16]. Additionally, the diets of the general Vietnamese population are not fully aligned with the quality defined by the national food-based dietary guidelines (FBDGs)[17]. However, these studies were conducted using the general nutritional survey conducted in 2009-2010, while the diet in Vietnam has shifted towards patterns with higher energy intake, processed foods, and animal source foods following the continuing nutritional transition[18; 19]. Concerning the cost and affordability, a healthy diet is unaffordable for approximately 70% of low-income households and the cost of healthy food groups (protein-rich foods, vegetables, fruits, and dairy) accounted for approximately 80% in the total cost of healthy diets[20]. However, to our knowledge, the cost of dietary patterns consumed by the general Vietnamese population has not been investigated.

Therefore, this study was designed to use the *a posteriori* approach to examine the empirical patterns in Vietnamese adults and their associations with sociodemographic characteristics, nutrient intakes, overall diet quality and cost.

SUBJECTS AND METHODS

Study population

The General Nutrition Survey 2019-2020 (GNS 2019-2020) was conducted by National Institute of Nutrition (NIN), Ministry of Health, Vietnam[21] and was carried out following the guidelines laid down in the Declaration of Helsinki and approved by the Medical Research Ethics Committee of NIN with decision number 441/VDD-QLKH on August 6, 2019. Written informed consents were obtained from the participants before data collection. NIN permitted access to the GNS 2019-2020 dataset for the analyses of this study. We used the sociodemographic, anthropometric data, and dietary intake data of a sample of 3,528 Vietnamese adults aged ≥ 20 years, including 880 men and 2,648 non-lactating, non-pregnant women.

Sociodemographic data included information about age, gender, region, occupation, education, and smoking status. The trained interviewers of NIN collected anthropometric data that included body weight (to the nearest 100g) and height (to the nearest 0.5cm) following a prepared protocol[21]. BMI was calculated as weight (kg) divided by height squared (m^2).

Dietary assessment

The multiple-pass quantitative 24HR technique was used to obtain the dietary intake data of the participants. A master database of standard recipes, retention factors, edible portions, and yield factors was developed during the pre-survey work at NIN and used to convert the dietary intake data into the raw gram of each of the food items. In this study, we used a 1-day dietary intake of the participants to calculate the food groups and energy and nutrient intakes.

The 2019 Vietnamese Food Composition Table (FCT) was the primary source used to estimate energy and nutrient intakes. Missing nutrient values were complemented with data from the 2017 Indian FCT [22], the 2015 Standard FCT in Japan[23], Food Data Central, The US Department of Agriculture (USDA)[24] (mentioned in order of use).

Dietary pattern analysis

We applied PCA to 24HR dietary intake data to derive dietary patterns. Food items from the GNS 2019-2020 database were first aggregated into food groups. We used the eight foundational food groups of the 2016-2020 Vietnamese FBDGs as the basic for food group classification, including grains, protein-rich foods, fats and oils, vegetables, fruits, dairy, sugar and sweet, and salt and sauces. We formed 21 food groups by dividing the main food groups into smaller sub-food groups, based on nutritional aspects (as recommended in the Vietnamese FBDGs) and cost (e.g., animal source protein-rich foods is more expensive than plant-based protein-rich foods). For example, the protein-rich foods were classified into red meat, poultry, processed meat, fish (including freshwater fish, diadromous fish, and marine fish), seafood (including crustaceans and molluscs), eggs, legumes and beans, and soy products, based on their nutritional compositions. Several food groups not found in the FBDGs composed their own groups (i.e., alcoholic beverages). The final 21 food groups were entered into the PCA as absolute weight in grams.

We applied the procedure for PCA using Stata software. First, we used the Kaiser-Meyer-Olkin test and Bartlett's test for sphericity examination to ensure that the data were appropriate for factor analysis. The Kaiser-Meyer-Olkin test reached the acceptable limit of 0.5, and a significance level for Bartlett's test below 0.05 proved a substantial correlation in the data. The PCA yielded the factors that are linear combinations of the included variables and explained the variation in the original variables. The orthogonal (uncorrelated) factors were obtained using varimax rotation. We decided on the number of factors that should be retained by running factor solutions ranging from two to nine, including food group components with an eigenvalue > 1. We examined the scree plots and the eigenvalues, suggesting that retaining two or three factors should be optimal. A three-factor solution was selected since this solution provided factors that were more interpretable and explicable. We examined factor solutions separately for men and women but retained the factor solution that included both men and women to maximize statistical power.

Factor loadings were calculated for each of the food groups across the three factors (dietary patterns). A dietary pattern score was calculated for each individual for the three factors, in which the standardized intakes of each food group were weighted by their factor loadings and summed up. These dietary pattern scores rank participants according to the degree to which they adhered to each dietary pattern, where they were scored for all three derived dietary patterns.

Diet quality measurement

Diet quality was assessed as different indicators, including nutrient adequacy for micronutrients, a global diet quality indictor (GDQS), and the Vietnamese Healthy Eating Index (VHEI). First, the nutrient adequacy for micronutrients (including 12 micronutrients calcium, potassium, magnesium, zinc, iron, folate, Vitamin B1, vitamin B2, vitamin A, vitamin C, vitamin B6, and vitamin B12) was determined via the probability approach to assess the adequate nutrient intake[25]. The estimated average requirements (EARs) for potassium was adapted based on the 2016 Vietnamese recommended dietary allowance (RDA) book[26] and the EARs for magnesium, zinc, folate, vitamin B1, vitamin B2, vitamin A, vitamin C, vitamin B6, and vitamin B12 were adopted from Allen *et al.*[27] (Supplementary Table 4.S1). Standard deviations (SDs) were derived via the formula RDA = EAR +2SD. The *normal* function in Stata was used to obtain the probability of adequacy (PA), except for iron and calcium. The PA of iron was calculated based on the US Institute of Medicine (IOM) recommendation on assessment of iron intake[25]. We used iron bioavailability of 10% instead of 18% according to the suggestion for a simple and monotonous diet based on mainly rice[28], and to be consistent with other studies in Vietnam[29; 30]. The PA of calcium was calculated using the approach demonstrated by Foote *et al.*, which compared intake levels to the adequate intake[31]. The average PA within a district showed the prevalence of nutrient adequacy[32]. The MPA was calculated as the average of all single PAs for each individual.

Second, we used a global diet quality indicator, the GDQS, to measure the diet quality of the derived dietary pattern[33]. The full GDQS has 25 food groups, in which each food group is scored based on the gram intake per day, resulting in a final score ranging from 0 to 49 points, with a higher score describing a healthier diet. The Positive Sub-metric (GDQS+) includes 16 healthy food groups and ranges from 0 to 32 points. The Negative Sub-metric (GDQS-) comprises nine unhealthy food groups, including red meat and full-fat dairy (we followed the recent validation analysis of GDQS by Fung *et al.*[(34)]). GDQS- ranges between 0 and 17 points, where a higher score represents a lower consumption of unhealthy food groups. Complete development and validation of the GDQS are described in detail in the study by Bromage *et al.*[(33)].

Lastly , we calculated the VHEI as another diet quality indicator. The VHEI was developed and evaluated to measure diet quality in terms of conformance to the 2016-2020 FBDGs for the general Vietnamese population aged ≥ 20 years. The index is an 80-point scale, with a higher score demonstrating higher adherence to the FBDGs and thus higher diet quality. The eight component scores with a maximum score of 10 points each reflect the recommendations relating to the eight food groups, including vegetables, fruits, grains, protein-rich foods, fats and oils, dairy, sugar and sweets, and salt and sauce. The scoring system of the VHEI is described in our previous study[(17)].

Diet cost measurement

We used the monthly price of food items in the list of food and non-alcoholic beverages in 63 provinces by the General Statistics Office (GSO), Vietnam, for the monthly CPI. The average price of all food items at the national level in 2019 was used. Because we had no access to the price of alcoholic beverages from the GSO, we adapted the price for various kinds of beer and wine from the Vietnamese Household Living Standard Survey (VHLSS) 2019-2020, which has been described in detail elsewhere[(20)].

A master database with all food items consumed by GNS 2019-2020 participants was completed by assigning the price for each food item listed. Since the price database did not cover all the food items of the GNS 2019-2020, we calculated the average price of each of the sub-food groups in terms of nutritional composition and then obtained the average price for food items with missing prices, for example, the average price of beans was assigned to red beans. A conversion was needed for some food items. For example, the price of eggs was given per ten eggs, so a conversion was made to obtain the price per kilogram. Edible and yield factors were also applied to convert the prices into the price per gram edible portion, using our previous database(20). The daily diet cost of the participants was calculated by multiplying the price of food items with the amount of consumed food based on the 24HR data. We also calculated the energy-adjusted diet cost as the daily diet cost per 2,000 kcal.

Statistical analysis

The statistical software package Stata version 15.0 was used to perform all statistical analyses. Descriptive statistics were presented as mean and SDs for continuous variables and percentages for categorical and ordinal variables. All analyses appropriately applied the sample weights of the GNS 2019-2020 dataset to account for the complex structure of the survey. A *P-value* of less than 0.05 was considered statistically significant.

We examined the associations of dietary pattern score with sociodemographic characteristics, diet quality and cost, using general linear models comparing means of outcomes across quintiles of the dietary pattern scores. Analysis of covariance was used to calculate adjusted mean and prevalence according to quintiles of dietary pattern scores. We calculated *P-value* for trend with quintiles of dietary pattern scores modelled as continuous variables. Partial Pearson correlation coefficients were calculated between each of the derived dietary patterns and daily energy intake, adjusted for gender and between each of the derived dietary patterns and nutrient intakes, adjusted for gender and energy intake.

RESULTS

Derived dietary patterns

Factor loadings for the three dietary patterns derived from the dietary intake of the general Vietnamese population using principal component analysis are presented in **Table 4.1**. The factor that we denoted “meat pattern” (factor 1) was identified by the consumption of red meat, processed meat, animal fat, rice and rice products, poultry, other vegetables, alcohol, and especially extremely high consumption of salt and sauces. Factor 2, named the “pescatarian pattern”, was characterised by greater consumption of rice and rice products, fish, plant-based oils, rich vitamin A vegetables, and lesser consumption of non-rice starchy staples, poultry, processed meat, dairy, and sugar and sweets. We derived a “healthy pattern” (factor 3) loaded with fruits (both rich vitamin A fruits and other fruits), plant-based oils, vegetables, seafood, eggs, and other plant-based protein sources such as legumes and beans and soy products. This “healthy pattern” was also characterised by non-rice starchy staples and tubers, nuts and seeds, and dairy and dairy products. Overall, the three derived dietary patterns explained 21.3% of the variation in dietary intake. Factor 1 (meat pattern) was the most dominant dietary pattern in the study population and explained 8.7% of the variance, whereas the remaining two factors explained 6.6% (factor 2) and 6.0% (factor 3) of the variation in dietary intake.

Table 4.1. Factor loadings of derived dietary patterns of participants in the Vietnamese General Nutrition Survey 2019-2020 (n=3,528)*

	Factor 1 **Meat pattern**	**Factor 2** **Pescatarian pattern**	**Factor 3** **Healthy pattern**
Rice and rice products	0.21	0.63	-
Non-rice starchy staples and tubers	-	-0.31	0.34
Red meat	0.51	-	-
Poultry	0.29	-0.20	-
Eggs	-	-	0.24
Processed meat	0.57	-0.23	-
Fish	-	0.55	-
Seafood	-	-	0.30
Legumes and beans	-	-	0.30
Soy products	-	-	0.23
Plant-based oils	-	0.41	0.50
Animal fat	0.40	-	-
Nuts and seeds	-	-	0.31
Dairy and dairy products	-	-0.24	0.27
Vitamin-A-rich vegetables	-	0.46	-
Other vegetables	0.32	-	0.32
Vitamin-A-rich fruits	-	-	0.40
Other fruits	-	-	0.48
Sugar and sweets	-	-0.23	-
Salt and sauces	0.69	-	-
Alcoholic beverages	0.26	-	-

(*) Factor loadings < 0.2 are not presented for simplicity.

Chapter 4

Sociodemographic characteristics of derived dietary patterns

Table 4.2 shows the means and percentages of sociodemographic characteristics by quintiles of dietary pattern scores (Q1 and Q5 are shown). individuals in the higher quintile of meat pattern were more often males, younger, smokers, attending high school and college, university or postgraduate, employed, and living in the Northern and central coastal areas and the Red River delta. The pescatarian pattern scores were associated with being male, a smoker, and mainly from the Northern and central coastal areas and the Mekong River delta. Higher healthy pattern scores were associated with being female, a non-smoker, having higher education, and were from the Red River delta.

Correlations with energy and nutrient intakes

Higher scores of all three derived dietary patterns were positively correlated with energy intake (adjusted for gender), is showed in **Table 4.3**. The correlations between dietary pattern scores and nutrient intakes (adjusted for gender and energy intake) are also shown in **Table 4.3**. Higher meat pattern scores were strongly correlated with a higher intake of sodium (r 0.53), saturated fat (r 0.42), monounsaturated fat (r 0.38), and total fat (r 0.36), and with lower intakes of carbohydrates (r -0.44), dietary fibre (r -0.14), and vitamin C (r -0.08). In contrast, adherence to the pescatarian pattern was correlated with a lower intake of saturated fat (r -0.33), monounsaturated fat (r -0.23), and total fat (r -0.22), but also a lower intake of some vitamins and minerals, including magnesium (r -0.10), vitamin B1 (r -0.14), vitamin B2 (r -0.14), and vitamin B6 (r -0.04). The healthy pattern was inversely correlated with carbohydrate intake (r -0.16) and strongly correlated with higher intakes of dietary fibre (r 0.53), polyunsaturated fats (0.45), and a number of vitamins and minerals such as potassium (r 0.48), vitamin C (r 0.47), magnesium (r 0.44), folate (r 0.40), and calcium and Vitamin B2 (r 0.29).

Table 4.2. Sociodemographic characteristics for the lowest and highest quintiles of derived dietary patterns of participants in the Vietnamese General Nutrition Survey 2019-2020 (n=3,528)

	Meat pattern			Pescatarian pattern			Healthy pattern		
Sociodemographic characteristics*	Q1 (n=702)	Q5 (n=707)	*P-value*†	Q1 (n=709)	Q5 (n=704)	*P-value*†	Q1 (n=708)	Q5 (n=709)	*P-value*†
Women (%)	72.5	32.0	<0.001	66.5	33.9	<0.001	42.5	58.5	0.001
Age, years (Mean ± SD)	35.6 ± 8.5	33.3 ± 6.3	<0.001	34.2 ± 8.4	34.5 ± 6.7	0.396	34.8 ± 7.8	34.2 ± 7.2	0.571
Smoker (%)	11.6	27.1	<0.001	11.2	28.2	<0.001	20.1	13.8	0.048
BMI, kg/m^2 (Mean ± SD)	22.6 ± 4.0	22.4 ± 2.9	0.596	22.5 ± 3.4	22.4 ± 2.8	0.335	22.3 ± 3.4	22.5 ± 3.1	0.365
Region (%)									
Northern midlands and mountain areas	19.8	6.9	ref	9.6	11.6	ref	22.9	8.4	ref
Red River delta	18.6	21.4	<0.001	23.8	17.6	0.021	11.2	31.3	<0.001
Northern and central coastal areas	15.8	25.9	<0.001	14.5	27.5	0.019	23.3	23.5	<0.001
Central highland	5.9	6.6	<0.001	5.3	6.0	0.869	9.6	3.5	0.744
Southeast	19.0	20.5	<0.001	30.7	12.7	<0.001	13.5	19.7	<0.001
Mekong River delta	20.9	18.7	<0.001	16.1	24.6	0.028	19.5	13.6	0.005
Education (%)									
No education	16.4	4.0	ref	6.9	8.4	ref	18.2	3.1	ref
Primary	17.4	8.8	0.201	10.9	16.1	0.112	20.6	7.9	0.124
Secondary	29.0	24.3	<0.001	28.7	27.4	0.706	28.9	20.8	<0.001
High school	16.4	27.1	<0.001	21.0	23.6	0.338	16.3	24.2	<0.001
Vocational training	5.9	9.7	<0.001	8.5	7.7	0.905	7.1	11.2	<0.001
College, university or postgraduate	14.9	26.1	<0.001	24.0	16.8	0.264	8.9	32.8	<0.001
Occupation (%)									
Farmer	26.1	14.7	ref	13.7	22.4	ref	35.6	9.6	ref
Employee	22.4	38.4	<0.001	30.0	26.8	<0.001	18.5	36.1	<0.001
Business or services	9.9	13.5	0.016	15.4	13.6	0.002	9.8	16.5	<0.001
Freelance	19.9	19.6	0.045	16.1	23.7	0.293	21.1	17.6	<0.001
Housewife	17.5	6.4	0.020	14.4	8.9	<0.001	9.2	12.6	<0.001
Others	4.1	7.4	0.011	10.4	4.6	<0.001	5.8	7.6	0.002

Q, Quintiles (Q1 = lowest adherence to the dietary pattern). SD, standard deviation. BMI, Body Max Index.
* Data are presented in mean and standard deviation or percentage (%), adjusted for sample weights.
† *P-value* for trend analysed by general linear model.

Table 4.3. Partial Pearson correlation coefficients between each of the derived dietary patterns and daily energy and nutrient intakes of participants in the Vietnamese General Nutrition Survey 2019-2020 (n=3,528)

	Meat pattern		**Pescatarian pattern**		**Healthy pattern**	
Energy and nutrient intakes	**r**	***P-value***	**r**	***P-value***	**r**	***P-value***
Energy intake (kcal)*	0.48	<0.001	0.50	<0.001	0.31	<0.001
Macronutrients (g)†						
Protein	0.30	<0.001	0.05	0.001	0.18	<0.001
Carbohydrate	-0.44	<0.001	0.22	<0.001	-0.16	<0.001
Dietary fibre	-0.14	<0.001	0.02	0.141	0.53	<0.001
Total fat	0.36	<0.001	-0.22	<0.001	0.25	<0.001
Saturated fat	0.42	<0.001	-0.33	<0.001	0.06	<0.001
Monounsaturated fat	0.38	<0.001	-0.23	<0.001	0.21	<0.001
Polyunsaturated fat	0.12	<0.001	0.05	0.005	0.45	<0.001
Micronutrients†						
Calcium (mg)	0.04	0.016	0.05	0.006	0.29	<0.001
Potassium (mg)	0.12	<0.001	0.20	<0.001	0.48	<0.001
Sodium (mg)	0.53	<0.001	0.02	0.181	0.06	<0.001
Magnesium (mg)	0.14	<0.001	-0.10	<0.001	0.44	<0.001
Zinc (mg)	0.05	0.006	0.004	0.801	0.19	<0.001
Iron (mg)	0.14	<0.001	0.03	0.116	0.28	<0.001
Folate (µg)	0.01	0.425	0.13	<0.001	0.40	<0.001
Vitamin B1 (mg)	0.35	<0.001	-0.14	<0.001	0.09	<0.001
Vitamin B2 (mg)	0.27	<0.001	-0.14	<0.001	0.29	<0.001
Vitamin A RAE (µg)	0.07	<0.001	0.05	0.002	0.07	<0.001
Vitamin C (mg)	-0.08	<0.001	0.04	0.001	0.47	<0.001
Vitamin B6 (µg)	0.34	<0.001	-0.04	0.024	0.15	<0.001
Vitamin B12 (µg)	0.04	0.013	0.08	<0.001	0.19	<0.001

* Adjusted for gender.
† Adjusted for gender and energy intake.

Quality of derived dietary patterns

Generally, the MPA was 0.49 ± 0.29 for the total population (table 4), and MPA for women (0.43 ± 0.35) was lower than for men (0.55 ± 0.21), as shown in Supplementary Table S2. Comparing the dietary patterns **(Table 4.4)**, the MPA was high in all Q5 of the three dietary patterns (0.70 ± 0.19 for the meat and pescatarian patterns and 0.72 ± 0.22 for the healthy pattern).

There was no clear association between adherence to the meat pattern and total GDQS, but adherence to this dietary pattern was associated with a higher GDQS+ and a lower GDQS-. Higher adherence to the pescatarian pattern was significantly associated with a higher total GDQS, GDQS+, and GDQS-. For the healthy pattern, the largest difference in GDQS and GDQS+ between Q5 and Q1 were observed: (22.0 ± 4.5 vs 16.1 ± 2.6, 10.8 ± 4.3 vs 4.5 ± 2.5, respectively), while the GDQS- was slightly higher for Q1 (11.6 ± 1.0) than Q5 (11.2 ± 1.6) with a *P-value* of 0.002 **(Table 4.4)**.

A similar trend was observed for the total VHEI scores in the healthy pattern, with significantly higher scores in individuals in Q5 than in Q1 (47.1 ± 9.2 vs 38.8 ± 6.4). In contrast, the total VHEI scores were significantly lower for participants who showed the highest adherence to the meat pattern compared to the lowest (41.3 ± 7.7 vs 42.5 ± 9.3), while for the pescatarian pattern no association was observed **(Table 4.4).**

Cost of derived dietary patterns

As also shown in **Table 4.4**, higher adherence to the meat and healthy patterns was associated with higher daily diet costs and diet costs per 2,000 kcal, while higher adherence to the pescatarian pattern was associated with greater daily diet costs, but lower energy-adjusted daily diet costs. Diet cost was positively associated with energy intake (r 0.53), demonstrating that those with higher energy intake had higher diet cost (data not shown). Thus, adjusting diet cost to cost per 2,000 kcal increases comparability, similarly as our partial correlations with nutrient intakes.

After adjusting for energy intake, the contrast in total cost between Q5 and Q1 was highest for the healthy pattern. Overall Q5 of the heathy pattern showed the highest cost of 87,242 VND (10.2 international dollars in 2017 Purchasing Power Parity). Seafood was the main food group that accounted for this highest cost. For the meat pattern, the cost of animal source foods, including red meat, poultry, fish, and seafood, were the major contributors to the high cost of the Q5. For the pescatarian pattern, the energy-adjusted total diet costs of Q5 were lower than Q1, although the cost of fish although fish contributed to a larger proportion of the diet costs in Q5 **(Figure 4.1).**

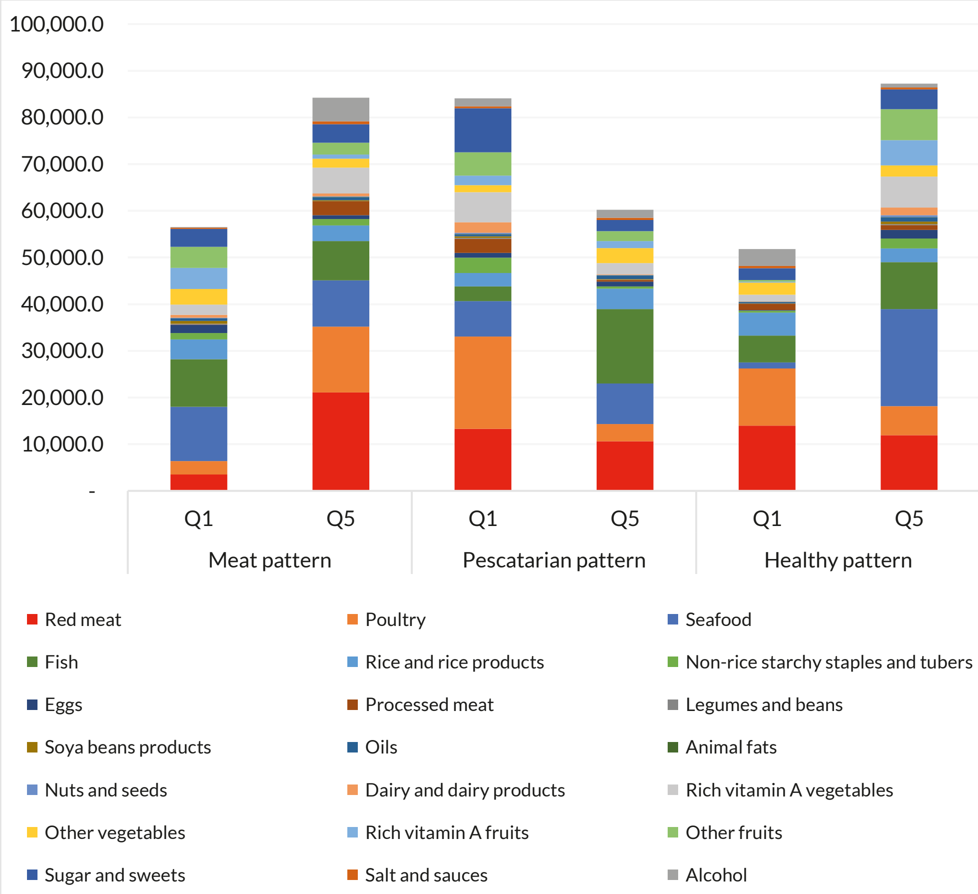


Figure 4.1. Energy-adjusted diet cost (mean ± SD) in Vietnamese Dong (VND) for the lowest (Q1) and highest (Q5) quintiles of derived dietary patterns across food group of 3,528 Vietnamese adults aged ≥ 20 years of Vietnamese General Nutrition Survey 2019-2020

Table 4.4. Means (standard deviations) of diet quality indicators and diet cost for the lowest and highest quintiles of derived dietary patterns of participants in the Vietnamese General Nutrition Survey 2019-2020 (n=3,528)

Diet quality and cost variables*	**Meat pattern**			**Pescatarian pattern**			**Healthy pattern**		
	Q1 (n=702)	**Q5 (n=707)**	***P-value*†**	**Q1 (n=709)**	**Q5 (n=704)**	***P-value*†**	**Q1 (n=708)**	**Q5 (n=709)**	***P-value*†**
Diet quality									
MPA	0.29 ± 0.31	0.70 ± 0.19	<0.001	0.40 ± 0.32	0.70 ± 0.19	<0.001	0.34 ± 0.27	0.72 ± 0.22	<0.001
GDQS	18.8 ± 5.1	19.2 ± 3.4	0.504	18.0 ± 4.4	19.8 ± 3.3	<0.001	16.1 ± 2.6	22.0 ± 4.5	<0.001
GDQS+	6.8 ± 4.9	8.4 ± 3.3	<0.001	7.1 ± 4.3	8.2 ± 3.3	<0.001	4.5 ± 2.5	10.8 ± 4.3	<0.001
GDQS-	12.0 ± 1.0	10.8 ± 1.3	<0.001	10.9 ± 1.8	11.6 ± 0.9	<0.001	11.6 ± 1.0	11.2 ± 1.6	0.002
Total VHEI score	42.5 ± 9.3	41.3 ± 7.7	<0.001	41.8 ± 9.6	42.3 ± 7.7	0.069	38.8 ± 6.4	47.1 ± 9.2	<0.001
VHEI component scores									
Grains	6.7 ± 2.7	7.0 ± 2.4	0.964	6.0 ± 2.6	6.7 ± 2.9	0.912	7.0 ± 2.8	7.1 ± 2.6	0.231
Protein-rich foods	4.9 ± 3.6	3.6 ± 3.3	<0.001	5.3 ± 3.7	4.8 ± 3.4	<0.001	5.4 ± 3.5	4.7 ± 3.7	0.001
Vegetables	5.4 ± 3.9	7.6 ± 2.8	<0.001	5.4 ± 3.8	8.1 ± 2.5	<0.001	5.5 ± 3.4	7.8 ± 3.2	<0.001
Fruits	3.5 ± 4.6	3.4 ± 3.3	0.342	3.8 ± 4.1	3.5 ± 3.6	0.579	0.6 ± 1.5	6.9 ± 3.8	<0.001
Dairy	0.2 ± 1.4	0.6 ± 1.8	0.001	1.2 ± 2.9	0.2 ± 1.0	<0.001	0.04 ± 0.5	1.2 ± 2.8	<0.001
Fats and oils	3.3 ± 3.2	6.1 ± 2.6	<0.001	3.9 ± 2.9	5.5 ± 2.8	<0.001	3.1 ± 2.3	5.4 ± 3.3	<0.001
Sugar and sweets	9.6 ± 1.9	9.5 ± 1.7	0.323	8.8 ± 3.1	9.6 ± 1.6	<0.001	9.8 ± 1.2	9.3 ± 2.2	0.002
Salt and sauces	9.0 ± 2.5	3.3 ± 3.3	<0.001	7.4 ± 3.9	3.8 ± 3.5	<0.001	7.3 ± 3.6	4.6 ± 4.2	<0.001
Diet cost									
Daily cost‡	40,186 ± 49,546	107,350 ± 50,538	<0.001	69,988 ± 54,968	82,288 ± 48,993	<0.001	51,456 ± 46,109	99,085 ± 60,894	<0.001
(In International Dollars)§	*4.7 ± 5.8*	*12.5 ± 5.9*	-	*8.2 ± 6.4*	*9.6 ± 5.7*	-	*6.0 ± 5.4*	*11.6 ± 7.1*	-
Energy adjusted cost‡,¶	56,495 ± 53,876	84,244 ± 36,894	<0.001	84,120 ± 45,830	60,197 ± 32,529	<0.001	51,804 ± 30,745	87,242 ± 51,118	<0.001
(In International Dollars)§	*6.6 ± 6.3*	*9.8 ± 4.3*	-	*9.8 ± 5.3*	*7.0 ± 3.8*	-	*6.0 ± 3.6*	*10.2 ± 6.0*	-

Q, Quintiles (Q1 = lowest adherence to the dietary pattern). MPA, Mean Probability of Adequacy. GDQS, Global Diet Quality Score, with a range from 0 to 49 points. GDQS+, GDQS Positive Sub-metric, with a range from 0 to 32 points. GDQS-, GDQS Negative Sub-metric, with a range from 0 to 17 points. VHEI, Vietnamese Healthy Eating Index, with a range from 0 to 80 points.
* Data is presented in mean and standard deviation, adjusted for sample weights.
† *P-value* for trend analysed by general linear model.
‡ Data is presented in local currency unit (Vietnamese Dong).
§ Data is deflated to 2017 using the National Consumer Price Index and converted from local currency unit in Vietnamese Dong to International Dollar ($) using 2017 Purchasing Power Parity exchange rates published by the World Bank.
¶ Energy adjusted cost is calculated as the cost per 2,000 kcal.

DISCUSSION

This study aimed to characterise differences in Vietnamese dietary patterns and compare the sociodemographic, diet quality, and diet cost of these patterns, using the most recent national survey in Vietnam. By applying PCA in a sample of 3,528 Vietnamese adult men and women aged ≥ 20 years participating in the GNS 2019-2020, we derived three major dietary patterns: meat, pescatarian, and healthy patterns.

Compared to our previous study, where we derived three dietary patterns (the traditional, pescatarian, and omnivorous pattern) using the GNS 2009-2010 dietary intake data, the pescatarian pattern is most similar to the earlier reported pescatarian pattern, whereas the meat and the healthy patterns are less similar to the traditional and the omnivorous patterns(16). Our three derived dietary patterns explained 21.3% of the total variance in dietary intake, which is higher than that observed in the previous study (14.7%)(16). However, the variance explained by each pattern might differ across studies since it depends on the number of variables included in the analysis and the correlation matrix between food groups(35; 36).

Participants with a higher score on the meat pattern were more likely to be male, younger, and smokers. This pattern was considered less healthy, as confirmed by a negative association with the VHEI and GDQS+. We expected the GDQS- would be even lower in the highest to the meat pattern group because the GDGS- does not contain the salt and sauce component like the VHEI, while adherence to this pattern was strongly associated with sodium intake. In contrast, the healthy pattern was more likely to be consumed by women, non-smokers, employed individuals and of higher education. This pattern was strongly associated with a higher diet quality measured by both GDQS and VHEI and the intake of dietary fibre polyunsaturated fat and numerous vitamins and minerals. Overall, MPA calculated for our study population was close to the cut-off value of 0.5 suggested by Kennedy *et al.*(37) and higher adherence to all the pattens was associated with higher MPA, though Vietnamese women were still in risk of micronutrient inadequacy. These outcomes suggest that proportions of the general Vietnamese population consume dietary patterns of

Chapter 4

different diet quality, which are linked with their sociodemographic characteristics. This information might help inform public health research and nutrition policy aiming to improve the diet quality of the population since the information on sociodemographic elements allows targeting of the most vulnerable groups in the development of effective public health interventions. Importantly, the presence of the healthy pattern derived from the current dietary intake data shows that healthy dietary patterns can be achievable in Vietnam.

Over ten years, the traditional pattern has been shifting toward the meat pattern, with lower loadings for rice and rice products but higher loadings for red meat, processed meat, and animal fat. In Vietnam, the increasing dominance of animal source foods, especially meat, in the diets is striking(14; 18). Hansen studied the specific case of meat consumption in Vietnam and indicated a dramatic increase since the initiation of economic reforms in 1986(38). The factors that contributed to this increase include the changes in systems of provision for meat, the positive social connotations attached to meat as a sign of development and improvement, the increase in eating away from home habits and the meat-intensification of traditional meals(38). This dietary change has also been caused in part by urbanization and changes in the food environment, especially food availability (e.g. increasing availability of pork)(14). As a consequence, saturated fats intake, largely from animal source foods, has also risen simultaneously(15). In our study, although higher adherence to the meat pattern was correlated with higher intake of several vitamins (i.e., vitamin B1 and vitamin B6), it was strongly correlated with higher intake of saturated fat and sodium and lower intake of fibre and vitamins (i.e., vitamin C). In addition, we observed higher adherence to the meat pattern was also strongly associated with higher diet costs. The environmental costs of dietary changes in Vietnam must also be considered. Our previous study explored the environmental impacts of Vietnamese dietary patterns, showing that meat was the main contributor to diet-related greenhouse gas emissions(16).

Vietnam has been one of the fastest growing economies globally, and the income of Vietnamese is expected to keep rising(39; 40). As the rise in income is usually associated with an increase in the demand for animal source foods[41] the demand for animal source foods is expected to keep rising in the country. Therefore, simultaneous effective nutrition interventions from the demand-side and food system interventions from the supply-side are needed to shift diets away from greater meat consumption. We agree with the proposition of Clark *et al.* that fisheries in Vietnam are uniquely positioned to shift the progress in the right direction of these goals[14]. Interestingly, after taking energy intake into account, higher adherence to the pescatarian pattern resulted in lower diet cost in the current study. Thus, promoting fish consumption might be a potential win-win solution to meet the demand for animal source foods whilst also meeting the cost, healthiness, and environmental targets.

Higher adherence to a healthy pattern was associated with higher diet cost (this pattern was characterised by greater consumption of fruits, plant-based oils and consumption of vegetables, seafood, eggs, plant-based protein-rich foods, nuts and seeds, and dairy). This finding supports the results of other studies which suggested that consuming a healthy diet was associated with higher diet cost in various settings. For example, a study conducted among the general US population showed that higher diet costs were associated with higher diet quality measured by the HEI-2005 for both men and women[42]. Rehm *et al.* also highlighted that higher diet cost was strongly associated with consuming more fruit and vegetables and fewer calories from solid fat, alcoholic beverages, and added sugars[42]. Timmins et al. imply that the better-quality diets, as signified by the consumption of fruit and vegetables, were more expensive[43]. In Belgium, a high-quality diet, verified by the Mediterranean Diet Score and the Healthy Diet Indicator, was more expensive than a low-quality diet[44]. In Mexico, diet cost was positively associated with diet quality, but only in urban areas[45]. Applying PCA to examine the costs of derived dietary patterns, Lopez et al. found that the Mediterranean pattern, characterised by olive oil, poultry, fish, low-fat dairy, legumes, fruits, and vegetables, is more expensive than the Western pattern, characterised by red meat, processed meats, eggs, sauces, pre-cooked food, fast food, caloric soft drinks, whole fat dairy, and potatoes[46].

A growing body of evidence has found that overconsumption of meat is unhealthy for human health and environment healthy[47; 48] and that shifting towards a more plant-based diet is more sustainable[49]. Increasing the consumption of legumes, vegetables and fruits and reducing unhealthy foods[50] are required to improve diet quality while ensuring environmental sustainability; however, promoting plant-based protein-rich foods in Vietnamese dietary patterns might not be a practical solution. In Vietnam, people are not consuming legumes and beans as staple foods or as protein-rich foods, and some animal source foods in the diets are still needed to meet the requirements of essential nutrients such as iron and vitamin B12[51]. Therefore, encouraging fish consumption might be a promising strategy for achieving healthy and sustainable diets in Vietnam, especially when people might be unwilling to substitute meats for plant-based foods. However, more research and investment and a strategy for proper management of fisheries and aquaculture are still needed to support this strategy in Vietnam, which are discussed further by Clark *et al.*[14].

The strengths of our study include the analyses of a robust dataset containing dietary intake data from a nationally representative sample, so the results are projected to be generalisable to the Vietnamese population. The combination of the GNS data and the CPI food price data suggests a practical way to include diet cost and quality measures in nutrition monitoring in the country. In addition, the use of both *a posteriori* derived and *a priori* defined also highlights the standing of these methods in exploring diet as a multi-dimensional exposure.

This study has a number of limitations. The diet cost reported here was calculated using 24HR data, which might underestimate or overestimate the cost since this method might fail to estimate portion sizes correctly or recall foods and beverages that are either forgotten or consumed occasionally. The weakness of measuring sodium intake via 24HR and using a 1-day dietary intake is also applied for the present study, which is discussed thoughtfully in our previous studies[17; 52]. A limitation of the CPI food price database is that it does not include prices on all relevant foods in the GNS 2019-2020, some of which might be cheaper or more expensive than the average values used in the calculations. Lastly, the PCA technique involves several subjective decisions; for example, the selection of included variables, the number of retained factors, the rotation method, and the way of labelling each factor.

The analyses in this study were based on the intrinsic monetary value of the dietary patterns and not on actual food expenditures measured in our previous study[(20)]. The estimates based on GNS data included foods consumed, whereas the VHLSS data were based on expenditures for purchased, but not necessarily consumed, foods. Although the measure used here did not permit estimations of food expenditures, it would be beneficial for future research to evaluate the affordability of a healthy diet with current dietary patterns[(53)]. The findings contribute to our understanding of the derivation of individual diet costs, which can provide insights into some of the financial drivers of food choice, diet quality and nutrition outcomes.

In conclusion, the findings in this study contribute to understanding the recent dietary patterns consumed by Vietnamese adults. The derived dietary patterns and their associations with sociodemographic characteristics, energy and nutrient intakes, diet quality, and cost are valuable insights for nutritional interventions aiming to improve specific diets consumed by the population and further enhance disease prevention through healthy eating in the long run. In our study population, for example, a dietary recommendation for Vietnamese men should address undesirable aspects of the meat pattern (i.e., overconsumption of meat and processed meat, animal fat, salt and sauces, and alcoholic beverages). In contrast, the consumption of a healthy pattern among a group of young Vietnam women should be encouraged.

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Chapter 4

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SUPPLEMENTARY MATERIALS OF CHAPTER 4

Table 4.S1. Estimated Average Requirements for twelve micronutrients included in the mean probability of adequacy calculation

	Men	Women	Source
Calcium (mg)	805	805	Aillen, 2020[27]
Potassium (mg)	2000	2000	Vietnamese RDA, 2016[26]
Magnesium (mg)	260	260	Aillen, 2020[27]
Zinc (mg)	12.7	10.2	Aillen, 2020[27]
Iron (mg)	19.2	22.4	Aillen, 2020[27]
Folate (µg)	250	250	Aillen, 2020[27]
Vitamin B1 (mg)	1.0	0.9	Aillen, 2020[27]
Vitamin B2 (mg)	1.3	1.3	Aillen, 2020[27]
Vitamin A (µg RAE)	570	490	Aillen, 2020[27]
Vitamin C (mg)	90	80	Aillen, 2020[27]
Vitamin B6 (µg)	1.1	1.3	Aillen, 2020[27]
Vitamin B12 (µg)	2.0	2.0	Aillen, 2020[27]

RDA, Recommended Dietary Allowances.

Table 4.S2. Micronutrient intakes and probability of adequacy of participants in the Vietnamese General Nutrition Survey 2019-2020 (n=3,528)

	Total population (n=3,528)		**Men (n=880)**		**Women (n=2,648)**	
	Intake*	**PA**	**Intake***	**PA**	**Intake***	**PA**
Calcium (mg)	490.3 ± 423.7	0.38 ± 0.34	534.9 ± 357.9	0.42 ± 0.25	450.4 ± 413.0	0.33 ± 0.40
Potassium (mg)	2629 ± 1244	0.66 ± 0.43	2903 ± 937.6	0.75 ± 0.28	2383 ± 1369*	0.58 ± 0.53
Magnesium (mg)	271.6 ± 188.3	0.40 ± 0.44	298.2 ± 135.5	0.49 ± 0.33	247.8 ± 222.7*	0.32 ± 0.50
Zinc (mg)	12.8 ± 11.8	0.46 ± 0.45	15.1 ± 10.4	0.52 ± 0.32	10.7 ± 9.9	0.42 ± 0.53
Iron (mg)	14.3 ± 9.5	0.50 ± 0.4	16.4 ± 7.8	0.70 ± 0.27	12.4 ± 9.3	0.32 ± 0.39
Folate (µg)	293.9 ± 219.2	0.46 ± 0.46	308.4 ± 157.8	0.50 ± 0.34	280.9 ± 262.6*	0.43 ± 0.55
Vitamin B1 (mg)	1.3 ± 0.8	0.63 ± 0.44	1.5 ± 0.6	0.69 ± 0.31	1.2 ± 0.9*	0.58 ± 0.54
Vitamin B2 (mg)	0.9 ± 0.6	0.20 ± 0.36	1.0 ± 0.5	0.25 ± 0.29	0.8 ± 0.6	0.15 ± 0.38
Vitamin A (µg RAE)	484.8 ± 609.6	0.30 ± 0.43	559.6 ± 535.3	0.32 ± 0.32	417.9 ± 546.0	0.29 ± 0.51
Vitamin C (mg)	119.7 ± 136.8	0.47 ± 0.47	108.6 ± 96.6	0.41 ± 0.34	129.6 ± 166.3*	0.53 ± 0.57
Vitamin B6 (µg)	1.9 ± 1.2	0.73 ± 0.41	2.3 ± 1.0	0.88 ± 0.22	1.7 ± 1.1	0.60 ± 0.53
Vitamin B12 (µg)	5.2 ± 8.3	0.64 ± 0.46	6.4 ± 7.0	0.70 ± 0.32	4.1 ± 8.0	0.58 ± 0.56
MPA	-	**0.49 ± 0.29**	-	**0.55 ± 0.21**	-	**0.43 ± 0.35**

PA, probability of adequacy. MPA, mean probability of adequacy.
* Data is presented in mean and standard deviation, adjusted for sample weights.
† Significantly different from men with P-value of <0.05 calculated from a linear regression, adjusted for energy intake (kcal).

Table 4.S3. Food group consumption of participants in the Vietnamese General Nutrition Survey 2019-2020 (n = 3,528)

Food groups*	**Total population (n=3,528)**	**Men (n=880)**	**Women (n=2,648)**
Rice and rice products	323.7 ± 190.2	389.9 ± 154.1	264.5 ± 172.4
Non-rice starchy staples and tubers	37.8 ± 76.3	36.1 ± 47.4	39.3 ± 101.3
Total meat	146.1 ± 144.7	179.9 ± 118.1	115.9 ± 141.8
Red meat	95.5 ± 112.2	117.9 ± 91.6	75.4 ± 111.7
Poultry	42.0 ± 85.5	52.5 ± 72.0	32.6 ± 83.4
Processed meat	8.6 ± 25.8	9.6 ± 18.5	7.8 ± 31.1
Eggs	16.9 ± 36.1	19.9 ± 30.0	14.2 ± 36.5
Processed meat	8.6 ± 25.8	9.6 ± 18.5	7.8 ± 31.1
Fish	78.0 ± 119.2	93.6 ± 103.1	64.1 ± 110.0
Seafood	28.6 ± 89.4	34.8 ± 75.1	23.2 ± 88.7
Legumes and beans	1.9 ± 8.9	1.8 ± 7.0	2.0 ± 9.7
Soy products	14.6 ± 50.4	16.6 ± 38.6	12.9 ± 57.1
Plant-based oils	14.3 ± 15.8	15.9 ± 12.0	12.9 ± 18.0
Animal fat	1.7 ± 4.0	2.0 ± 3.1	1.4 ± 4.4
Nuts and seeds	2.2 ± 10.0	2.1 ± 7.3	2.2 ± 12.0
Dairy and dairy products	13.1 ± 52.0	8.4 ± 30.0	17.3 ± 71.2
Total vegetables	230.1 ± 180.3	238.2 ± 135.9	222.8 ± 207.2
Vitamin-A-rich vegetables	100.1 ± 126.6	139.0 ± 108.1	122.0 ± 158.9
Other vegetables	130.0 ± 141.1	99.2 ± 90.9	100.8 ± 152.5
Total fruits	118.3 ± 192.6	95.1 ± 136.5	139.0 ± 232.0
Vitamin-A-rich fruits	39.5 ± 125.5	26.9 ± 82	50.9 ± 160.7
Other fruits	78.7 ± 134.1	68.2 ± 103	88.1 ± 150.4
Sugar and sweets	55.8 ± 124.3	59.4 ± 93.5	52.6 ± 143.2
Salt and sauces	15.5 ± 19.1	17.8 ± 13.3	13.5 ± 23.4
Alcoholic beverages	78.0 ± 344.5	161.3 ± 353	3.4 ± 56.5

* Data is presented in mean and standard deviation, adjusted for sample weights.

Chapter 4

Table 4.S4. Food group consumption of participants in the Vietnamese General Nutrition Survey 2009-2010 (n=8,225) and Vietnamese General Nutrition Survey 2019-2020 (n=3,528)

Food groups*	**GNS 2009-2010**	**GNS 2019-2020**
Rice and rice products	379.1 ± 149.7	323.7 ± 190.2
Non-rice starchy staples and tubers	21.9 ± 56.4	37.8 ± 76.3
Meat total	84.6 ± 100.3	146.1 ± 144.7
Red meat	67.8 ± 83.2	95.5 ± 112.2
Poultry	14.9 ± 58.6	42.0 ± 85.5
Eggs	12.8 ± 25.6	16.9 ± 36.1
Processed meat	1.8 ± 11.0	8.6 ± 25.8
Fish	57.3 ± 79.7	78.0 ± 119.2
Seafood	11.0 ± 33.8	28.6 ± 89.4
Legumes and beans	1.5 ± 12.9	1.9 ± 8.9
Soy products	21.6 ± 63.3	14.6 ± 50.4
Plant-based oils	6.6 ± 19.6	14.3 ± 15.8
Animal fat	2.6 ± 7.4	1.7 ± 4.0
Nuts and seeds	3.6 ± 17.8	2.2 ± 10.0
Dairy and dairy products	10.9 ± 35.5	13.1 ± 52.0
Vegetables	198.0 ± 126.2	230.1 ± 180.3
Fruits	59.3 ± 114.5	118.3 ± 192.6
Sugar and sweets	8.9 ± 35.7	55.8 ± 124.3
Salt and sauces	18.2 ± 18.2	15.5 ± 19.1
Alcoholic beverages	-	78.0 ± 344.5

GNS 2009-2010, General Nutrition Survey 2009-2010. GNS 2019-2020, General Nutrition Survey 2019-2020.
* Data is presented in mean values and standard deviation, mean values adjusted for sample weights.

The daily work of fishermen in the early morning at Cua Lo Beach, Nghe An.

Chapter 5

COST AND AFFORDABILITY OF HEALTHY DIETS IN VIETNAM

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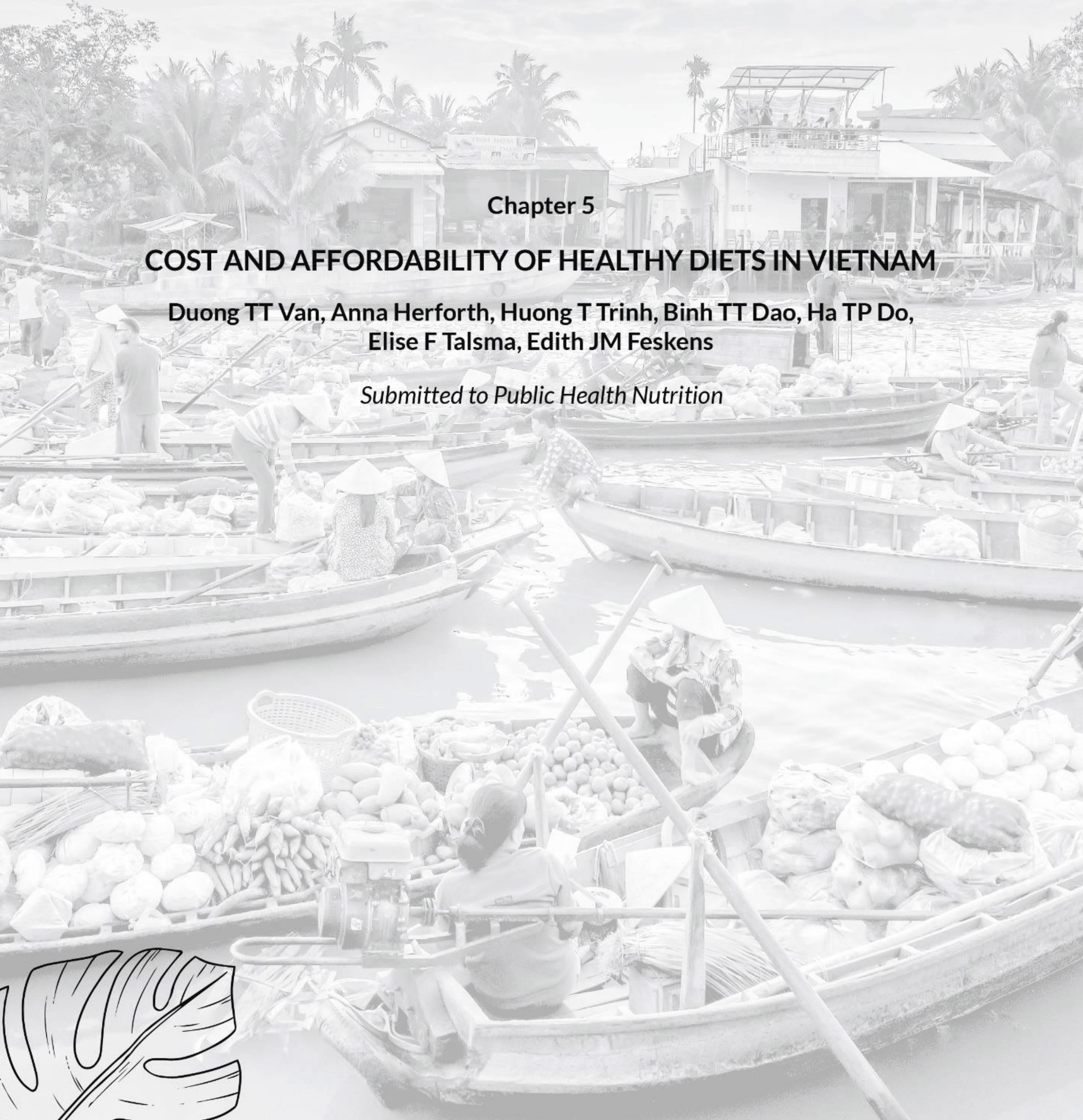

ABSTRACT

As the essential drivers of diet quality, the cost and affordability of healthy diets challenge food security, nutrition and health. In this study, we used the Cost of a Healthy Diet (CoHD) indicator to estimate the lowest cost to meet the 2016-2020 Vietnamese food-based dietary guidelines (FBDGs) and compared the cost differences by food group, region, and seasonality. The affordability of healthy diets was measured by comparing the cost of healthy diets relative to both total food expenditures and incomes. We estimated that the average CoHD between 2016 and 2020 in Vietnam was 3.08 international dollars using 2017 Purchasing Power Parity (24,070 Vietnamese Dongs). The nutrient-rich food groups, including protein-rich foods, vegetables, fruits, and dairy, composed approximately 80% of the total cost of healthy diets in all regions, with dairy accounting for the largest portion of this. Between 2016 and 2020, the cheapest form of a healthy diet were affordable for all high-income and upper-middle-income households but unaffordable for approximately 70% of low-income households, where adherence to the Vietnamese FBDGs can cost up to 70% of their income. Our findings suggest that interventions in local food systems must be implemented to reduce the cost of nutrient-rich foods to support the attainment of a healthier diet in the Vietnamese population, especially for low-income households.

Key words: cost of healthy diets, affordability, seasonality, food-based dietary guidelines, healthy diet

INTRODUCTION

Poor diet quality plays a central role in morbidity and mortality worldwide due to both insufficient intake of healthy foods and excessive intake of unhealthy foods(1). The cost and affordability of healthy diets are among the essential drivers of food choices, diet quality and nutrition outcomes(2; 3) and are currently our biggest challenges to food security, nutrition, and health(4). For some individuals, access to sufficient dietary energy is also a challenge, let alone the access to healthy diets. A growing body of evidence shows that a healthy diet is more expensive than an unhealthy diet(5). Nutrient-rich foods, such as fruits, vegetables, protein-rich foods, and dairy, account for a much higher proportion of the total cost of a healthy diet than energy-dense foods, such as starches, fats and oils, and sugary and salty products(4).

As higher relative costs can directly affect the consumption of nutrient-rich foods, a shift to healthier diets requires these foods to be available and affordable, especially for poor populations(6). The poor tend to be more sensitive to food prices and are likely to spend all of their income on foods(7); consequently, they face more barriers in affording healthy diets and improving their diet quality(8). Furthermore, the cost and affordability of healthy diets are significantly variable across food groups, geographical zones, seasonal differences, and local food systems. For example, the higher perishability and lower tradability of healthy foods such as fruits, vegetables, and animal source protein-rich foods, often result in higher prices as they are more dependent on production and food supply chain efficiency at the local level(3). Therefore, conducting country's specific analyses of the cost and affordability of healthy diets can offer the insights required to perform local interventions and systemic innovations in the food system, making healthier diets more accessible for poorer populations(8).

In Vietnam, achieving food security requires special attention to access to healthy diets foods for all population groups . Our previous work showed that Vietnamese households with lower incomes have less access to healthy diets, and therefore have lower diet quality(9). FBDGs are state-published definitions of the healthy diets appropriate for the population(10), and adherence to FBDGs can be used to measure diet quality[9]. Despite this, no studies have assessed whether the Vietnamese FBDGs are feasible and affordable for all. If certain subpopulations cannot adhere to the FBDGs due to lower incomes, their diet quality will remain limited. To this end, reducing food costs will facilitate higher adherence to FBDGs and, therefore, increase the diet quality of the population.

Thus, the aims of the present study were: 1) to estimate the minimum cost of meeting the healthy diets recommended by the 2016-2020 Vietnamese FBDGs and to compare the differences in the costs by food group and by region; 2) to examine the seasonality in the cost of healthy diets; and 3) to assess the affordability of healthy diets in Vietnam. Achieving these outcomes will provide information on the cost of specific components of a healthy diet, such as what (i.e., food group), when (i.e., seasonality), where (i.e., region), and to whom (i.e., low-income households) food must be made more affordable. This, in turn, can facilitate interventions to support local systems in ensuring the affordability of healthy diets and increase the possibility of achieving higher diet quality in the Vietnamese population.

SUBJECTS AND METHODS

Data

CPI food price data

In this study, we used the average monthly price of food items in the list of food and non-alcoholic beverages collected across 63 provinces by the General Statistics Office (GSO) for the monthly Consumer Price Index (CPI). We obtained price data of 176 food items at the national level (average of 63 provinces) and regional level (data of 25 provinces representing six geographical regions) from January 2016 to December 2020 (Supplementary Table 5.S1).

We used CPI data to calculate the cost of healthy diets because it allows us to look at the trend in cost and affordability over time. The monthly CPI food price database are well represented at both national and regional levels, allowing us to estimate regional spatial and seasonal variations. The CPI data are also collected more frequently than household survey data, suggesting an effective way to use existing food price data for food security and nutrition measurement.

Vietnam Household Living Standard Survey

We used the Vietnam Household Living Standard Survey (VHLSS) data to calculate mean daily food expenditure and daily per capita household income. This survey has been conducted by the GSO with technical support of the World Bank every two years since 2002. Each VHLSS wave is made of two sub-surveys, including household sub-survey and commune sub-survey. The households in each VHLSS survey are selected by a two-stage area sample design where communes are selected in the first stage, and three enumeration areas per commune are selected in the second stage. The sampling procedure of this survey has been described in more detail elsewhere[11; 12; 13]. We used data from three latest VHLSS surveys at the household sub-survey level, including VHLSS 2016 (9,399 households), VHLSS 2018 (9,167 households), and VHLSS 2020 (9,388 households) for our analysis.

Inflation adjustment and currency conversion

We adjusted the nominal values of both CPI food price data and VHLSS data for monthly inflation rates from 2016 through 2020 using the CPI. We collected monthly CPIs for food items (CPI_{Food}) from the GSO, Vietnam, and adjusted the food prices to a base of reference period at which CPI_{Food} = 100[14]. Then we converted local currency unit Vietnamese Dong (VND) into International Dollar ($) using the most recent PPP exchange rates published by the World Bank[15], and not market exchange rates. A reference period of December 2017 was applied for both inflation adjustment and currency conversion. Thus, the cost of healthy diets, food expenditure and income data are reported in 2017 PPP$ and simply presented as $ in the text.

Methods

The cost of healthy diets measurement

In the present study, healthy diets are defined based on the 2016-2020 Vietnamese FBDGs for adults, as described in more detail below. We estimated the cost of healthy diets in Vietnam using the Cost of a Healthy Diet (CoHD) indicator developed by Herforth *et al.*[16; 17], which has been used in a global analysis[17] and in several other countries in Asia[18; 19]. In this method, the food items with the lowest cost in each food group were averaged, and then these averages from each food group were summed up to give a total minimum daily cost of meeting the healthy diets recommended by the FBDGs. For ease of explanation, we use the term CoHD to describe the cost of healthy diets in the following text.

2016-2020 Vietnamese food-based dietary guidelines

There are recommendations relating to the eight foundational food groups in the 2016-2020 Vietnamese FBDGs, including grains, protein-rich foods, vegetables, fruits, dairy, fats and oils, sugar and sweets, and salt and sauces. In **Table 5.1**, the definition of servings of each food group and the foods to be included in in each food group are derived from the graphic presentation and the official background document of the 2016-2020 Vietnamese FBDGs (written and published in Vietnamese)[20], and information provided by the National Institute of Nutrition, Ministry of Health, Vietnam. We included six food groups in the calculation of the cost of healthy diets, including grains, protein-rich foods, fats and oils, vegetables, fruits, and dairy.

Table 5.1. Composition of a healthy diet recommended by the 2016-2020 Vietnamese food-based dietary guidelines for adults

Food groups	Main food items	Recommended servings daily	Definition of one serving
Grains	Rice, bread, noodles, potato, corn, casava	12 – 15	Provides 20g carbohydrate
Protein-rich foods	Red meat, poultry, seafood, egg, legumes and beans, soy products	5 – 6	Provides 7g protein
Fats and oils	Animal fat, plant-based oils, butter, nuts, and seeds	5 – 6	Provides 5g total fat
Dairy	Milk, yogurt, cheese	3 – 4	Provides 100mg calcium
Vegetables	All type of vegetables, mushroom	3 – 4	Eighty grams of edible vegetables
Fruits	All type of fruits	3	Eighty grams of edible fruits
Sugar and sweets	Sugar, sweets, honey	< 5	Provides 5g free sugar
Salt and sauces	Salt, seasoning, sauce	< 1	Provides 5g salt

The Cost of a Healthy Diet (CoHD) calculation

The steps followed in the construction of CoHD are described below:

Step 1: 176 food items in the original CPI food price dataset were classified into eight food groups based on the recommendations in the 2016-2020 Vietnamese FBDGs. We excluded foods in 'sugar and sweets' and 'salt and sauces' groups; foods that are not recommended for a healthy diet such as trans fats, processed meats; foods that are non-caloric, ingredients, condiments, baby foods, tea, coffee, alcoholic beverages; and foods with an unclear composition. In the case of multiple types of the same food, only the item with the lowest cost was retained (for example, in the case of rice, Xi Deo rice and Tam Thom rice were both classified simply as rice, and the more expensive item was dropped). These exclusions resulted in a final CPI food price dataset of 88 food items for CoHD calculation. The number of food items for each food group in both the original CPI food price dataset and final CPI food price dataset is shown in Supplementary Table S4.

Step 2: the price unit of each food item in the final CPI food price dataset was standardized to price per gram. For the food items that were in non-standard units such as corns and eggs (given in price per ten items), estimates of the standard weight of these items were employed.

Step 3: all the food items were matched with the global database developed by Herforth et al.[17] for the global analysis to obtain the food composition information for edible portion, energy intake, and nutrient content (protein, carbohydrate, total fat, and calcium). This global database used information from the United States Department of Agriculture Food Data Central 2020[21].

Step 4: the price for each food item was converted into price per gram edible portion, as follows:

$$\text{Price conversion } = \frac{\dfrac{Serving\ size\ (in\ gram)}{Price\ unit\ of\ food\ item}}{\text{Edible portion}}$$

Step 5: the two cheapest food items for grains, protein-rich foods, and fruits; the three cheapest food items for vegetables; and the cheapest food item for oils and fats and dairy were selected for the CoHD basket [17]. The recommended number of servings for each group was multiplied by the average price per serving for each food group to generate the cost of that food group. Finally, the costs of all food groups were summed to obtain the total CoHD.

Seasonality measurement

We used seasonal-trend decomposition (STL) as a seasonal adjustment method developed by Cleveland *et al.*[22]. This model decomposes time series into seasonal, trend, and remainder components using a filtering algorithm based on the local regression (LOESS). STL assumes an additive relationship between the seasonal, trend, and remainder components as follow:

$$y_t = S_t + T_t + R_t$$

Where y_t is the value of the time series at point t, S_t is the seasonal component at point t, T_t is trend-cycle at point t, and R_t is remainder component at point t. The STL algorithm performs smoothing on the time series using LOESS regression in two loops: the inner loop iterates between seasonal and trend smoothing and the outer loop minimises the effect of outliers, as further described in detail elsewhere(22). We used STL with monthly seasonality to decompose time series of total CoHD and CoHD by region and food group from January 2016 to December 2020 to determine seasonality effects. All seasonality models were run in EViews 10.0.

Affordability measurement

We used the indicators described by Herforth *et al*.(17) for affordability measurement. For the first affordability indicator, we calculated the CoHD as the percentage of typical daily food expenditures in each region. The source of national average food expenditures used in this affordability indicator is from the 2016, 2018, and 2020 VHLSS survey. The food expenditure was demonstrated per adult female equivalent (AFE) unit per day. Using the AFE as a reference, the household consumption was corrected to individual consumption based on the recommendations of the Human Energy Requirements, considering age and gender(23). For the second indicator, the average CoHD relative to mean daily per capita household income were estimated by region and household income quintile. GSO performed the measurement of daily per capita household income for each VHLSS survey, and we followed their strategy(11; 12; 13). For the third affordability indicator, we calculated the percentage of Vietnamese who cannot afford healthy diets across the region and income quintile between 2016 and 2020 following the coming steps. We first estimated the proportions of daily total food expenditures relative to the income of each consumer segment in high-, upper-middle-, lower-middle- and low-income households. We then multiplied these proportions by their daily income to end up with the daily amounts that could be spent on food by each consumer segment and further compared it with the CoHD.

RESULTS

The cost of healthy diets

After inflation adjustment, the average CoHD from 2016 to 2020 in Vietnam was $3.08 in international dollars using 2017 PPP exchange rate (24,070 VND). Over this period, the CoHD was lowest in 2019 at $3.02 (23,559 VND) and highest in 2017 at $3.17 (24,788 VND) per day. The CoHD in 2016, 2018 and 2020 were $3.04 (23,755 VND), $3.08 (24,063 VND) and $3.10 (24,186 VND) per day, respectively (data not shown).

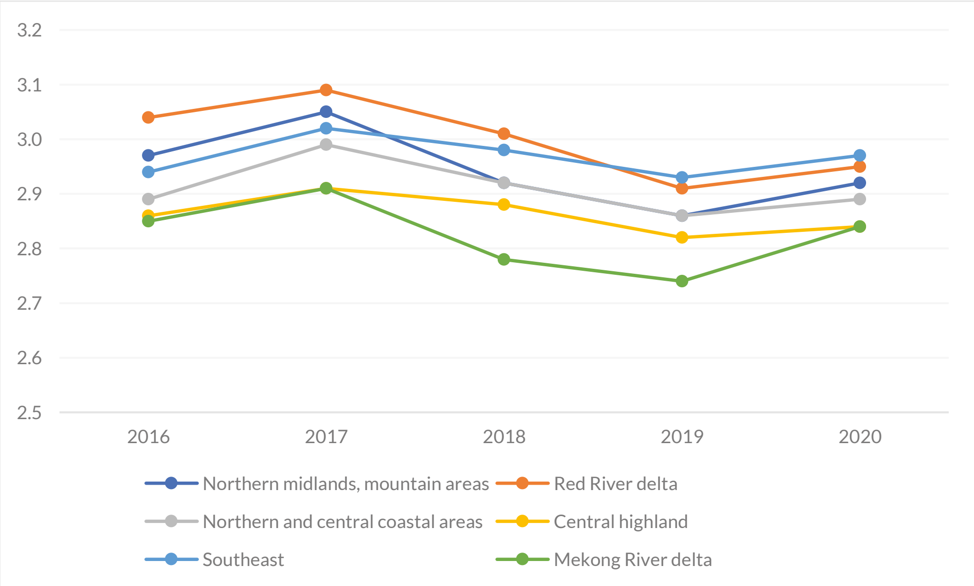

Figure 5.1. The average cost of a healthy diet in 2017 international dollar for an adult per day from 2016 to 2020, by region

Among the six regions, the average CoHD was the highest in the Red River delta and the lowest in the Mekong River delta. Although differences between the regions existed, they showed a similar trend over time; all increased from 2016 to reach a peak in 2017, decreased from 2017 to 2019, then increased again in 2020 **(Figure 5.1).**

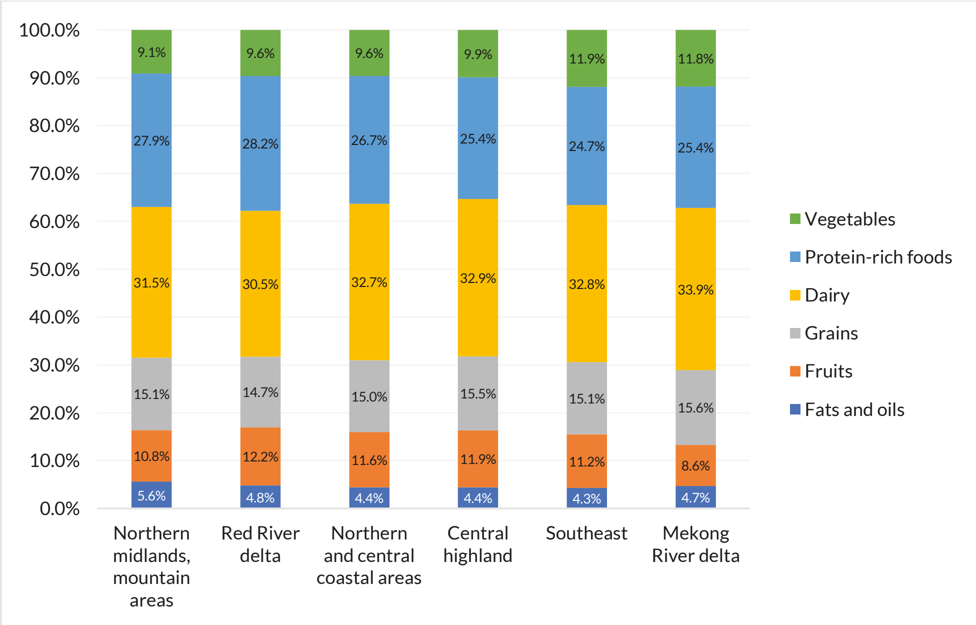

Figure 5.2. Cost contribution (percentage share of total cost) of each food group in a healthy diet by region (average data from 2016 to 2020)

The nutrient-rich food groups, including protein-rich foods, fruits, vegetables, and dairy composed approximately 80% of the total CoHD in all regions. In particular, dairy contributed the largest portion of the total CoHD, and fats and oils contributed the least in all regions. The smallest variation in the cost share by food group was observed in fats and oils with a 1.0% difference between regions, while the largest was in fruits with a 3.2% difference. The cost share of vegetables was highest in the Southeast (11.9%) and lowest in the Northern midlands and mountain areas (9.1%). The cost-share of protein-rich foods was highest in the Red River delta (28.2%) and was lowest in the Southeast (24.7%). The cost share of grains was comparable among regions at around 15.0% **(Figure 5.2).**

Seasonality in the cost of healthy diets

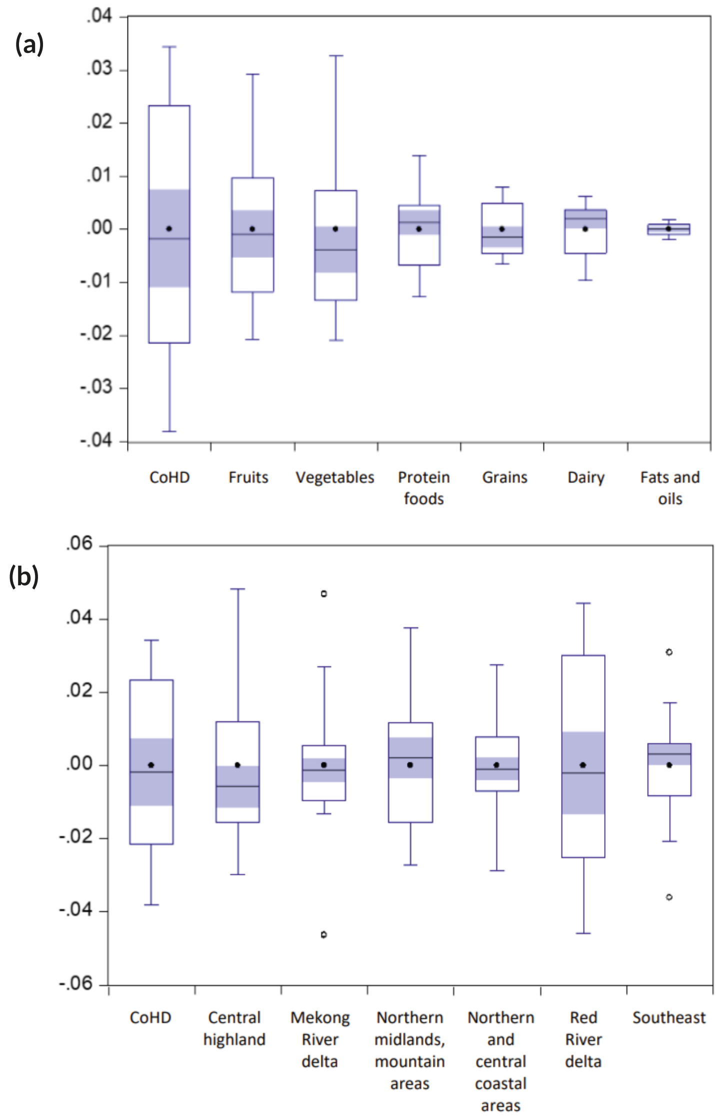

Figure 5.3. Seasonal variation (in 2017 international dollars) in cost of a healthy diet by (a) food group and (b) region. The size of the box shows the IQR. The bottom and top rules illustrate the fifth and fifty-nine percentiles, respectively. The vertical bar rule inside the box is the median value for the region or food group

The seasonal variation in the CoHD by region showed the highest in the Red River delta, followed by the Central highland; the lowest showed in the Southeast and the Mekong River delta **(Figure 5.3b).** Across the food groups made up for a healthy diet, a significant seasonal effect in the cost was observed only for vegetables and fruits but not for other food groups such as grains, protein-rich foods, fats and oils, and dairy (**Figure 5.3a)**. The seasonal variation in cost of vegetables and fruits was likely to be lower in the hot-humid season (from May to August) and higher in the cold-humid season (from November to February); however, the seasonal variation in cost of vegetables dropped in January before increasing in February (**Figure 5.4**).

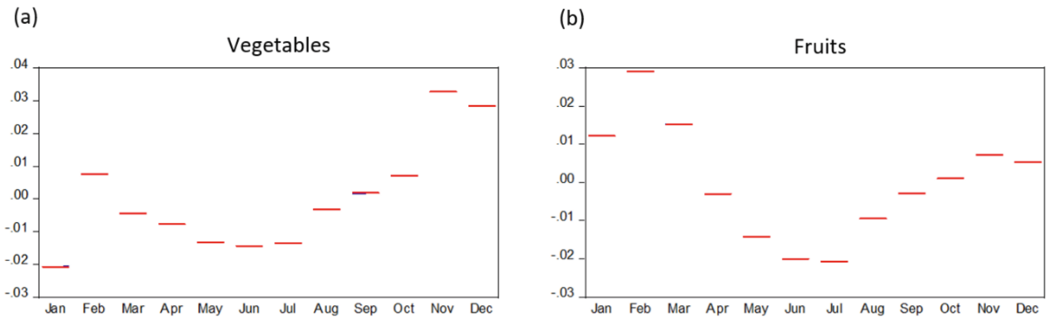

Figure 5.4. Seasonal variation in cost (in 2017 international dollars) of (a) vegetables and (b) fruits

Affordability of healthy diets

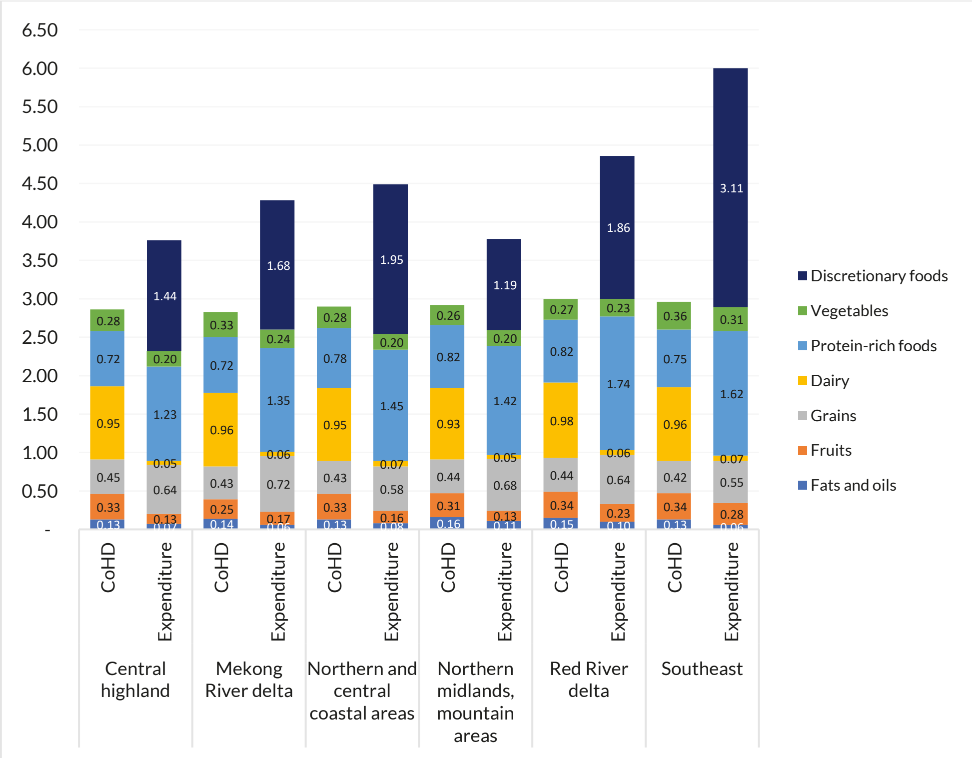

Figure 5.5. The average cost of healthy diets and mean daily total food expenditure (per AFE) for each food group by region

In general, across regions, expenditure on grains and protein-rich foods was in excess of the amount needed to meet the 2016-2020 Vietnamese FBDGs, whereas expenditure on other food groups, including vegetables, fruits, fats and oils, and dairy, was below the CoHD. Particularly, spending on dairy was less than $0.1 per day, falling short of the amount needed to meet the dairy recommendation at approximately $1.0 per day. Spending on other discretionary foods, such as sugary and salty foods, coffee, alcoholic beverages and other beverages, as well as meals away from home, accounted for a large portion of the total food expenditure, especially in the Southeast **(Figure 5.5).**

Table 5.2. The cost of healthy diets as a share of mean daily total food expenditure per AFE by region*

	2016	2018	2020	Average†
Northern midlands,	95.9	98.1	85.4	93.5
mountain areas	(62.2 - 138.8)	(67.5 - 142.6)	(57.9 - 127.7)	(62.3 - 136.4)
Red River delta	80.1	73.4	60.6	70.4
	(59.6 - 109.6)	(52.3 - 102.0)	(44.2 - 81.6)	(50.9 - 96.8)
Northern and central	86.2	76.2	64.6	74.9
coastal areas	(61.0 - 122.0)	(55.1 - 107.5)	(45.8 - 90.0)	(53.1 - 107.2)
Central highland	95.2	93.2	76.8	87.9
	(62.7 - 150.0)	(63.4 - 135.7)	(51.1 - 116.7)	(59.1 – 133.0)
Southeast	62.1	57.7	49.1	56.2
	(45.3 - 89.4)	(40.8 - 81.1)	(35.9 - 69.1)	(40.0 - 80.1)
Mekong River delta	88.5	79.5	69.1	79.3
	(64.5 - 120.4)	(57.7 - 109.4)	(51.0 - 95.7)	(56.6 - 109.2)
National average	**84.6**	**78.0**	**66.1**	**75.6**
	(59.0 - 120.3)	**(55.0 - 111.0)**	**(46.6 - 94.1)**	**(52.8 - 109.4)**

AFE, adult female equivalent.
* Data is presented in median and interquartile range.
† Average from 2016 to 2020.

At the national level, affordability of healthy diets relative to a standard of total food expenditure has improved from 2016 to 2020, as shown by a reduction in the share of the CoHD to total food expenditure. A similar trend was observed across regions, except for the Northern midlands and mountain areas, where the share of CoHD to total food expenditure increased from 2016 to 2018, before decreasing from 2018 to 2020. The Southeast, followed by the Red River delta showed the highest affordability of healthy diets as a share of typical daily food expenditure, while the Northern midlands and mountain areas and the Central highland showed the lowest **(Table 5.2).**

Table 5.3. Percentage of people who cannot afford healthy diets, by income level and by region

	2016	2018	2020	Average*
Average†	28.9	19.6	9.9	20.0
Region				
Northern midlands and mountain areas	42.1	38.3	25.9	36.3
Red River delta	22.1	11.6	2.8	12.2
Northern and central coastal areas	31.9	21.0	10.2	21.8
Central highland	37.2	31.0	17.7	28.4
Southeast	7.2	6.2	1.6	5.6
Mekong River delta	26.9	13.6	5.1	15.7
Income level				
High-income	0.0	0.0	0.0	0.0
Upper-middle-income	0.0	0.0	0.0	0.0
Middle-income	2.7	0.0	0.0	3.0
Lower-middle-income	54.1	30.6	0.1	28.6
Low-income	87.8	67.3	49.2	68.4

* Average from 2016 to 2020.
† Average of all income levels and all regions.

Table 5.3 shows that the cheapest form of a healthy diet recommended by the national FBDGs (CoHD) was not affordable for 68.4% of low-income households, while almost all people from high-income, upper-middle-income and middle-income households would be able to afford it. There was a dramatic decline in the number of people who cannot afford healthy diets in lower-middle-income households, where 54.1% of lower-middle-income households cannot afford the CoHD in 2016, but only 0.1% cannot afford it in 2020. Over 36% of the population residing in Northern midlands and mountain areas cannot afford the CoHD, while only 5.6% of people from the Southeast cannot afford it.

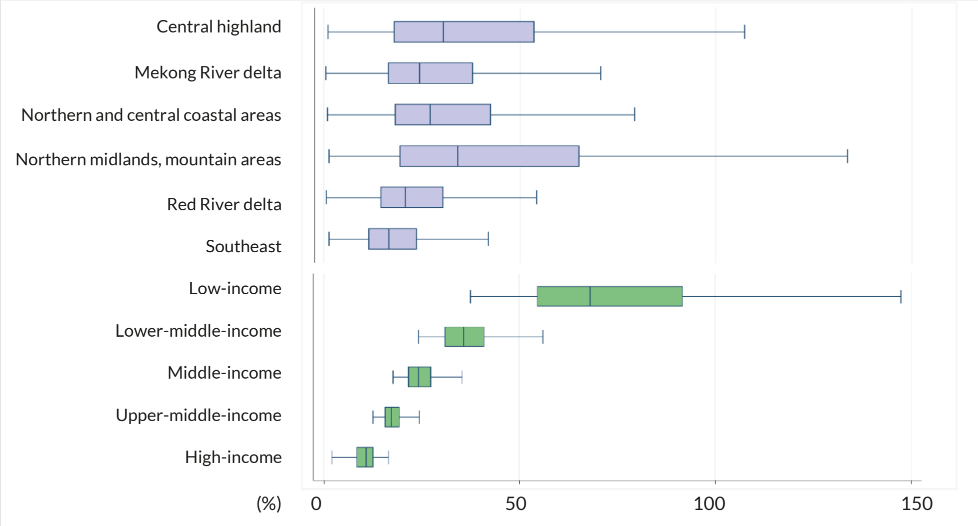

Figure 5.6. The average cost of healthy diets as a proportion of mean daily per capita household income by region and income level. The size of the box shows the IQR. The bottom and top rules illustrate the fifth and fifty-nine percentiles, respectively. The vertical bar rule inside the box is the median value for the region or income level

As shown in **Figure 5.6**, across regions, the affordability of healthy diets, as a percentage of mean daily per capita household income, was the lowest in the Northern midlands and mountain areas (34.0%; IQR 19.4-65.1) and the Central highland (30.3%; IQR 17.9-53.7). In contrast, the highest affordability was observed in the Southeast (16.5%; IQR 11.4-23.7) and the Red River delta (20.8%; IQR 14.5-30.4). The affordability of healthy diets, as a percentage of mean daily per capita household income was 10.8% (IQR 8.5-12.7) in high-income households, 17.3% (IQR 15.7-19.4) in upper-middle-income households, 24.2% (IQR 21.7-27.4) in middle-income households, 35.7% (IQR 31.1-41.1) in lower-middle-income households, and 68.1% (IQR 54.5-91.7) in low-income households.

DISCUSSION

Using the national average CPI food price data from January 2016 to December 2020, we estimated that the national minimum cost to meet the healthy diets recommended by the 2016-2020 Vietnamese FBDGs was approximately $3.08 (2017 PPP) per person per day (the average between 2016 and 2020). Our estimation is slightly lower than the estimate for Viet Nam from the global International Comparison Program (ICP) dataset, of $3.59 (2017 PPP)[(17)]. This slight difference can be partially explained by the difference in the time scale and the difference in the food price databases used for the calculations. We used our national CPI food price database, while the Herforth *et al.* used the World Bank's ICP food price database of national average prices for 2017[(17)]. Regardless, using either figure, the cost of healthy diets in Vietnam is far more expensive than the updated international poverty line of $2.15[(24)].

The cost of healthy diet calculation allows substitution within each food group to meet the recommendations for a healthy diet[(18)]. Vegetables and fruits, protein-rich foods, and dairy constituted the majority of the CoHD (approximately 80%) in all regions. Globally, agricultural production already ensures sufficient calories for the world's population; however, much of this production consists of energy-dense staple foods and insufficient volume and diversity of nutrient-rich foods[(25)]. In Vietnam, the composition of the food basket has been changing remarkably, and the demand for dietary diversity has been increasing due to the country's economic growth over the last decade[(26)]. This has led to calls for effective interventions to shift the local food systems toward the production of more diverse nutritious foods. Our findings imply that food policies should move from meeting energy needs to meeting dietary recommendations. This goal can only be achieved if diverse, nutrient-rich foods are more accessible and affordable. Thus, policies governing agriculture, marketing, and trade should be adapted to address this matter along the national food supply chain. These food policies should focus on several aspects: low productivity and inadequate diversification in food production; high levels of pre-harvest and post-harvest loss in quality and quantity of agricultural products; and insufficient market infrastructure, since these were identified as key factors affecting the cost of nutritious foods and the affordability of healthy diets[27].

In our seasonality analysis, vegetables and fruits had significant seasonal cost variations while other food groups did not. The cost of fruits and vegetables tended to decrease from May to July and increase from November to February, which is maybe explained by their availability during the peak season. Other studies also showed that highly perishable foods like fruits and vegetables are more sensitive to seasonality than foods with a longer lifespan, such as grains[28; 29]. Outcomes from a study conducted in an urban district and a peri-urban district in Northern Vietnam found that the peak availability of fruits is during the hot-humid season (May to August) and that availability is lowest in the cold-humid season (December to February)[30]. Seasonal variability in food prices may have consequences for food price volatility and availability of food products and further impact food security, nutrition, and health[31]. This is particularly problematic for Vietnamese people, who prefer fresh foods, especially vegetables and fruits from the fields or wet markets, rather than frozen or canned products[32]. Thus, to maintain diet quality throughout the year, transport and storage systems across the country should develop strategies robust to seasonality that can supply vegetables and fruits in consistent quantities.

Our study confirms that dairy is the most expensive component of healthy diets. It also shows that current expenditures on dairy are close to zero, as observed previously[9]. Although Vietnam's dairy industry has developed in recent times and contributed significantly to the local needs, retail milk price remains high in Vietnam[33]. Nevertheless, evidence is lacking as to whether the cause of low dairy consumption is due to the high cost of dairy or other reasons. For example, Vietnam is one of the countries in Asia with the highest prevalence of lactose malabsorption, which might cause digestive discomfort following consumption and reinforce dairy avoidance in the population[34]. There is also a growing body of evidence showing the impacts of dairy products on the environment, which might be another potential reason for low dairy consumption[35]. However, dairy is still recommended as a food group in the Vietnamese FBDGs based on its contribution to nutrient intakes, particularly calcium.

These results also point out one of the limitations of the current Vietnamese FBDGs, that they do not take these various socio-cultural and environmental factors into account. To address this limitation, it is crucial to explore the synergies and trade-offs between diet quality, affordability, and other factors (i.e., environmental sustainability, food preferences) to make the Vietnamese FBDGs more affordable, acceptable, and sustainable.

In the present study, the underspending of Vietnamese people on fruits and vegetables and dairy, compared to minimum expenditures to obtain diets consistent with FBDGs, is contrasted with overspending on grains and protein-rich foods. Our previous work also showed that the Vietnamese dietary pattern is dominated by grains (of which white rice is the primary source), which provide approximately 70% of total dietary energy intake(9). Given this dominance, it is unsurprising to see that the Vietnamese population overspends on these foods; and similar observations are found elsewhere in the literature, especially for Asian countries(18; 27). Although rice demand is decreasing in both rural and urban households in Vietnam(26), it still remains a key food item, as the price of rice affects directly household calorie intake, and keeping rice available at a reasonable price allows the poorest to more easily diversify out of the staple and into more nutritious foods(36).

Purchasing more than the absolute lowest cost on protein-rich foods reflects the actual consumption of animal source protein-rich foods, which are more expensive than the plant source protein-rich foods selected in our calculations. The cost of a healthy diet basket based on the Vietnamese FBDGs fulfils more than 80 percent of nutrient requirements on average (calculated based on the Recommended Dietary Allowances for Vietnamese) for both males and females (Supplementary Table S3). However, choosing this basket may lead to iron (for female), zinc, vitamin A, and vitamin B12 deficiency due to selecting only plant-based protein-rich foods. A solution to prevent such nutrient deficiencies could be to add a small quantity of animal source foods such as egg, fish, or meat to the cost of a healthy diet basket, although this would increase the costs(17). Animal source and plant-based protein-rich foods with low environmental impacts should be considered in order to reduce both diet costs and environmental costs.

The cost and affordability of healthy diets differ significantly across regions, and the share of each food group to the total cost of healthy diets also varies by region. Regions in Vietnam are known to be different in terms of socioeconomic characteristics and also expenditures on food[37]. The Northern midlands and mountain areas showed the lowest affordability of healthy diets. One reason may be due to issues like poverty which is more pronounced in the rural area and this part of the country[13]. In contrast, the Southeast and the Red River Delta areas showed the highest affordability. These two regions have the highest average incomes[13] in Vietnam and consist of the largest cities in Vietnam with weighty urban population growths, food system transformations, and subsequent nutrition transitions. Our previous study also showed that the diet quality of the general population varied by region, as the largest percentage of participants with higher diet quality scores were from the Red River delta[9]. These results further support the findings that households with higher income have access to healthier foods that may be unaffordable to households with lower income, which positively impacts their diet quality.

Between 2016 and 2020, although the healthy diets recommended by the FBDGs was affordable for all people in high-income households and upper-middle-income households, it was unaffordable for approximately 70% of low-income households, where adherence can cost up to almost 70% of their income. It should be kept in mind that the calculation of the cost is likely to be an underestimate as it does not consider individual tastes and preferences, but instead simply chooses the lowest-priced items in each food group. Thus, households in the low-income class would have to spend the majority of their total income just to adhere to healthy diets. In such circumstances, consuming a healthy diet is infeasible. Remarkably, we also observed a dramatic decrease in the percentage of people who cannot afford healthy diets of lower-middle-income households from 2016 to 2020. Here, the role of income is more obvious than the cost since the cost of healthy diets showed a tiny increase during this period (after inflation adjustment), while income increased significantly. Trinh *et al.*

also observed a strong correlation between calorie intake and income for the poorest households, indicating that there is still room for income-based policies to fight against malnutrition in Vietnam[38]. Household income level affects not only calorie intake but also diet quality. Another study in Vietnam showed that urban, rich households consume less energy-dense foods such as rice and more nutrient-rich foods such as fruits and vegetables and animal source protein-rich foods and that rural, poor households will eventually follow this food basket change when their income increases[26]. Thus, higher income and lower food prices are together required to make healthy diets more affordable for Vietnam's poor population. Bell *et al.* found that other factors beyond food prices and household income, such as consumer preferences, food safety, taste, convenience, and other food quality attributes, also drive food consumption patterns among Vietnamese populations[39]. Therefore, these factors, along with other social factors, must also be considered in order to enable people to follow the diets recommended by the national FBDGs [40].

In conclusion, the calculations of the cost of the current FBDGs would be valuable for the development of the new 2021-2025 Vietnamese FBDGs, to make them more feasible and achievable. The CoHD is a straightforward indicator, so local policymakers and researchers can apply it on available food price data to track the affordability of healthy diets on a timelier and more regular basis. This would enable regular evaluation of the ability of the local food system to deliver healthy diets and further protect food security, nutrition and health in the country.

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SUPPLEMENTARY MATERIALS OF CHAPTER 5

Table 5.S1. The list of 25 provinces representing six regions in Vietnam, based on the General Nutrition Survey 2019-2020 sample size selection*

Region	Provinces	Population in 2019
Northern midlands and mountain areas	Cao Bằng	530,341
	Sơn La	1,248,415
	Thái Nguyên	1,286,751
	Bắc Giang	1,803,950
Red River delta	Hà Nội	8,053,663
	Quảng Ninh	1,320,324
	Hải Dương	1,892,254
	Hưng Yên	1,252,731
	Hà Nam	852,800
Northern and central coastal areas	Thanh Hoá	3,640,128
	Nghệ An	3,327,791
	Thừa Thiên Huế	1,128,620
	Quảng Ngãi	1,231,697
	Khánh Hoà	1,231,107
Central highland	Gia Lai	1,513,847
	Đắk Lắk	1,869,322
	Lâm Đồng	1,296,906
Southeast	Tây Ninh	1,169,165
	Bình Dương	2,426,561
	Đồng Nai	3,097,107
	Hồ Chí Minh	8,993,082
Mekong River delta	Bến Tre	1,288,463
	Đồng Tháp	1,599,504
	Cần Thơ	1,235,171
	Cà Mau	1,194,476

* Source from National institute of Nutrition, Ministry of Health, Vietnam.

Table 5.S2. Nutrient reference values for a representative Vietnamese adult*

	Unit	Male†	Female‡
Energy	kcal	2,570	2,050
Macronutrients			
Protein	g	69.0	60.0
Carbohydrate	g	370.0-400.0	320.0-360.0
Dietary fibre	g	38.0	25.0
Total fat	g	57.0-71.0	46.0-57.0
Micronutrients			
Calcium	mg	800.0	866.7
Potassium§	mg	2,500	2,000
Magnesium	mg	340.0	270.0
Iron‖	mg	11.9	26.1
Zinc¶	mg	20.0	16.0
Vitamin B1	mg	1.3	1.1
Vitamin B2	mg	1.5	1.2
Niacin	mg	16.0	14.0
Vitamin A	µg RAE	850	650
Vitamin E (alpha-tocopherol)§	mg	6.5	6.0
Vitamin C	mg	100.0	100.0
Vitamin B5	mg	5.0	5.0
Vitamin B6	µg	1.3	1.3
Folate	µg	400.0	400.0
Vitamin B12	µg	2.4	2.4

RAE, Retinol Activity Equivalent.
* Values are Recommended Dietary Allowances (RDAs) or Adequate Intake (AI) adapted from the 2016 Vietnamese recommended dietary allowances book(41).
† Values shown are for a Vietnamese man aged 20-29 years.
‡ Values shown are for a Vietnamese non-pregnant, non-lactating woman aged 20-29 years.
§ Values are Adequate Intake (AI).
‖ Based on iron bioavailability of 10%.
¶ Based on zinc low absorption.

Table 5.S3. Percent of nutrient recommendations met by the Cost of a Healthy Diet (CoHD) pattern according to mean adequacy ratio

Energy and nutrient intakes*	**Average values of a CoHD pattern†**	**NAR-Male**	**NAR-Female**
Energy	2020	0.79	0.99
Macronutrients (g)			
Protein	75.2	1.00	1.00
Carbohydrate	313.4	0.85	0.98
Dietary fibre	12.4	0.33	0.50
Total fat	51.7	0.91	1.00
Saturated fat	12.2	-	-
Monounsaturated fat	16.8	-	-
Polyunsaturated fat	15.9	-	-
Micronutrients			
Calcium (mg)	695.3	0.87	0.80
Potassium (mg)	4,145	1.00	1.00
Sodium (mg)	1,260	-	-
Magnesium (mg)	538	1.00	1.00
Iron (mg)	15.9	1.34	0.61
Zinc (mg)	10.6	0.53	0.66
Vitamin B1 (mg)	1.2	0.92	1.00
Vitamin B2 (mg)	1.5	1.00	1.00
Niacin (mg)	9.7	0.61	0.69
Vitamin A (μg RAE)	335.5	0.39	0.52
Vitamin E (mg)	4.2	0.65	0.70
Vitamin C (mg)	111.9	1.00	1.00
Vitamin B5 (mg)	7.4	1.00	1.00
Vitamin B6 (μg)	1.7	1.00	1.00
Folate (μg)	1,111	1.00	1.00
Vitamin B12 (μg)	1.7	0.71	0.71
Mean Adequacy Ratio (MAR)*		**0.83**	**0.86**

CoHD, Cost of a Healthy Diet. NAR, Nutrient Adequacy Ratio. RAE, Retinol Activity Equivalent. MAR, Mean Adequacy Ratio.
† Nutrient values are analysed based on the 2019 Vietnamese Food Composition Table[42].
* Data is the average of 60 CoHD patterns, from January 2016 to December 2002.
‡ Values are analysed across 20 nutrients with reference values adapted from Table S2.

Chapter 5

Table 5.S4. Number of food items by food group for Consumer Prices Index food prices data

Food groups	Main food items	Number of food items	
		Original CPI list	Final CPI list
Grains	Rice, bread, noodles, potato, corn, casava	18	12
Protein-rich foods	Red meat, poultry, seafood, eggs, legumes and beans, and soy products	42	39
Vegetables	All type of vegetables and mushroom	14	14
Fruits	All type of fruits	16	12
Dairy	Milk, yogurt, cheese	8	8
Fats and oils	Animal fat, plant-based oils, butter, nuts, and seeds	4	3
Discretionary foods	Sugary and salty foods, coffee, alcoholic beverages and other beverages, and foods eating away from home	74	0
Total		**176**	**88**

A bright morning at the Floating Market in Can Tho.

Chapter 6

GENERAL DISCUSSION

Improving access to and consumption of healthy diets are among the crucial targets of food system and nutrition research[1]. Taking Vietnam as the local food system in focus for study, this thesis has attempted to fill in the data gap of diet quality and access to healthy diets by generating the essential tools for assessing the diet quality and the cost and affordability of healthy diets. Key insights necessary to facilitate effective interventions and support policy decisions have been identified to support food and nutritional security in the country.

MAIN FINDINGS

The first study in this thesis (chapter 2) describes the process of developing a national diet quality indicator for general Vietnamese population, the Vietnamese Healthy Eating Index (VHEI) based on the 2016-2020 Vietnamese food-based dietary guidelines (FBDGs). The index is the first of its kind for Vietnam and is calculated using dietary intake data of a large national representative sample (GNS 2009-2010), reflecting the diet quality of Vietnamese adults. Through an in-depth evaluation strategy described in chapter 3, the VHEI proved to be a valid indicator for ranking participants based on their adherence to the dietary guidelines and a valuable measure of diet quality. Here, the VHEI was evaluated on its reliability and validity (construct, criterion, and relative validity) using another nationally representative sample (GNS 2009-2010) and a sample of a validation study conducted as part of the International Dietary Data Expansion (INDDEX) Project's validation of the INDDEX24 Dietary Assessment Platform. The novelty in this evaluation is the relative validity of the VHEI when it is derived from different dietary assessment methods, including weighed food record as a benchmark and 24-hour individual dietary recalls using the computer-assisted personal INDDEX24 platform or a pen-and-paper questionnaire.

Moving from the *a priori* approach used in chapters 2&3 to the *a posteriori* approach, chapter 4 studied the empirically derived dietary patterns among Vietnamese adults. We derived three dietary patterns within the GNS 2019-2020 participants: a meat pattern, a pescatarian pattern, and a healthy pattern. Compared to another study on the dietary pattern in Vietnam using the GNS 2009-2010 dietary intake data[2], the pescatarian pattern is most similar to the pescatarian pattern previously derived, whereas the meat and the healthy patterns were less similar to the traditional and the omnivorous pattern. One of the key findings of the study in chapter 4 is that higher adherence to the healthy pattern is characterised by greater consumption of fruits and plant-based oils and that consumption of certain vegetables, seafood, eggs, plant-based protein sources, nuts and seeds, and dairy was associated with both higher diet quality measured by the Global Diet Quality Score (GDQS), VHEI, and the mean probability of adequacy(MPA) and higher diet cost (both before and after energy adjustment).

The last study in this thesis (chapter 5) zoomed in on one key component of a food system, namely food access concerning the cost and affordability of healthy diets. The results showed that the local food system failed to deliver healthy diets to all classes of the population. Approximately 70% of low-income households cannot afford the cheapest form of a healthy diet recommended by the 2016-2020 Vietnamese FBDGs, largely in the Northern midlands and mountain areas and the Central highlands of the country. The nutrient-rich food groups, including protein-rich foods, vegetables, fruits, and dairy, composed approximately 80% of the total cost of healthy diets (the cheapest version) in all regions, with dairy accounting for the most considerable portion of this.

SYNTHESIS

Quality of Vietnamese diets

The studies in this thesis used two national nutrition surveys (GNS 2009-2010 and GNS 2019-2020), which are compiled in annual United Nations agency reports and are important sources of information on the prevalence and causes of malnutrition in the country. At the national level, daily dietary energy consumption using GNS 2019-2020 data was estimated around 2,000 calories per adult (aged ≥ 20 years), with approximately 61% of the energy intake consumed coming from carbohydrates, and about 22% and 17% of energy from fats and protein, respectively (chapter 3). This composition was different compared to the results of GNS 2009-2010, which reported approximately 15%, 69%, and 16% for protein, carbohydrates, and fats, respectively (chapter 2), and the results from the study by Kim *et al.* who used the 2016 Vietnamese Household Living Standard Survey (VHLSS) for their analysis. Results from this study showed that at the national level the composition of macronutrients that contributed to energy intake was approximately 70% from carbohydrates, and approximately 17% and 13% of energy intake from fats and protein, respectively[(4)]. Based on the World Health Organization (WHO) recommendations for a balanced diet, with the adequate contribution of macronutrients to total energy intake for the prevention of noncommunicable diseases (NCDs) that contain 10-15% from protein, 15-30% from fats, and 55-75% from carbohydrates[(3)], the composition of carbohydrates and fats in the recent Vietnamese diet (GNS 2019-2020) were within the range, but protein was not.

Applying the VHEI in the two surveys yielded intriguing results on Vietnamese diet quality. In Vietnam, the diets of the general population do not fully align with the recommendations in the national FBDGs. The nationwide average VHEI of 43.3 out of 80 using GNS 2009-2010 and 43.7 out of 80 using GNS 2019-2020 (chapters 2&3). Although the total VHEI scores were not largely different after ten years, the component scores showed several differences; specifically, the scores of fats and oils and fruits increased, whereas scores of other components decreased (**Figure 6.1**). Though the score of fruits improved slightly, fruit consumption was still low in the population. In other studies, Vietnamese adults were already found not to meet the WHO recommendation for fruit and vegetable consumption[(5)], a finding that concurs with our analysis.

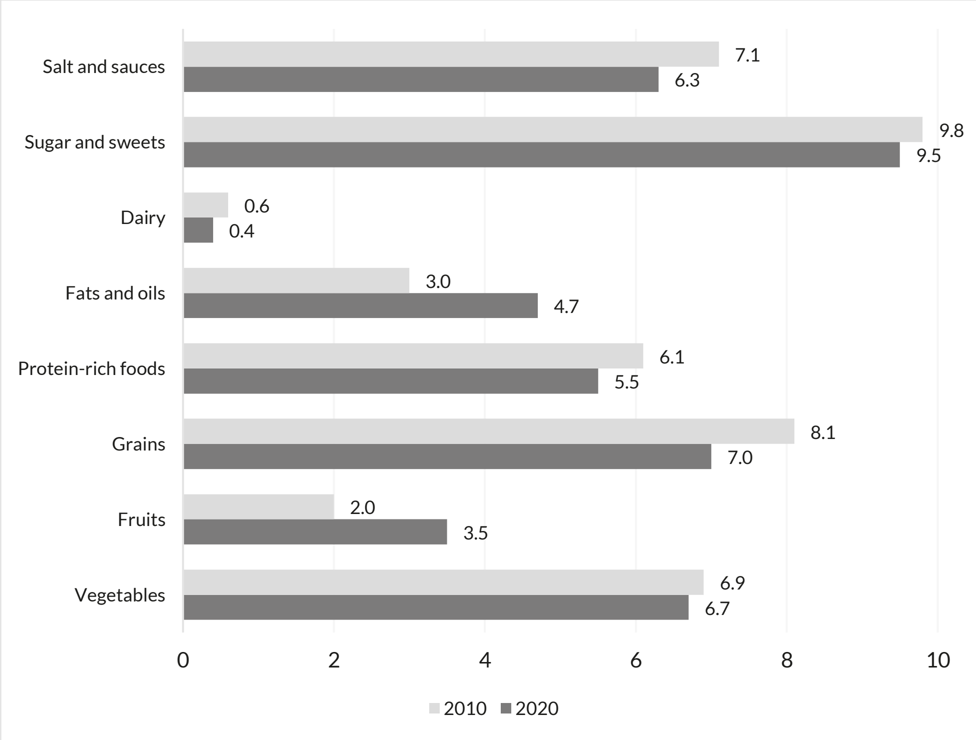

Figure 6.1. Mean component scores of the Vietnamese Healthy Eating Index calculating from the Vietnamese General Nutrition Surveys 2009-2010 & 2019-2020

Following economic growth and fast urbanisation, LMICs have begun to experience a switch from mostly starchy, low fat, high fibre content diets to increased consumption of processed foods which are higher in fats, sugar and salt. Nutrition and health concerns are no longer limited to undernutrition and micronutrient deficiencies but also to the high prevalence of overweight and obesity and diet-related NCDs[6; 7]. Like most of these LMICs, Vietnam has experienced a marked nutrition transition. Over a decade, the consumption of animal source foods has continually risen. This is especially the case with daily meat consumption (including both red meat, poultry, and processed meat), which increased from approximately 85g per adult in 2010 to approximately 145g per adult in 2020 (data adapted from chapters 2&3) and was markedly higher in men (approximately 180g per day) compared to women (approximately 115g per day). In contrast, daily rice and rice products consumption decreased from approximately 380g per adult to approximately 325g per adult. The “traditional” dietary pattern, characterised by significant consumption of rice and rice products, has switched to the “meat” pattern, with people preferring to eat diets containing less rice but more animal source and processed foods, which are high in added salt or animal fat. The contribution of fats to total energy intake also increased from approximately 16% in 2010 to approximately 22% in 2020 (data adapted from chapters 2&3). Other studies also showed that Vietnamese diets are quickly shifting towards more unhealthy patterns, with an increase in fat intake and meat consumption co-occurring with a decrease in vegetable intake[8; 9]. Many of these changes are driven by the vast economic growth that Vietnam has experienced. Since the launch of the economic reforms in 1986, Vietnam has recorded impressive achievements in growth performance and has gone from one of the world's poorest nations to an LMIC[10]. This change has been resulted in growth of an urban population that requires different diet (i.e., Westernised food consumption patterns)[11; 12], increase in per capita affluence and changes in food environments[13] (analysed further in the next section).

Despite the above-mentioned findings, we observed that not all people have shifted their diets in an unhealthy direction due to the fact that we derived a healthy pattern with higher fruits and vegetables, dairy, seafood, and nuts and seeds in our study population. Those who consumed this pattern were more likely to be female, living in the Red River delta, employed, and of higher education (chapter 4). The consumption of a healthy dietary pattern, in some contexts a positive marker for a better healthy eating diet, has increased in a certain portion of the population in the country. A study by Trinh *et al.* also found that females’ diets were more diverse than those of males, and urban households in Vietnam reported prioritising their personal health and the natural content of food, and would increase seafood and fruit consumption if their income were to increase[14]. However, shifting the whole population in this direction might be a challenge, as discussed in the next section.

The dietary changes in Vietnam have also been related to the changing nutritional status of the population. The prevalence of overweight and obesity among Vietnamese adults is 38.9% (32.3% overweight and 6.6% for obesity) using WHO BMI cut-off points for the Asian population(15). These numbers were higher than the results reported by Nguyen *et.al*, who showed overweight and obesity increased from 2.3% in 1993 to 15.0% in 2015(8) among 18-65 years old Vietnamese(8). The prevalence of overweight and obesity was higher in men (34.9% overweight and 7.1% obesity) than in women (30.0% overweight and 6.1% obesity). The marked increase in overweight and obesity among Vietnamese adults observed in recent years and also in this thesis is of concern, and therefore should be among the key targets in the upcoming nutrition interventions in the country.

Parallel to the increase in overweight and obesity, however, is a decrease in prevalence of undernutrition and micronutrient deficiency among the general Vietnamese population. Diet quality in terms of nutrient adequacy of Vietnamese diets has improved over the last ten years, evidenced by a MPA increase from 0.38 (GNS 2009-2010)(2) to 0.49 (GNS 2019-2020). The MPA calculated from the GNS 2019-2020 for Vietnamese adults ≥20 years was close to the cut-off value of 0.5 suggested by Kennedy *et al.*(16) for the total population; however, the MPA of women was lower (0.43) than MPA for men (0.55). The intake of calcium, magnesium, zinc, folate, vitamin B2, vitamin C, and vitamin A was still insufficient for the total population. Comparing between genders, the intake of calcium, magnesium, zinc, iron, folate, vitamin B2, and vitamin A were inadequate for women, while vitamin C was low in men (chapter 4). Our findings support that women of reproductive age are still amongst the most vulnerable groups and are thus a highly relevant group of interest to include in nutritional programmes. Though adult men did not suffer severely from inadequate micronutrient intake, a higher prevalence of overweight and obesity and higher adherence to the “meat” pattern (greater in red meat, processed meat, animal fat, salt and sauces, and alcohol consumption) was observed.

Inadequate access to healthy diets and how to address

The nutrition problems that plague Vietnam are linked to poor diet quality and the types of food people can access. Access to healthy diets is a prerequisite for consuming them; when food security is under threat, so is diet quality[17]. Chapter 5 showed that nutrient-rich foods accounted for approximately 80% of the total cost to afford the cheapest version of healthy diets recommended by the FBDGs, in all regions. What has also been told in chapters 4&5 is that increasing the consumption of nutrient-rich foods to meet a healthy diet will face the barrier of the cost constraint, which significantly limits the ability of the population to achieve higher diet quality, especially for those with low-income. These results, together with the findings in chapter 2&3, showed that diet quality scores for nutrient-rich foods such as fruits, dairy, and protein-rich foods remain low in the population. For those who adhered to the healthy pattern, GDQS+ (positive sub-metric for healthy food groups) score was much higher than those with lesser adherence, while the GDQS- (negative sub-metric for unhealthy food groups) stayed similar (chapter 4), suggesting that most of the dietary shortcomings originated from underconsumption of healthy foods rather than overconsumption of unhealthy foods.

"Those Vietnamese who adhered to a healthy dietary pattern also spent more (chapter 4)."

If the national FBDGs are reachable as evidence-based standards of healthy diets, and if the food price database is realistic, then there is clear evidence of inadequate access to healthy diets in the country. These findings might reflect many aspects of the local food systems. They reveal a widespread lack of access to healthy diets and expose problems in local food environments, where healthy diets are too expensive or food availability is not necessarily proportional to requirements[18].

Their interactions with the food environments shape food acquisition and consumption by the population[19]. Different food environments can drive access to healthy or unhealthy diets and further affect nutrition and health outcomes[20]. Although we looked deeply at the affordability aspect in the current thesis, how food environments also include availability, properties of food (i.e., safety, quality, convenience, and sustainability), and food marketing and vendor properties[21; 22]. Though future research is still needed to capture a complete picture of the food environment in Vietnam, the scientific evidence we provided across all chapters of this thesis can be considered the first effort to prove that there is a need to improve the food environment in the country. Policies play such important roles in determining food availability, access, properties and marketing[18]; thus, policies in Vietnam must support the vision toward a healthier food environment for the population.

Policy discussion is out of the scope of this thesis, though we highlighted key areas to be borne in mind by policymakers in the country when considering fiscal measures, such as the need to focus on which certain foods (i.e., dairy, fruits) or nutrients (i.e., saturated fats) or what type of policies should be made. For example, price policies that address affordability and purchasing incentives for different foods can be a crucial policy tool since food prices affect, to a certain degree, how much and which types of food people buy[23]. However, to our knowledge, few countries have introduced price policies that intend to influence consumer purchases and food consumption in recent years[24].

"The cheapest version of a healthy diet recommended by the Vietnames food-based dietary guidelines was unaffordable for approximately 70% of low-income households, costing up to 70% of their income (chapter 5)."

Food prices belong to the external dimension of the food environment, whereas income makes up the internal dimension[25]. Besides food prices, income poses a significant barrier for many consumers trying to balance diet quality with affordability. We found lower household income was associated with poorer diet quality (chapter 2); indeed, the cheapest version of a healthy diet was still unaffordable for approximately 70% of low-income households, costing up to 70% of their income (chapter 5). Household food purchases should be considered a critical intervention target to improve diet quality among low-income populations in the country. Economic and social policies that aim to achieve an adequate income for all are therefore needed, together with nutrition and food policies that simultaneously undertake food insecurity. However, *"expectations for a positive effect of income on nutrition may need to be tempered with an understanding of what foods consumers are likely to purchase as their income rises"*, according to Herforth and Ahmed[21], because rising incomes worldwide may increase the demand for animal source foods by 70%[26].

Other examples for policy actions that address accessibility to nutrient-rich foods are comprehensive marketing restrictions and easy-to-understand front-of-pack nutrition labels[22]. Income transfers, whether as cash, vouchers, or in kind, have been regularly encompassed as policy tools to improve the affordability of nutrient-rich foods[27]. Evidence show that vouchers have been particularly effective in increasing nutrient-rich foods consumption, for instance in Northern Ecuador[28]. Making habitually-consumed staple foods more nutritious can also be an option to improve the affordability of healthy diets[22]. Food fortification is a cost-effective approach to enhancing nutrient intake and nutritional status of a population[29] and is related to economic benefits[30]. Interventions such as biofortification of cereals and legumes or (mandatory) postharvest fortification of cereal flours, rice, and other such grain products, improve the nutrient content of the food supply, especially in regions where staple foods dominate [31; 32]. Successful programmes in some LMICs have shown effectiveness in addressing micronutrient deficiencies among vulnerable populations through aligning fortification with social, economic and environmental dimensions simultaneously. One example is the "*Mandatory Rice Fortification*" programme launched in early 2018 by the Prime Minister's Office of India[33].

In the current thesis we were unable to characterise other elements of food access, including food availability, transportation, and processing, due to a complete lack of data. Other studies in Vietnam, however, had these data available and have interpreted these dimensions in their analyses[14; 34; 35]. Results from a *'Vietnam partial food systems baseline assessment'* report showed that urban consumers have the most convenient access to food outlets compared to peri-urban and rural ones, showing geographic location and ease of access are among the key drivers[34]. Other studies also showed that transportation and distance to sources of nutrient-rich foods impact low–income and rural communities[36]. Vegetables and fruits availability was more affected by the season than other foods in the rural areas in Vietnam, which might affect the access to these nutrient-rich foods in those areas during seasons of lower availability[34]. We also found that the cost of vegetables and fruits was affected by seasonality (chapter 5), which might be due to the lower availability mentioned earlier. In Vietnam, the food processing industry has grown rapidly, which, together with food imports, has led to new and processed food products being available in the retail food outlets. This strengthens the trend towards the adoption of Westernised food consumption patterns that result in overweight and obesity and other nutrition-related outcomes[11].

Recommendations for Vietnamese food-based dietary guidelines

FBDGs, including the Vietnamese FBDGs and similar guidelines published by other countries, are designed to promote the consumption of foods to meet dietary requirements. In this thesis, the 2016-2020 Vietnamese FBDGs were used as a standard of healthy diets to develop the diet quality index (chapters 2&3) and to analyse the insights between food access and the FBDGs (chapters 4&5). Below, we offer some suggestions based on our research findings for developing upcoming versions of the FBDGs in Vietnam.

First and foremost, the elements of the current FBDGs are well structured, and the manual for interpretation of the FBDGs is also well developed. However, the information about the development process (i.e., methodology document) is still lacking, which might generate questions as to whether the diet based on the FBDGs reflects the quality of dietary intake for the target populations. Thus, scientific evidence for the development of any FBDGs should be stated obviously (i.e., through the scientific publications or the official website of NIN) so that researchers or other readers can access it. More information about the evaluation of the Vietnamese FBDGs should be provided so that the readers understand that the evidence-based integrated messages are reasonable. Such behaviour is seen by the Dutch Health Council in the Netherlands[37] or the Department of Agriculture and the Department of Health and Human Services in the US[38], who have done well in developing and sharing the information regarding their FBDGs through websites, reports, and publications. Understandably, Vietnam is an LMIC with limited resources and a lack of research-based evidence for developing the FBDGs; thus, we hope the results and lessons proposed in this thesis could serve as valuable starting points for future endeavours.

Currently, 75% of FBDGs among 90 countries (where FBDGs are currently available) for which they exist contain recommendations regarding dairy consumption(39). In some FBDGs, messages specific to dairy typically coalesced around its health benefits, such as bone, teeth, muscle, cardiometabolic, gut and immune(40). In the Vietnamese FBDGs, dairy and dairy products (i.e., yoghurt and cheese) are recommended to be consumed three to four servings daily, and the health value of dairy is solely in terms of its nutrient content (i.e., calcium). Unfortunately, promoting this message will be a massive challenge in Vietnam, as we observed that approximately 99% of the population failed to meet these recommendations (in two national nutrition surveys, GNS 2009-2010 and GNS 2019-2020) and this correlated with inadequate calcium intake. In addition, recommending this amount of dairy would increase the cost of meeting the FBDGs and make the FBDGs become less affordable, since we found that dairy accounted for the largest part of this cost. Recent evidence has also highlighted controversies regarding dairy consumption and environmental sustainability(41; 42; 43). Hence, it is currently unclear whether to keep the current dairy message in the FBDGs or to find

Highlights

- Approximately 99% of the population failed to meet the recommendation of consuming three to four servings of dairy and dairy products daily.
- Dairy accounted for the largest part of the total cost to meet the cheapest form of the healthy diet recommended by the national food-based dietary guidelines.
- Calcium intake was inadequate among the general Vietnamese population.

an alternative solution to meeting the calcium requirements for the population; more evidence is therefore needed.

Saturated fat intake has an established link with inverse cardiovascular health outcomes, and strong evidence supports public health guidelines to recommend reducing saturated fat consumption to less than 10% of total energy intake version (which would mean less than 22g in a 2,000 kcal diet)[44; 45]. Daily saturated fat intake of Vietnamese adults was approximately 15g in GNS 2019-2020. Although this intake is still under 10% of total energy intake, it was quite a large increase compared to the intake of GNS 2009-2020 (approximately 10g). In the Vietnamese FBDGs, however, no such distinction of made regarding the type of fats, especially saturated fat. Unlike in Vietnam, other FBDGs have stated more straightforward messages concerning fat intake[37; 39; 46]. For example, Dutch FBDGs released a nutrient-based message to limit saturated fatty acid consumption to less than 10% of total energy intake in the 2006[47] and a food-based message to replace butter, hard margarine, and solid cooking fats with soft margarine, liquid cooking fats, and vegetable oils was made in the 2015 version[37; 48]. This might be an important missed opportunity for improving one of the major nutrition concerns and, hopefully, one that can be remedied in a future version of the Vietnamese FBDGs.

It will be more beneficial for the population if recommendations for other food groups (e.g., grains, protein-rich foods) in the FBDGs are also stated more clearly. For example, in the current versions, various protein-rich foods (including meat, poultry, fish, seafood, eggs, soy products, legumes and beans) are gathered in one group. However, we found that different protein sub-food groups or grain sub-food groups play different roles in delivering nutrient values, health benefits, cost, and environmental impacts. For instance, meat consumption is increasing rapidly in the population yet costs more and is more environmentally demanding. In contrast, promoting fish consumption might be a potential win-win solution to meet the demand for animal source foods whilst also meeting the cost, healthiness, and environmental targets, as discussed in chapter 4. Though health benefits of whole grains warrant their preference over refined grains in a healthy diet[49; 50], this message is poorly conveyed in the Vietnamese FBDGs; thus, this distinction should be considered in order to address low dietary fibre intake of the population.

Although alcohol consumption was not well measured in our study populations, other studies provided clearer evidence of harmful alcohol use among the general Vietnamese population, especially men[51; 52]. Alcohol consumption in Vietnam is quite high compared with other countries in the WHO Western Pacific Region[53]. The harmful use of alcohol is a major risk factor for disability and deaths worldwide and is associated with several health targets of the SDGs[54]. Since 2018, WHO has also called for more strong actions to tackle harmful use of alcohol[54]. The National Assembly of the Socialist Republic of Vietnam approved the law on the prevention and control of alcohol-related harm, effective from January 1, 2020[53]; however, the recommendation of alcoholic beverages is not a component of the Vietnamese FBDGs. In other countries, such as the United States, China, Sweden, The Netherlands, France, and Italy, consumption of alcohol is particularly limited in their FBDGs[55]; thus, this seems like a major missed opportunity for dietary guidance and public health in Vietnam.

Last but not least, there has been a call for better engagement of sustainability in FBDGs in recent years[56]. These guidelines are considered incomplete if they ignore the indirect health impacts caused by food production and consumption[56; 57]. Some FBDGs have well incorporated sustainability, including the Dutch FBDGs [58] and the Nordic nutrition guidelines[58]. However, most of the FBDGs are not compatible with at least one of the global health and environmental targets[59]. In some situations, the diets recommended by the FBDGs could have caused even higher environmental impacts than the current average diets due to the specific recommendations for certain food groups. For example, the FBDGs of the UK, US, and China were incompatible with the actions needed to combat climate changes [59; 60]. There has never been a more important time to improve the FBDGs worldwide to be healthier and more sustainable[56; 59] and Vietnam should not be left behind this ongoing global effort.

METHODOLOGICAL CONSIDERATIONS

Development of the Vietnamese Healthy Eating Index: an application of the *a priori* approach

Selecting components and assigning foods to components

The VHEI includes eight components: two (vegetables and fruits) in the adequacy category (getting enough of certain foods or nutrients), four (grains, protein-rich foods, fats and oils, dairy) in the optimum category (consume foods within an optimal range), and another two (sugar and sweets, and salt and sauces) in the moderation category (limit consumption of certain foods or nutrients), representing the 2016-2020 Vietnamese FBDGs[61; 62] (chapter 2). We decided to follow the recommendations in the FBDGs fully, however the components "dairy" and "sugar and sweet" were found indiscriminating in ranking participants since these food groups are consumed occasionally by the study population.

Eight component scores of the VHEI represent eight food groups. Foods to be included in each component were derived from the graphic presentation, the official background document of the FBDGs[62], with added information provided by NIN. However, our classifications might be different from other countries. For example, we grouped potatoes into the grains component, while they are classified as vegetables in the USA[63] and Japan[64]. We grouped legumes with other protein-rich foods, which is similar to the USA[63] and some European countries[65], but they are considered vegetables in Canada[66] or a distinct component in the French diet quality index[67]. Nuts and seeds are classified into the fats and oils component, whereas they are considered protein-rich foods in the USA[63] or a separate component in the Dutch Healthy Diet 2015 index[48]. These differences might limit direct comparison between diet quality indices or the application of country-specific indices for other countries. Thus, a global diet quality index such as the GDQS is preferable when comparison between diet quality across countries is desired[68].

Scoring system

All VHEI components were weighted equally as none of them was recommended more than the others in the FBDGs[61; 62]. This approach has been used in many other diet quality indices, such as the Japanese Food Guide Spinning Top score[64] or the Canadian Healthy Eating Index (HEIC-2009)[66]. However, others have argued that applying weighting factors is useful for increasing diagnostic capacity[69; 70]. It is not reasonable that all components of an index have the same health impacts. However, in order to ascribe higher weights to those components that influence our health to a greater extent, evidence is needed on the individual health effects of the index components and particularly on their relative impacts[71].

All VHEI components were calculated using discrete recommended servings instead of a density approach (based on energy intake). This density approach has been adopted differently in the literature since some indices apply it, such as the HEI-2005[72] and HEI-2010[73], Japanese Food Guide Spinning Top score[64], but some do not, e.g., Canadian Healthy Eating Index (HEIC-2009)[66], or do so for only certain components, such as the Dutch Healthy Diet index (DHD-index)[47]. Using a density approach for all components may be problematic because of the difficulties in obtaining a precise energy intake level. However, such an approach has its own advantages; for example, the score can be calculated independently from energy intake. Some have argued that those consuming a higher energy intake will have a higher chance of achieving higher scores simply because they are consuming more food, which may not necessarily prove they are consuming a higher quality diet. However, in chapter 3, the VHEI proved its ability to measure diet quality independently of total caloric intake. Other authors have recommended considering energy intake when using their indices (i.e., the Dutch Healthy Diet index), but this since positive associations with nutrient intakes were observed both before and after energy intake adjustment this does not appear necessary for the VHEI (chapters 2&3).

Suggestions for advanced analysis

Though we carefully evaluated the VHEI regarding its reliability and validity (construct, criterion, and relative validity) in chapter 3, we missed the evaluation between our index against biomarkers and clinical parameters of nutrition status due to the lack of available data. This drawback therefore limits our comparison with similar studies[74; 75]. For example, van Lee *et al.* showed that combining four biomarkers (including serum total cholesterol and carotenoids, EPA and DHA omega-3 fatty acids in plasma phospholipids, and 24-hour urinary sodium) was the best available approach to evaluate their diet quality index[75]. An important limitation of this thesis is that it does not provide evidence to support that VHEI is a suitable indicator for capturing diet-related NCDs risk. This is because of the limited number of NCDs outcomes in the data. As mentioned earlier in the general introduction section, due to the need for the costly resource, prospective cohort data concerning nutrition and health is entirely lacking in Vietnam; therefore, we call for more investigation into this type of research in Vietnam and other LMICs. This would enable future research to perform more advanced analysis in further investigating the linkages between diet quality, which can be measured by the VHEI and nutrition and health outcomes (e.g., diet-related NCDs) when this data is available. Future research in Vietnam will benefit from more advanced analyses if dietary and laboratory data are available. There is a need for a dietary assessment method (i.e., a screener) to quickly skim healthy eating patterns in some time-limited settings (i.e., general and clinical practices). Therefore, future research can use the VHEI as a foundation for developing a tool for such circumstances. For example, a short FFQ (34 items) based on the Dutch Healthy Diet index (DHD-index) proved to be a useful tool when applied to study determinants of dietary intake[76]. Future research might also be interested in determining the feasibility and validity of a cut-off value for the definition of poor diet quality based on the VHEI in the general Vietnamese population. Through our in-depth evaluation strategy, the VHEI proved to be a valid measure of diet quality for the general Vietnamese population; however, a modification to the VHEI might be needed in the future. This may be necessary when the updated version of the FBDGs is available, or when new evidence is available to demonstrate that several old components should be excluded or that several new components should be included in order to better reflect diet quality in Vietnam.

Derivation of Vietnamese dietary patterns from PCA: an application of the *a posteriori* approach

In addition to an *a priori* dietary pattern analysis method, we used PCA, an *a posteriori* dietary pattern analysis method, which derived three main dietary patterns within the GNS 2019-2020 participants: a “meat” pattern, a “pescatarian” pattern, and “healthy” pattern. We then used the VHEI and other diet quality indicators to evaluate these derived dietary patterns. Their associations followed our expected direction, suggesting the effectiveness of these approaches in complementing each other for their different applications in nutritional epidemiology research(77).

The use of conventional PCA with its limitations has been discussed thoroughly in chapter 4 and will not be repeated here. Instead, we describe novel exploratory methods that, unlike PCA, are not commonly adopted in the literature but might be useful in addressing these limitations. (78). For instance, the Treelet transform analysis is a latent class approach combined an amalgamation of PCA and hierarchical clustering analysis(79). The Gaussian graphical models is an exploratory analysis, which identifies the conditional independence structure in the data by examining pairwise correlation between two variables controlling for other variables models(80). The reduced rank regression can handle multiple response variables, though it is unsuitable if the functional relationship to model between dietary variables and the dependent variable is nonlinear(81; 82). Contrary to PCA, reduced rank regression treats dietary intake data as independent variables(82). It also considers prior knowledge about variables potentially relevant for the pathophysiological consequences of dietary intake, though it is exploratory by design, making it more likely a hybrid approach(78; 82).

The Cost of a Healthy Diet indicator

In chapter 5, we used the CoHD indicator developed by Herforth *et al.*[83; 84], which is applied in global analysis and several countries[85; 86; 87]. It was named the Cost of a Recommended Diet (CoRD) in these previous analyses[85; 86; 87]; however, since the FAO currently adopts it for global use, they and the authors are shifting to using the term CoHD[83]. The indicator is straightforward and necessitates only two pieces of data. The first piece of data is the recommended quantity (in edible grams) of each food group in a recommended healthy diet, for which we used the recommended servings of food groups in the 2016-2020 Vietnamese FBDGs. In applying this, we assumed that the quantity of all food groups recommended in the FBDGs fulfil the estimated average requirements for energy and nutrient intakes for a general Vietnamese adult. We thoughtfully evaluated the nutrient content of our CoHD pattern (the cheapest version of the FBDGs with mostly plant-based protein-rich foods) and found that the average number of recommended servings already meets most of the nutritional needs.

The second piece of data is the price per edible gram of food items within each food group. The authors explained that this indicator could be adopted using either the underlying retail food prices collected to calculate the country's CPI or food prices derived from household survey data[83; 84], both of which have their own advantages and disadvantages[88]. We chose to use the CPI data for reasons such as seasonality and that it is less time-intensive for further application in Vietnam), as discussed in chapter 5. One noteworthy limitation of those food price databases is that they cannot cover a wide range of food items, especially the large representative sample like the national nutrition survey that we used (this applied for both chapters 4&5).

We chose to calculate the CoHD since this indicator uses the national FBDGs that are typically tailored to country-specific food preferences and nutritional conditions. However, some have argued that the CoHD indicator estimated the lowest cost of healthy diets by selecting the cheapest items in each food group, and therefore some habitually-consumed foods might not fall into the CoHD patterns, leading to an underestimation of the cost of healthy diets by the CoHD [88]. Mahrt *et al.*[88]

introduced a modification to the CoHD indicator called the Cost of a Healthy Diet - Food Preferences to gain insight into the cost of acquiring the recommended healthy diet while considering actual dietary preferences. By means of the research objectives, researchers with access to household survey data in Vietnam might be interested in using this modified CoHD indicator in their future research to take into account consumer tastes and preferences.

Practical challenges in dietary assessment

Across the chapters, we experienced numerous challenges relating to data gaps when analysing dietary intake data in Vietnam. The difference in dietary assessment methods used in the GNS 2009-2010 (household consumption data) and GNS 2019-2020 (individual dietary intake data) might introduce bias when comparing results across the chapters. The GNS 2009-2010 used in chapter 2 were on the household level and needed to be converted to the individual level. We used the Adult Female Equivalent (AFE) concept, which is modified from the Adult Male Equivalent (AME) method first introduced by Weisell *et al.*[(89)]. This conversion has several limitations which have been discussed in the same chapter. Namely, it might inaccurately estimate dietary intake since approximations were created for one reference household member while the distribution among household members was not considered.

Although other datasets (i.e., GNS 2019-2020, INDDEX24) that we used were at the individual level, they were still based on intake of 1-day recall. In theory, several recalls must be carried out to estimate usual or long-term average daily intake, which is not only the targeted measure but also a stumbling block to dietary assessment. However, in practice, usual dietary intake is very difficult to assess and is assessed with significant measurement error, especially in low resource settings like Vietnam. In addition, a diet contains numerous dishes, foods, nutrients and other components, each of which have distinctive attributes[(90)]. These components are not only correlated with each other but also differently consumed; for example, some are consumed daily by almost everyone (e.g.., rice), while others are consumed episodically (i.e., dairy), meaning that 24HR data are zero-inflated. Thus, with its measurement error and zero inflation, this multivariate data required complex models or statistical methods to capture patterns of usual dietary intake. Nonlinear mixed effects software was attempted by Tooze *et al*.[91] and Kipnis *et al*.[92] to fit even simple versions of this model; still, it failed due to the complexity and dimensionality of the model. Later, Zhang *et al.* introduced a highly nonlinear, zero-inflated, repeated measures with multiple latent variables model, in which they used survey-weighted Monte Carlo computations to fit the model in order to take both measurement error and episodically-consumed foods into consideration[90]. This approach has been used to administer the HEI-2010 and HEI-2015 to the US population[93; 94]. We tried to apply this approach in chapter 3 to administer the VHEI using the GNS 2019-2020 data (with 24HR as a dietary assessment method with 15% of repeated recalls available) under the guidance of the author from the abovementioned studies, Dr K W Dodd (National Cancer Institute, USA). However, it has not yet been successful due to several reasons, including the outlier's treatment and the modelling of episodically consumed foods (i.e., dairy).

Vietnam is an LMIC with a complex food system, complicated diets, and customary eating practices that create numerous challenges for accurate dietary assessment, whether measured through direct observation and weighing or by a recall. For example, eating food from a shared bowl with chopsticks is a challenge to the estimation of portion sizes during the survey or to converting the collected data into grams during the analysis. Vietnamese cuisine is famous for complicated recipes (e.g., one dish can be made from many ingredients and cooked in many ways), making it very difficult to create standard recipes. The increasing occurrence of food eating away from home in a complicated street foods environment like Vietnam is also among the challenges. Despite our best efforts in developing an extensive database for Vietnamese street foods, it is impossible to cover all of them.

The Vietnamese FCT published by the National Institute of Nutrition (NIN) is available but does not include a wide range of locally eaten mixed recipes, and the information values of many food items are non-existent. In order to estimate energy and nutrient intakes of different dietary intake datasets, we spent a significant amount of time obtaining missing values in the current FCT from other sources (i.e., the 2017 Indian FCT, the 2015 Standard FCT in Japan, and the 2020 Food Data Central, The United States Department of Agriculture). We also needed to make several assumptions to complete this task. For example, there are some food items that were not available in any of the FCTs, and thus the nutrient values of similar food items were replaced. Furthermore, data on the nutrient content of processed foods and retention factors of cooked foods were completely missing, which prevented us from making more precise estimations.

Salt intake measured via 24-hour recalls is considered inaccurate due to recall bias and the lack of information about salt added at the table by the individual(95). However, it has been used in many studies and national surveys, including our own studies and the previous National Health and Nutrition Examination Survey (NHANES) from 2009-2010 to 2017-2018(96). Future research has room to overcome these weaknesses by measuring 24-hour urinary sodium excretion, which is considered the gold standard for measuring population salt intake(97), though this is not always feasible and is considered burdensome for study participants. In countries with fewer resources, spot urine sodium measurements can be used in a representative sample as an alternative strategy(98).

SOCIETAL LINKAGE AND IMPACTS

Regarding potential impacts, this thesis has yielded several research outcomes linked to societal goals such as improved food security and nutrition and innovative applications and practical uses with them. The applications and implications of the research findings to achieve nutrition outcomes through effective interventions have been discussed in the individual chapters. Beyond the project's local setting, what we have learned from studies conducted in Vietnam would offer opportunities to draw lessons and implications for other settings, especially countries with similar concerns and experiences with the nutrition transition.

Regarding the collaboration between researchers and related stakeholders, we have linked our research activities with the NIN and GSO, the two main stakeholders of this research project. We have also proposed to communicate the research findings with these institutes directly. Chapters 2&3 focused on developing and evaluating the VHEI based on the 2016-2020 Vietnamese FBDGs and application examples. Chapter 5 calculated the cost to meet the healthy diets recommended by these FBDGs. These tasks have been successfully accomplished; thus, we plan to report these findings to the NIN, the organization responsible for developing FBDGs in Vietnam. The NIN can use the cost and consumption patterns related to the 2016-2020 Vietnamese FBDGs as the scientific evidence for the development of the 2021-2025 Vietnamese FBDGs and the VHEI as a monitoring tool in their future activities. Chapter 5 explored the minimum cost of meeting the healthy diets using the Cost of a Healthy Diet (CoHD) indicator, the comparison in the CoHD by food group and by region, the seasonality, and the affordability of healthy diets in Vietnam using a routinely collected databases from GSO. Thus, the routine use of the CoHD by GSO using its own data might offer further opportunities for nutrition-sensitive monitoring related to food systems in Vietnam.

We also aim to effectively disseminate the results of this thesis to other stakeholders and decision-makers. First the preliminary findings will be shared with our key CGIAR Initiative on Sustainable and Healthy Diets through Food System Transformation (SHiFT) partners, including the Institute for Policy and Strategy for Agriculture and Rural Development (IPSARD) and the Vietnam Academy of Agriculture Sciences (VASS). Our partners also include other renowned international research institutes and programmes such as the International Food Policy Research Institute (IFPRI), The Alliance of Bioversity International and CIAT, and the International Dietary Data Expansion Project and the Food Prices for Nutrition Project (both implemented by Tufts University), amongst others. Researchers from our current partners, including national medical universities (i.e., Hanoi Medical University, University of Medicine and Pharmacy at Ho Chi Minh City), international universities and organizations (i.e., Tsukuba University, Japan National Institute of Health and Nutrition, Queensland University of Technology), would also be interested in the findings of this thesis. This network allows numerous possibilities to communicate the project outcomes to a more general audience, including national policymakers, through workshops, policy briefs, and publications, in which the innovations and practices evaluated and ascertained in the research project will be documented. The results of this thesis will also be shared at professional conferences and international meetings. The research described in this thesis is continued by the CGIAR Initiative on Sustainable and Healthy Diets through Food System Transformation (SHiFT; Sustainable Healthy Diets Through Food Systems Transformation - CGIAR) and a new project funded through the Innovative Methods and Metrics for Agriculture and Nutrition Action programme (IMMANA; https://www.anh-academy.org/immana/fellowships).

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A street vendor in Hanoi's Old Quarter, she sell flowers on street on a beautiful morning.

SUMMARY

This thesis fills the data gap of diet quality and access to healthy diets by generating essential tools for assessing the diet quality and the cost and affordability of healthy diets in a low-and-middle-income country, Vietnam.

Chapter 1 introduces how food systems for improved nutrition and health research can contribute to the global health and development targets, presents background literature, and conceives the critical research questions.

In chapter 2&3, we apply the *a priori* approach to develop, evaluate, and apply the Vietnamese Healthy Eating Index (VHEI), the first diet quality indicator for the general Vietnamese population. In these two studies, the dietary intake data of two large national representative samples, the Vietnamese general nutrition survey 2009-2010 and the Vietnamese general nutrition survey 2019-2020, are used. The VHEI proves to be a valid tool for ranking Vietnamese adults (aged ≥ 20 years) based on their adherence to the Vietnamese food-based dietary guidelines (FBDGs) and a valid indicator for measuring diet quality.

In chapter 4, we apply the *a posteriori* approach to study three empirically derived dietary patterns (the meat, pescatarian, and healthy patterns) consumed by the general Vietnamese population using the Vietnamese general nutrition survey 2019-2020 dietary intake data. Different diet quality indicators, including the Global Diet Quality Score (GDQS), the VHEI, and the mean probability of adequacy (MPA), are used to assess and compare the quality of these dietary patterns. We also calculate the cost of consuming these dietary patterns by merging the dietary intake and Consumer Price Index food price databases. The results show that higher adherence to the meat pattern was associated with lower diet quality and higher diet cost. Adherence to the healthy pattern, characterised by high consumption of fruits, plant-based oils and certain consumption of vegetables, seafood, eggs, plant-based protein sources, nuts and seeds, and dairy, was associated with both higher diet quality and higher diet cost.

In the last single study of this thesis (chapter 5), we apply the Cost of a Healthy Diet (CoHD) indicator to estimate the lowest cost to meet the 2016-2020 Vietnamese FBDGs. We also compare the cost differences by food group, region, and seasonality and assess the affordability by comparing the cost of healthy diets relative to both total food expenditures and income. The average lowest cost of healthy diets was 3.08 international dollars using the 2017 Purchasing Power Parity exchange rate (24,070 Vietnamese Dongs). The nutrient-rich food groups, including protein-rich foods, vegetables, fruits, and dairy, composed approximately 80% of the total cost in all regions, with dairy accounting for the largest portion of this. We found that, in Vietnam, a cheapest form of healthy diets recommended by the national FBDGs are affordable for all high-income and upper-middle-income households but unaffordable for approximately 70% of low-income households, costing up to 70% of their income.

In the last chapter, the cooperative findings of the four studies in this thesis are synthesised, focusing on the key insights to facilitate nutrition interventions and inform policy decisions in achieving higher diet quality for the population in the country. The methods used in each study with their limitations and suggestions for future research are also discussed in this chapter. This thesis closes with a brief discussion on societal linkage and the impacts of the research outcomes that were successfully achieved.

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ABOUT THE AUTHOR

Van Thi Thuy Duong (Katie) is a lecturer and researcher at the Department of Nutrition and Food Science, University of Medicine and Pharmacy at Ho Chi Minh City, Vietnam. Her research mainly focuses on the linkages between diet quality, nutrition, and health outcomes on one side and branches out to investigate the relations between agriculture, food systems and nutrition on another side. Fully funded by Vietnam Government, in 2017, Duong received her master's degree in Human Nutrition at the University of Chester, the UK. Then, she became a fellow of the NIHN Fellowship Program for Asian researchers at the Japan National Institute of Health and Nutrition. From 2018 to 2022, she conducted her PhD in the Division of Human Nutrition and Health, Wageningen University, The Netherlands, as part of the CGIAR Research Program on Agriculture for Nutrition and Health (A4NH). Recently, Duong is awarded a post-doctoral IMAMANA Fellowship to continue researching the linkages between food access and nutrition in Vietnam. Besides nutrition research, she has experience as a nutrition consultant at FV International Hospital and a nutrition manager at Fitness & Lifestyle Group (FLG), Vietnam. Duong also runs her own blog and nutrition brand, Katie's Nutrition.

OVERVIEW OF COMPLETED TRAINING ACTIVITIES

Training activities	Institute/ Department	Year
Discipline specific activities		
Exposure Assessment in Nutrition Research	Graduate School VLAG	2018
Healthy and Sustainable Diets: Synergies and Trade-off	Graduate School VLAG	2019
Micronutrient Forum's 5th Global Conference, CONNECTED	Micronutrient Forum	2020
A4NH Flagship 1 Annual Meeting	CGIAR	2020
5th Annual Agriculture, Nutrition and Health Academy Week (#ANH2020)	ANH Academy	2020
10th International Conference on Diet & Activity Methods (eICDAM 2021)	Wageningen University and Research	2021
6th Annual Agriculture, Nutrition and Health Academy Week (#ANH2021)	ANH Academy	2021
7th Annual Agriculture, Nutrition and Health Academy Week (#ANH2022)	ANH Academy	2022
Nutritional Science Days	Dutch Academy of Nutritional Sciences	2022
22nd International Congress of Nutrition	IUNS	2022
General courses		
PhD Week	Graduate School VLAG	2019
Scientific Writing	Wageningen In'to Languages	2019
English Speaking & Pronunciation	Wageningen In'to Languages	2019
Scientific Publishing	Wageningen Graduate Schools (WGS)	2019
Communication with the Media and the General Public	Wageningen Graduate Schools (WGS)	2021
Reviewing a Scientific Manuscript	Wageningen Graduate Schools (WGS)	2022
W21-576 Tailor-made Scientific Writing	Wageningen In'to Languages	2022
The Essentials of Scientific Writing and Presenting	Wageningen In'to Languages	2022
Writing Grant Proposals	Wageningen In'to Languages	2022
Writing Proposition for your PhD	Wageningen Graduate Schools (WGS)	2022
Last Stretching of your PhD	Wageningen Graduate Schools (WGS)	2022
Other activities		
Writing of Research Proposal	Graduate School VLAG	2018
PhD Tour in Italy and Switzerland	Division of Human Nutrition and Health	2022
Weekly/monthly presentations and seminar, etc.	Division of Human Nutrition and Health	2018 - 2022

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