Zentrum für Entwicklungsforschung (ZEF)

THE ROLE OF THE FOOD ENVIRONMENT AS A DRIVER OF DIET QUALITY IN CHILDREN AND ADOLESCENTS

A CROSS-SECTIONAL ANALYSIS OF EXTERNAL AND INDIVIDUAL FACTORS

Dissertation

zur Erlangung des Grades

Doktor der Ernährungs- und Lebensmittelwissenschaften (Dr. troph.)

der Agrar-, Ernährungs- und Ingenieurswissenschaftlichen Fakultät
der Rheinischen Friedrich-Wilhelms-Universität Bonn

von

Janosch Michael Klemm

aus

Münster

Bonn 2025

Referentin: Prof. Dr. Ute Nöthlings

Korreferent: Prof. Dr. Christian Borgemeister

Tag der mündlichen Prüfung: 01.04.2025

Angefertigt mit Genehmigung der Agrar-, Ernährungs- und Ingenieurswissenschaftlichen Fakultät der Universität Bonn

Acknowledgements

I would like to thank my supervisor Prof. Dr. Ute Nöthlings for navigating me through nearly four years of research and its related excitement and frustration, for being optimistic, supportive, available, a well of knowledge and believing in the value of this work. Thank you also to my second supervisor Prof. Dr. Christian Borgemeister for unwavering support, pragmatic and prompt guidance, strategic advice and giving me a home for this research at ZEF. I learned more than I thought I could and hoped I would.

Several post-docs from the University of Bonn have been generous with their knowledge and patient with mine: Dr. Ines Perrar, Dr. Kolade Oluwagbemigun, Dr. Martin Parlasca and Dr. Hannah Ameye. Thank you for making each manuscript better, taking the time and effort to work on minute details, being diligent and constructive and letting me build on your experience and expertise.

This work would not have been possible without its study participants, especially the students and their parents in Accra. Thank you to all collaborators from the government and academia in Ghana that – despite full schedules and numerous obligations – helped me with their contacts, insights and discussion. I am indebted to the whole team at the School Health Education Programme Department at the Ministry of Education for not only allowing this research to take place, but also to provide it with such support (and all the right letters!). Doris Hushie, Ernest Amoah Ampah, Theresa Oppong Mensah, Patrick Banafo, Stephen Abanfo, Kwabena Bempah Tandoh, Cynthia Nyarko, Grace Homiah, and Philipina Tupper, as well as all teachers who supported the data collection at the schools visited: Thank you for receiving me so warmly.

Thank you to Prof. Dr. Peter Quartey and Dr. Aba Crentsil from ISSER University of Ghana for hosting me during my research stay in Accra; Prof. Dr. Richmond Aryeetey, Prof. Dr. Amos Laar, Dr. Deda Ogum, Prof. Dr. Anna Lartey and Prof. Dr. Matin Qaim for providing me with invaluable comments, helpful advice and knowledge on everything related to nutrition, food environments and policy. My whole research team in Ghana - Kezia, Abdul Rashid, Joseph, Bernice, Eric, Felix, Joshua, Joshua, Kingsford, Lawrie, Nana, Solomon, Terrence, Vivian - thank you for making this fun, being in good spirits, your conscientiousness and showing me all the good street food around the research sites!

Work on the DONALD-data was greatly eased and supported by the help from PD Dr. Ute Alexy – I appreciate you making time for this and discussing my very first manuscript in this field with me. I am grateful to Dr. Saskia De Pee for many things – among them having been able to use and work on data from the Fill the Nutrient Gap Analysis at the World Food Programme, as well as my former colleagues Jane, Zuzia, Mysbah, Sabrina, Claudia, Chris and Greg for jointly analysing and writing those manuscripts. I received crucial pointers from Samuel Muli and Guido Lüchters on all statistical matters.

Thank you to Ana, Timo and Max from the One Health and Urban Transformation Graduate School at ZEF for everything from support on administrative forms to well-catered-jour-fixes, building and keeping alive the graduate programme and for taking care of all the invisible work. To my fellow research colleagues, batch associates, travel buddies, monday-meeting attenders, train delay sufferers, office sharers, conference visitors (and session skippers), lunch companions, politics debaters, fruit and vegetable snackers, coffee breakers and pizza eaters: I consider myself lucky to have shared this experience with you. Thank you for your kindness.

I am grateful for the financial support of the Ministerium für Kultur und Wissenschaft des Landes Nordrhein-Westfalen.

Most importantly, thank you to my family for guiding me on what matters.

Table of Contents

Acknowledgements .... *I*

Summary .... *V*

Zusammenfassung .... *VII*

Acronyms and Abbreviations .... *IX*

Tables and Figures .... *X*

List of publications during dissertation period .... *XI*

1. Introduction *1*

2. Background and motivation *2*

2.1. Of plates and people: diet quality and individual factors **2**

2.2. You eat where you are: defining the food environment **3**

2.3. What we know: existing evidence on the food environment **10**

2.3.1. Availability 10

2.3.2. Prices and affordability 11

2.3.3. Product Characteristics 12

2.3.4. Promotion 13

2.4. What we do not know: gaps in food environment research **14**

2.4.1. Conceptual gaps 14

2.4.2. Evidence gaps 15

2.4.3. Gaps in scope and research methods 16

3. Research Objectives *18*

4. General Methods *20*

4.1. Conceptual Framework **20**

4.2. Study design and participants **21**

4.3. Indicators and assessments **23**

4.3.1. Individual Factors 23

4.3.2. Diet quality and nutritional status 23

4.3.3. Market assessments 24

4.3.4. Spatial measures and assessment 24

4.4. Statistical analyses **25**

5. Publications *26*

Study I: The role of the food environment for dietary intake in LMICs **26**

Study II: The association between residence and dietary intake in a HIC **38**

Study III: Individual-level drivers of diet quality in adolescents in Ghana **51**

Study IV: School food environment and adolescents' diets in Ghana **65**

6. Discussion *94*

6.1. Conclusions from this research **94**

6.2. Weaknesses and strengths of this approach **98**

6.3. Relevance and policy recommendations **99**

7. Summary and Outlook 101
References......102
Annex and materials...... i
A. Supplementary Materials for Study I......ii
B. Supplementary Materials for Study II......xi
C. Supplementary Materials for Study III...... xiv
D. Supplementary Materials for Study IV...... xv

Summary

The food environment, typically considered the place where individuals interface with food supply, is increasingly discussed for its role and opportunity to influence diet quality of individuals. Available studies suggest that the food environment plays a role for diet quality, but the pathway behind this remains unclear. It is also not well understood to what degree the role of the food environment is mitigated by individual factors, such as wealth, education or sex. Additionally, detailed analysis on the role of the food environment for specific age group (children and adolescents) is lacking. Lastly, a better understanding of how food environments differ from each other is needed to inform targeted, effective policies to improve diet quality. For example, whether some urban areas differ from other urban areas, or if food environments within low- and middle-income countries (LMICs) are different from high-income countries (HICs).

Consequently, the aim of this research was to investigate if, and to what degree, the food environment is associated with the diet quality of children and adolescents. More specifically, we analysed the relationship between food environment indicators and diet quality of young children in 20 LMICs (**study I**) and identified the variation of diet intake among individuals aged 6-18 years within Dortmund, Germany (**study II**). Additionally, individual-level factors that influence diet intake among adolescents (**study III**) and the association between food environment indicators and diet quality around schools in Accra, Ghana (**study IV**) were investigated.

Results from **study I** show that diet intake and quality vary across geographical settings. This study (n = 247 subnational areas, 6-23 months) highlights that high variation of food environment indicators (e.g. food price and availability) exists across LMICs. It also shows a superordinate association between food environment indicators and diet quality at the subnational level. **study II** (n = 360, 6-18 years) captures variation at the city level, using data from the Dortmund Nutritional and Anthropometric Longitudinally Designed (DONALD) Study and shows that, in comparison to the North of Dortmund, students in the South have lower BMI, lower intake of sugar-sweetened Beverages and higher intake of vegetables.

Results from **study III** suggest that individual level factors create dependency of adolescents (n = 409, 12-15 years) on the food environment. We report that daily food

budget is negatively associated with overall diet quality and positively with food group diversity. Food environment indicators are also associated with diet quality after controlling for individual factors (**study IV**). Research conducted in Accra documents that pricing of foods from vendors (n = 1,340) in and around schools (n = 12) are associated with diet intake of students (n = 409, 12-15 years) in the same location. This association persists even after controlling for individual factors, indicating that some drivers of dietary quality are outside the control of the individual.

In conclusion, the food environment is an important factor in understanding the variation in diet quality for children and adolescents. This result was confirmed by data from observational studies carried out in subnational areas in 20 LMICs, Dortmund, Germany and Accra, Ghana. The consistent association of financial indicators (both prices and budget) with diet quality suggests that affordability should be a key consideration for policies aiming to ensure access to a healthy, nutritious diet within the food environment. Public health policies targeting the pricing of foods available and attractive to adolescents or children are needed to support improvement of the diet quality of these age groups.

Zusammenfassung

Das Lebensmittelumfeld wird generell als der Ort verstanden, an dem einzelne Personen mit dem Lebensmittelangebot in Berührung kommt. Dieses wird zunehmend mit Blick auf seine Relevanz für Ernährungsqualität diskutiert. Bestehende Studien deuten zwar darauf hin, dass das Lebensmittelumfeld eine Rolle für Ernährungsqualität spielt, aber genaue Mechanismen bleiben hierbei unklar. Es ist beispielsweise nicht erforscht, inwieweit die Rolle des Lebensmittelumfelds durch individuelle Faktoren wie Bildung oder Geschlecht abgeschwächt werden kann. Außerdem fehlt eine detaillierte Analyse der Rolle des Ernährungsumfelds für bestimmte Altersgruppen (Kinder und Jugendliche). Um gezielte, wirksame Maßnahmen zur Verbesserung der Ernährungsqualität zu entwickeln, bedarf es ebenfalls eines besseren Verständnisses davon, wie sich verschiedene Lebensmittelumfelde voneinander unterscheiden. Hiermit ist zum Beispiel gemeint, ob sich städtische Gebiete untereinander unterscheiden oder ob sich das Lebensmittelumfeld in Ländern mit niedrigem und mittlerem Einkommen (LMICs) von dem in Ländern mit hohem Einkommen (HICs) unterscheidet.

Ziel dieser Dissertation war es daher, zu untersuchen, ob und inwieweit das Lebensmittelumfeld mit der Ernährungsqualität von Kindern und Jugendlichen zusammenhängt. Konkret wurde die Beziehung zwischen Indikatoren des Lebensmittelumfelds und der Ernährungsqualität von Kleinkindern in 20 LMICs (Studie I) analysiert und die Variation der Nahrungsaufnahme von Personen im Alter von 6 bis 18 Jahren in Dortmund, Deutschland (Studie II) ermittelt. Darüber hinaus wurden Faktoren auf individueller Ebene, die die Nahrungsaufnahme von Jugendlichen beeinflussen (Studie III), und der Zusammenhang zwischen Indikatoren des Lebensmittelumfelds und der Ernährungsqualität in der Umgebung von Schulen in Accra, Ghana (Studie IV), untersucht.

Die Ergebnisse von Studie I zeigen, dass die Nahrungsaufnahme und die Qualität der Ernährung je nach geografischem Umfeld variieren. Diese Studie (n = 247 subnationale Gebiete, Kleinkinder im Alter von 6-23 Monate) unterstreicht, dass es in LMICs große Unterschiede bei den Indikatoren für das Lebensmittelumfeld (z. B. Preis und Verfügbarkeit von Lebensmitteln) gibt. Sie deutet auch auf eine übergeordnete Assoziation zwischen Lebensmittelumfeld und Ernährungsqualität (auf subnationaler

Ebene) hin. Studie II (n = 360, 6-18 Jahre) erfasst die Unterschiede zwischen zwei Stadtgebieten anhand von Daten der Dortmund Nutritional and Anthropometric Longitudinally Designed (DONALD) Studie. Sie zeigt, dass Schüler im Süden Dortmunds einen niedrigeren BMI, einen geringeren Konsum von zuckergesüßten Getränken und einen höheren Konsum von Gemüse im Vergleich zum Norden aufweisen. Ergebnisse der Studie III deuten zusätzlich darauf hin, dass individuelle Faktoren eine Abhängigkeit der Jugendlichen (n = 409, 12-15 Jahre) von der Lebensmittelumgebung begünstigen können. Zum Beispiel ist das tägliche Lebensmittelbudget negativ mit der Gesamtqualität der Ernährung und positiv mit der Vielfalt der Lebensmittelgruppen assoziiert.

Ebenfalls wurde ein Zusammenhang zwischen Indikatoren für das Lebensmittelumfeld und Indikatoren für die Nahrungsaufnahme festgestellt (Studie IV). Die durchgeführten Untersuchungen belegen, dass die Lebensmittelpreisgestaltung von Händlern (n = 1,340) in und um Schulen (n = 12) mit der Ernährungsqualität von Schülern (n = 409, 12-15 Jahre) zusammenhängen. Diese Assoziation bleibt auch bestehen, nachdem für individuelle Faktoren adjustiert wurde, was darauf hindeutet, dass bestimmte Faktoren von Ernährungsqualität außerhalb der Kontrolle des Individuums liegen.

Das Lebensmittelumfeld ist daher ein wichtiger Faktor für ein besseres Verständnis (der Unterschiede in) der Ernährungsqualität von Kindern und Jugendlichen. Dieses Ergebnis wurde durch Daten aus Beobachtungsstudien bestätigt, die in subnationalen Gebieten in 20 LMICs, in Dortmund, Deutschland und in Accra, Ghana durchgeführt wurden. Die konsistente Assoziation von finanziellen Aspekten (sowohl Preise als auch individuelles Budget) mit Ernährungsqualität legt nahe, dass die Erschwinglichkeit im Lebensmittelumfeld ein wichtiger Gesichtspunkt für politische Maßnahmen sein sollte, wenn sie darauf abzielen, den Zugang zu einer gesunden, nahrhaften Ernährung zu gewährleisten. Preisregulierung von Lebensmitteln, die für Jugendliche und Kinder verfügbar und attraktiv sind, sind vielversprechend, um die Qualität der Ernährung dieser Altersgruppen zu verbessern.

Acronyms and Abbreviations

BMI – Body Mass Index

BMI-SDS –Body Mass Index Standard Deviation Score

CPI – Consumer Price Index

DHS - Demographic and Health Surveys

DONALD - Dortmund Nutritional and Anthropometric Longitudinally Designed

DQQ – Dietary Quality Questionnaire

FAO – Food and Agriculture Organisation

FGDS – Food Group Diversity Score

GAIN – Global Alliance for Improved Nutrition

GDR – Global Dietary Recommendation

HIC – High Income Country

HLPE – High Level Panel of Experts

IPC – International Price Comparison

LMIC – Low- and Middle-Income Country

MDD-W – Minimum Dietary Diversity for Women

NCD – Non-Communicable Disease

SES – Socio-Economic Status

SSB – Sugar Sweetened Beverages

UK – United Kingdom

USA – United States of America

WFP – World Food Programme

WHO – World Health Organization

Tables and Figures

Table 1: Key theoretical frameworks including or focusing on the food environment 5

Table 2: Systematic Reviews carried out on the topic of the food environment. 8

Table 3: Existing systematic reviews on food environment measurements 17

Table 4: Characteristics and indicators used in the different studies reported here.......21

Figure 1: Schematic overview of the framework used in this study, adapted from the High Level Panel of Experts and Food Systems Dashboard. 6

Figure 2:Conceptual overview of the food environment domains and indicators used in study III and IV of this dissertation (adapted from the Food Systems Dashboard and HLPE framework)..20

Figure 3: Conceptual graph displaying the main drivers between movements of diversity and balance between favourable or more unfavourable patterns.................................97

List of publications during dissertation period

Original Research

Klemm, J; Coffey, C; Balagamwala, M; Turowska, Z; Kuri, S; de Pee, S. 2024. Exploring the relationship between food environment indicators and dietary intake of children 6-23 months; findings from 20 low and lower-middle income countries. *Global Food Security* 42, 5. doi.org/10.1016/j.gfs.2024.100795

Klemm, J; Perrar, I; Borgemeister, C; Alexy, U; Nöthlings, U. 2024. Place of Residence Is Associated with Dietary Intake and BMI-SDS in Children and Adolescents: Findings from the DONALD Cohort Study. *Int. J. Environ. Res. Public Health* 21, 46. doi.org/10.3390/ijerph21010046

Klemm, J; Muli, S; Oluwagbemigun, K; Parlasca, M; Crentsil, A; Ogum, D; Quartey, P; Laar, A; Lartey, A; Borgemeister, C; Nöthlings, U. 2024. Individual-level drivers of food choices and diet quality among adolescents in urban West Africa: evidence from Accra, Ghana. *Maternal & Child Nutrition* doi.org/10.1111/mcn.13775

Klemm, J; Ameye, H; Parlasca, M; Muli, S; Laar, A; Lartey, A; Borgemeister, C; Qaim, M; Nöthlings, U. (submitted) Effects of the food environment on diet quality of adolescents in urban West Africa. Evidence from a cross-sectional study in Accra, Ghana. *Under review at Health and Place - JHAP-D-25-00629*

List of co-authored publications during dissertation not included in this document

Kuri, S; Turowska, Z; Damu, C; **Klemm, J** and de Pee, S. 2024. "Affordability of nutrient-adequate diets as an indicator for food and nutrition security. Evidence from fill the nutrient gap analyses" Global Food Security 42.

Turowska, Z; **Klemm, J** and de Pee, S. 2024. "Analyzing diet cost and affordability: A dataset from Fill the Nutrient Gap analyses (2015–2021)" Global Food Security 42.

Bose, I; Baldi, G; Kiess, L; **Klemm, J**; Deptford, A and De Pee, S. 2021. "The Difficulty of Meeting Recommended Nutrient Intakes for Adolescent Girls" Global Food Security 28.

Turowska, Z; **Klemm, J**; Hobbs, N; and de Pee, S. 2021. "Risk of nutritional deficiencies increases during female adolescence: A comparison of the cost of a nutritious diet across sex and age" Field Exchange, 66: 76-80.

List of Presentations during dissertation period

2024 Tropentage, Wien [poster]: *Individual-level drivers of food choices and diet quality among adolescents in urban West Africa: evidence from Accra, Ghana*

2023 Federation of European Nutrition Societies (FENS), Belgrade: *Place of Residence Is Associated with Dietary Intake and BMI-SDS in Children and Adolescents: Findings from the DONALD Cohort Study*

2023 Food Environment Research Network (FERN), virtual: *Individual-level drivers of food choices and dietary quality among adolescents in urban West Africa: evidence from Accra, Ghana*

2023 German Congress of Geography (DGK), Frankfurt: *Place of Residence Is Associated with Dietary Intake and BMI-SDS in Children and Adolescents: Findings from the DONALD Cohort Study*

2023 German Nutrition Society Congress (DGE): *Place of Residence Is Associated with Dietary Intake and BMI-SDS in Children and Adolescents: Findings from the DONALD Cohort Study*

2022 International Congress on Nutrition (ICN), Tokyo [poster]: *Exploring the relationship between food environment indicators and dietary intake of children 6-23 months; findings from 20 low and middle income countries.*

1. Introduction

There is an increasing discussion on the role of the food environment for the diet quality of individuals [1,2]. Of specific interest are foods that are considered risk-factors for Non-Communicable Diseases (NCDs) [3]. A heightened exposure to unfavourable foods is thought to increase the risk of consuming these foods [4–6]. This is in particular of interest for children and adolescents in low and middle-income countries (LMICs) [7,8], which have shown worrisome trends of overweight and obesity over the past years, while micronutrient deficiencies and undernutrition persist [9]. The co-existence of these different forms of malnutrition termed ‘triple burden of malnutrition’ [10] in LMICs and among these individuals has led to interest in better understanding how individuals engage with the food environment [11,12] and how it might relate to overall diet quality.

The main objective of this research was therefore to provide insight into the role of the food environment for diet quality. To explore whether patterns of association persist across multiple countries, we investigated the variation of diet quality related to food environment indicators at the subnational level from 20 LMICs. Using data from the DONALD-Study carried out in Dortmund, Germany, we analysed whether variation in diet quality exists within a city in a high-income country (HIC), after controlling for individual or household level factors. Additionally, we collected and analysed detailed data on adolescents and their school food environment in Accra, Ghana, as an example of a LMIC.

This dissertation is structured as follows. Chapter 2 gives an overview of the background of food environment research and uses identifies research gaps to motivate the main objectives of this dissertation, which are summarized in Chapter 3. Chapter 4 provides a concise brief on the general methods used. Chapter 5 includes the four publications or manuscripts, respectively, supplementary files for which are listed in Annex A-D. These findings are discussed in the context of existing literature as well as their policy relevance (Chapter 6). The thesis is concluded by providing an outlook on this field of research (Chapter 7).

2. Background and motivation

The aim of this chapter is to provide the background and motivation for the conducted studies within existing conceptual frameworks, current literature and research gaps.

This chapter will first provide key definitions for diet quality used in this study (as main outcome) as well as individual factors as an important predictor of diet quality (section 2.1). Section 2.2 gives a brief overview of existing food environment research as the main focus for this dissertation, followed by a description of the main conceptual analyses carried out and key findings of empirical food environment research (section 2.3). The main research gaps are described in section 2.4, ending on the ones this dissertation is aiming to fill.

2.1. **Of plates and people**: diet quality and individual factors

Human health is determined by what humans eat [13], which is why it is important to categorize and understand the drivers of diet quality. A myriad of different ways to classify diet quality exist, with no universally accepted terminology. It would exceed the scope of this dissertation to discuss the different conceptual differences and similarities. Regarding foods and food groups, the following terminology is used throughout this dissertation, except if stated otherwise: '**Favourable**' is used for foods and food groups that are associated with decreased and '**unfavourable**' is used for foods that are associated with heightened risk of NCDs [13]. Whether consumption of foods leads to a healthy diet depends on the overall consumption pattern. 'Healthy' is consequently used only in reference to diets. A '**healthy diet'** has been defined as a diet that "provides adequacy without excess, of nutrients and health promoting substances from nutritious foods and avoids the consumption of health-harming substances" [14] as part of the effort to provide a common understanding and reference for the United Nations Food Systems Summit. It should be noted that in most publications focussing on the cost of diet quality, the technical definition of a healthy diet rests on food-based dietary guidelines and a diet that meets adequate levels of macro and micronutrients is referenced as a 'nutrient-adequate' or 'nutritious' diet [15–18].

Therefore, for diets, I will use the following language, except where otherwise stated and explained: '**Diet quality**' refers to the adequacy, diversity and balance of foods consumed over a specified period of time [19–21]. '**Diet diversity**' refers to the count of food groups in a diet.[1] In this dissertation it can refer to a diet diverse in different snack foods or processed meats or to a diet diverse in different types of fresh foods (green leafy vegetables, Vitamin a-rich fruits) [22]. '**Diet balance**' refers to the direction in which diversity leans with regard to the two pathways of the World Health Organization (WHO) recommended healthy diet [13]: foods to consume in moderation and foods to increase consumption of. Detailed technical definition and an overview of what indicators are used by each study are provided in the general methods chapter.

In this dissertation, individual factors consider aspects that relate directly to the background of the specific person consuming foods [2]. The individual factors referred to here are informed by the Food Systems Dashboard adapted High Level Panel of Experts (HLPE) framework on food systems [23] and the food environment framework by Turner et al. (2018) [12]. Individual factors include information on individuals' life situation (background characteristics such as marital status, employment or faith), economic status (food budget or household wealth) [11] or cognitive and aspirational features (knowledge, attitudes or practices). More broadly described individual factors affect how individuals interact with the food environment and what foods they can chose to consume. As with diet quality, precise definition of indicators and reference of these are provided in the general methods chapter.

2.2. **You eat where you are**: defining the food environment

Food environments are of major importance for diet quality. They shape the access and the options that individuals have for food access and are in turn framed by the food supply. Food environments are most commonly defined to consist of food availability, food price and affordability, food characteristics and promotion [24].

The food environment has received increased attention as a factor for diet quality since the early 2000s, when the first articles on this subject were published [25–27]. Research was initially motivated by the public health concern of rising rates of obesity in the United States of America (USA) and the United Kingdom (UK). This has led to terminology such

[1] It is explicitly distinct from the indicator or metric Minimum Dietary Diversity for women (MDD-W), which consists of 10 favourable food groups and for which a threshold of 5 is used to determine the binary indicator of meeting or not meeting MDD-W, which is associated with micronutrient adequacy at population level.

as “food desert” (reportedly dating back to a description by a Scottish public housing resident in 1990s [26]) or “food swamps” [28,29]. These terms were coined to highlight the difficulty of accessing fresh, nutritious foods in inner-city areas while emphasizing the abundance of energy-dense foods that are often rich in saturated fatty acids [29,30]. While such concepts have been useful in characterising urban areas in the USA and UK their applicability to other countries is considered limited [31]. Several studies from HICs provide evidence that availability – high for unfavourable and low for favourable foods – is a major driver behind dietary patterns that ultimately lead to overweight and NCDs [30,32–41].

Research of the food environment in low-middle income countries began mostly in the 2010s, with first seminal work conducted in Brazil [42,43]. In addition to research conducted typically in urban areas and with a focus on overweight and obesity, studies investigated diets across the urban-rural continuum and also included indicators such as dietary diversity. Much of this early research focussed on availability of different foods as the key measure for the food environment.

Common to all these studies is their focus on the intersection of food supply with food demand. Subsequently, the first efforts of systematically describing the food environment, either as part of the whole food system or as singular area of focus started arising in the early 2010s as well [3,44], with the most cited frameworks being the 2017 HLPE [2] and the framework published by Turner et al in 2018 [12].

Different conceptual frameworks vary in their categorization, range and terminology of what the food environment exactly includes, but common to all these definitions is a description of where the specific food that a consumer may eat “meets” the consumer. While initially this was described as the surroundings that would *impact* or even “determine” [1] a consumer’s choice [3], in more recent definitions, terminology has shifted towards that of an “interface” [11,12], emphasizing the bidirectionality and interactive element of the food environment.

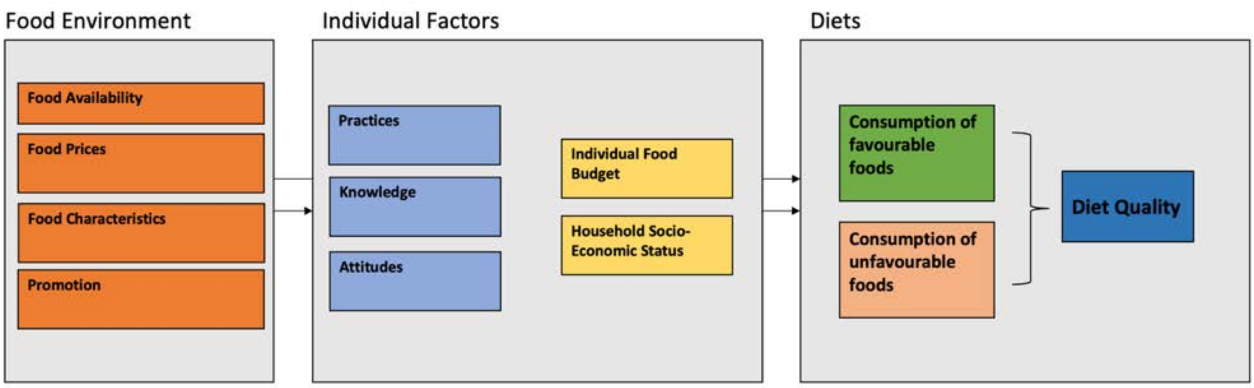
Table 1 provides an overview of different food systems or food environment frameworks and the respective terminology that is relevant for this dissertation. Essential typology or focus-areas are summarized based on the described aim of the publication.

Table 1: Key theoretical frameworks including or focusing on the food environment

Publication	Typology/ Key Focus	Definition
Swinburn et al. 2013	Role for overweight/ obesity	"the collective physical, economic, policy and sociocultural surroundings, opportunities and conditions that influence people's food and beverage choices and nutritional status" [3]
Herforth and Ahmed 2015	Market-oriented food environments	"the availability, affordability, convenience, and desirability of various foods." [44]
FAO 2016	Part of a conceptual Food System understanding	"Food environments comprise the foods available to people in their surroundings as they go about their everyday lives and the nutritional quality, safety, price, convenience, labelling and promotion of these foods" [45]
Global Panel 2017	The link between diet quality and food systems	"the food environment [is influenced by actions and policies across the food system, these collectively] determine[s] the availability, accessibility, affordability and desirability of foods to consumers" [1]
HLPE 2017	Part of a comprehensive Food System Framework	"the physical, economic and socio-cultural context in which consumers engage with the food system to make their decisions about acquiring, preparing and consuming foods" [2]
Turner et al. 2018	Interface with focus on external domain vs personal domain	„the interface where people interact with the wider food system to acquire and consume foods" [12]
Downs et al. 2020	Interface with focus on natural (wild vs cultivated) and built (informal vs formal) food environments	„the consumer interface with the food system that encompasses the availability, affordability, convenience, promotion and quality, and sustainability of foods and beverages in wild, cultivated, and built spaces that are influenced by the socio-cultural and political environment and ecosystems within which they are embedded." [11]

Notably, over time the conceptual frameworks became wider in scope, likely due to research showing the need to reflect more complex interactions between individuals and their surroundings. While the first conceptual outlines of a food environment were focussed on their role for overweight and obesity [3], it quickly became part of a market-based understanding of how individuals access their food within the wider food system [24,44]. Turner et al. (2018) emphasize the difference between external and personal domains, highlighting that individual factors such as desires, beliefs shape dietary intake [12]. In addition to an emphasis on the personal domain, non-market based food environments have also been given increased attention: Downs et al. (2020) include dimensions of wild and informal food environments to capture diet intake of indigenous populations, subsistence farmers and sources of other non-market oriented consumption patterns [11]. Throughout this dissertation, I align with the adapted HLPE terminology used in the framework published alongside food systems dashboard [23]. Unique to this adaptation of the HLPE framework is the distinction between external factors and individual factors that Turner et al. introduce [12] while retaining the mutual influence on diets. Figure 1 provides a schematic overview of the three main components (food environment, individual factors and diets) and their respective subcomponents as used in this dissertation, adapted from the HLPE framework.

Figure 1: Schematic overview of the framework used in this study, adapted from the High Level Panel of Experts and Food Systems Dashboard.



Note: A more detailed version of this framework, populated with indicators used in two of the individual studies is provided in the general methods of Chapter 4 (Figure 3).

Although different in focus, the listed frameworks (expectedly) share similarities. In a narrative review on design of (market-oriented) food environments, Toure et al. (2021)

highlight four common domains among these conceptual frameworks: Food availability, food price and affordability, food characteristics and promotion [24].

While other domains of the food environment exist, often shaped by the specific focus of a given food environment framework, they are less common and not aligned [24]. However, this can be helpful in sharpening the discussions for specific disciplines or domains. For example, some frameworks [12,44] include discussion of the desirability of foods, others the sustainability properties of commodities [11], while the Global Panel and HLPE emphasize the accessibility of foods [1,2]. Research looking at cultural or psychological drivers may be usefully structured by Herforth and Ahmed (2015) [44], whereas research on the sustainability component may in turn be aided by the specific considerations put forward by Downs et al. (2020) [11].

It is worth pointing out that while much of the research and evidence came initially from HICs, much of the more recent conceptual work has been designed with LMICs in mind [7,12,44]. This is evident from work highlighting different socio-cultural drivers and informal built and wild natural food environments. These aspects are considered to play a role in overall diet quality, which was a consideration largely absent in earlier empirical and conceptual work focussing on overweight and obesity.

A full conceptual analysis of the differences and commonalities across food environment frameworks is provided in Toure et al. (2021) [24]. Despite the strong – and consistent throughout frameworks – *theoretical* relationship between the food environment and diets, the evidence on these relationships remains limited. Table 2 provides an overview of the key findings of existing systematic literature reviews referenced. The majority of studies conducted on the food environment come from HICs. Studies from LMICs are emerging since the late 2010s, as shown by recent reviews, but lack of evidence from those contexts are still considered a major research gap [7].

This is an important gap to consider as *empirical* evidence on the role of the food environment in HICs may not easily transfer to LMIC contexts. As most of the research from HICs focused on obesogenic pathways, the food environment's relation to undernutrition, micronutrient deficiencies or overall diet quality is underexplored. No systematic comparison between features of the food environment in LMICs and HICs is known to the author.

Table 2: Systematic Reviews carried out on the topic of the food environment.

Type	Citation	Type of studies included	Focus	LMICs in studies*	Key Finding
Narrative review	Toure et al. 2021	Conceptual	Market food environment frameworks	N/A	"There is conceptual consensus among frameworks that availability, price, food characteristics, and promotion are key domains of the market food environment." [24]
Review of systematic reviews	Lindberg Hansen et al. 2022	Systematic reviews	Effectiveness of food environment policies in improving diets	5/358	"Pricing policies (tax/subsidy) appear effective in altering intake and purchase of targeted foods and beverages." [46]
Systematic review	Williams et al. 2014	Observational (30)	Retail food environment around schools and obesity-related outcomes	1/30	"Little evidence for an effect of the retail food environment on consumption, but some on body weight. [...] it is possible that the effect on body weight is a result of residual confounding." [47]
Systematic review	Engler-Stringer et al. 2014	Observational (26)	Food environment and children's diet	1/26	"Moderate evidence of the relationship between the community and consumer nutrition environments and dietary intake in children up to 18 years of age." [48]
Systematic review/ meta-analysis	Micha et al., 2018	Intervention (91)	Quantitative effects of school food environment policies on children's habitual dietary intake	1/91	"Direct provision policies increased fruit intake [...]. Competitive food/beverage standards reduced SSBs [...] and unhealthy snacks [...]. School meal standards increased fruit intake [...]. Measures of adiposity were generally unchanged." [49]
Systematic mapping	Osei-Kwasi et al. 2020	Intervention (1) and observational (38)	Dietary behaviours in urban food environments in Africa	39/39	"Dietary behaviour was significantly associated with a range of individual and household environmental factors: household income, educational level, employment, land ownership, socio-economic status (SES), ethnicity and financial insecurity." [50]
Systematic review	Carducci et al. 2020	Intervention (17)	Effect of food environment interventions on anthropometrics	17/17	"this systematic review yielded limited evidence to support a beneficial effect of food environment interventions on anthropometric and weight-status outcomes in LMICs. Future work should identify key components of the food environment that may be amenable to modification." [51]

Type	Citation	Type of studies included	Focus	LMICs in studies*	Key Finding
Scoping review	Downs and Demmler 2020	Intervention (64)	Food environment interventions targeting children and adolescents	14/64	"we found evidence to support the adoption of several school-based interventions […] interventions aimed at improving the external food environments that children and adolescents interface with will be increasingly necessary. These interventions need to simultaneously address the multiple forms of malnutrition. However, to date little evidence from LMICs exists about what does, or does not work." [52]
Systematic scoping review	Turner et al. 2020	Intervention (2) and observational (68)	Food environment research in low- and middle-income countries	70/70	"Evidence from low-quality studies show that food availability is associated with dietary outcomes at both the community and school scales across multiple LMICs, although associations were found to vary by vendor type. Evidence regarding associations between food environment exposure and nutrition status is inconclusive at present, whilst evidence related to health outcomes is almost nonexistent." [8]
Systematic review	Westbury et al. 2021	Intervention (7) and observational (67)	Food environment and diet/nutrition in low-middle income countries	74/74	"Consistent evidence reported an association between availability […] and dietary behaviour, […] accessibility to food […] was associated with diet" [7]
Systematic review	Atanasova et al. 2022	Intervention (58)	Causal impact studies of dietary intake and obesity-related outcomes	3/58	"Number and distance to unhealthy food outlets increased the likelihood of fast-food consumption, availability and distance to healthy food outlets significantly improved children's dietary intake" [4]
Systematic review	Shaw et al. 2023	Observational (34) and interventional (2)	Environment and food purchases and dietary behaviors of adolescents	0/36	"Greater exposure to food outlets classified as unhealthy was associated with less healthy food purchases and dietary intakes." [5]
Systematic review/ meta-analysis	Pineda et al. 2024	Observational (103)	Food environment and obesity in adult population	8/103	"Fast-food outlet proximity was positively and significantly associated with obesity, […] no significant associations were found for restaurants, convenience stores or any of the body mass index measures." [6]

** this indicates the number of individual studies that were included in the systematic review that were conducted in LMICs, compared to the total number of studies included. LMICs – Low and Middle Income Countries*

Of high relevance to this research are findings from four systematic reviews, as they particularly reflect on LMIC food environments [7,8,24,50]. Toure et al. (2020) emphasize the need to develop typologies of vendors that are unique or relevant to LMICs and state that research should conduct assessments of informal markets across all domains of the market food environment [24]. Similarly, Westbury et al. (2021) stress sparsity of evidence on product price as well as affordability at the neighbourhood level [7].

In the next section, I will use the four common domains to summarize available evidence on the food environment and its relationship to diet quality or nutrition and health outcomes.

2.3. What we know: existing evidence on the food environment

In this section I will briefly outline the main evidence available for the food environment following the common domains. I will provide a brief definition of each domain, reflect on the availability of evidence in empirical research and summarize the findings from the highlighted systematic literature reviews of the food environment. Where applicable, I will complement them with specific studies that have either been published after the review(s) or fell outside the defined scope.

2.3.1. Availability

Availability is understood as the physical presence of food [12,44]. The FAO defines availability as "the existence of food coming from either own production or the market" [53]. It is among the most researched dimension of the food environment, with many studies investigating whether presence of certain foods alone is associated with their intake.

Among existing evidence predominantly from HICs, it has been well documented that density – measured by number of foods available - of ultra-processed foods is positively associated with obesity [4,6]. This appears to translate to findings from LMICs which show that availability characteristics in the direct neighbourhood are associated with dietary behaviour in adults [54]. Some studies also report an association with health or nutrition outcomes, but not consistently so [7]. There appears to be a substantial urban-rural gradient when it comes to availability in LMICs [55,56]. Recent studies show that food variety is much larger in urban than in rural settings and that this is associated with dietary adequacy [56,57].

Availability at the school food environment level was among the more common aspects found among studies in LMICs, with three out of four studies finding an association of availability with diets [7]. Research carried out on the school food environment in Ethiopia finds that availability of packaged/processed foods is high and "difficult to resist" [58]. Evidence from school food environments in LMICs highlight that 'unhealthy foods' and beverages are widely available around the school food environment [59–61]. This is also confirmed by studies from Ghana, which emphasize ubiquity of snack foods available with little 'healthy' alternatives present [62–65].

2.3.2. Prices and affordability

Affordability refers to the ability to purchase a commodity given its price and the purchasing power of an individual or household or "people's financial capacity to acquire sufficient food, which in turn depends on household income and food prices" [53]. This means that prices are a purely external factor, while affordability is a mix of the external factor price with individual characteristics, namely budget.

Many publications show a general association between affordability and consumption. This is especially the case for prices or affordability and diets overall, which is well researched at a global scale with data from the International Price Comparison (IPC) project, which includes data from LMICs [18,66,67]. This evidence typically combines estimated cost of a diet with household income [18]. In the context of food environment research, the association between food prices and observed consumer choice for a specific commodity group or commodity has been less systematically researched.

In HICs, pricing policies are shown to be effective in influencing intake of sugar-sweetened beverages (SSBs) and unfavourable foods at the general population level [46,68]. In LMICs, evidence on the role of food price for diet quality remains scarce: Of the 74 studies reported in the most current systematic literature review only 4 include studies with prices, 3 of which come from the same country (Brazil) [7]. In a recent study Ameye et al. (2023) find that differences in prices partly explain disparities in nutrient consumption between rural and areas in Tanzania [56]. Evidence from sugar tax suggests an association with higher prices and a decrease in consumption of SSBs in Mexico and Chile [69–71].

In the context of schools, no evidence is known to the author that connects prices of specific foods to their intake. This is very likely because of widespread availability of school meal programmes, financed by parents, governments or donor agencies in LMICs, which limit how many foods need to be bought by students. A scoping review on industrial diets among adolescents in Ghana found no study that included food prices [72]. While most of the studies included some form of affordability measure, the authors note that these typically collect wealth indices as measure of socio-economic status and do not capture and analyse detailed food budget of students. Research, including a principal component analysis on dietary patterns in Ghanaian students, found that students with any pocket money are nearly five times more likely to consume a diet high in sweets ("sweet tooth pattern") [73].

2.3.3. Product Characteristics

Product characteristics refer to food quality, safety, processing and packaging. Of these, measures of food quality, safety and packaging are sparse across the literature and are rarely included as part of food environment research [24]. The degree of processing a food has undergone, on the other hand, has been studied and discussed relatively well since a landmark publication of Monteiro et al. in 2017 [74,75].[2] So called 'ultra-processed foods' have been linked to non-communicable diseases in numerous studies [76,77] and are tracked in several food environment studies [60,78,79]. Results show that ultra-processed foods are highly available in nearly all food environments: globally [74], at the local level [39] as well as around schools [60].

Evidence from Ghana has covered several of these domains, including those that are under-researched according to systematic reviews. Food safety and quality have been found to be of acceptable levels in urban Ghana [80,81]. Research carried out on the degree of processing of foods available emphasizes the extent to which processed foods are available [54,65,73].

---

[2] Several different classification schemes exist when it comes to degree of processing. The most common is NOVA [75], but there are at least five additional ones, including the Food Compass System, the SIGA classification and schemes used by the European Prospective Investigation into Cancer (EPIC), International Food Information Council and University of North Carolina [164]. Ultra-processed foods have been shown by one randomized controlled trial [101] to be associated with increased energy intake and body weight, but there is no consensus on whether and which features – or mechanisms – of ultra-processed foods contribute to greater energy intake [164]. As degree of processing is not a main concern of this study, it is not extensively discussed here.

While product characteristics and especially processing – in particular initiatives on reformulation or lightly processed nutritious foods – remain an important area of investigation, they are not considered among the main research areas of this thesis.

2.3.4. Promotion

Promotion relates to marketing and advertisement of foods. It is considered a fairly well researched dimension, with studies and evidence highlighting how marketing and promotion is influencing the consumption [24].

It is almost trivial to state that effective promotion boosts consumption of food products. In HICs, the high degree of promotion of foods to children is well-documented [82–85]. Implementation of measures to decrease promotion to children, drawing comparisons to banning alcohol, tobacco or gambling for children, are often clouded by questioning the causal nature, for example for foods rich in dietary sugars [86]. Many of the findings on product characteristics have informed nutrition labelling and similar initiatives to make product characteristics visible to the consumer and to inform decision-making on which food to eat [87,88]. Some of these are not necessarily considered as promotion in the strict sense of advertisement. Voluntary labels have been introduced in HICs (such as the Nutri-Score) but remain debated [89–92].

Consequently, many LMICs have also taken steps to address promotion of foods as part of creating healthier food environments. As Toure et al. (2021) highlight, much of the research focuses on contexts where overconsumption of energy-dense foods is part of the dietary transition [24]. Targeted marketing and promotion of SSBs to children around schools has been documented by some studies in LMICs [93,94].

Research shows that the marketing of unhealthy food and beverages around schools is recognized as problematic by school communities in Ghana, but that there are barriers to improve the promotional nature of the food environment [62]. A systematic review of adolescent diets reports that the most advertised foods in Ghana are SSBs, followed by other sweet drinks and instant noodles (‘Indomie’) [72]. The same review highlights the purposiveness with which advertisements are placed near schools and that miniature, cost-friendly packaging is often used to attract children and adolescents [72]. Marketing and advertisement have been linked to the consumption of energy-dense foods [62,95,96]. It is less clear to what extent marketing and advertisement can improve intake of fresh, nutritious foods. Some local initiatives, such as the Obaasima seal in Ghana [97], have attempted to use promotion for fortified foods, but (to date) no clear evaluation exists.

Marketing regulation and promotion have been used as a central element in Ghanaian policies to reduce the consumption of unfavourable food groups among children [98,99]. Due to established evidence on this dimension, especially in Ghana, it is not considered as part of the design of the research presented here.

2.4. What we do not know: gaps in food environment research

In the previous sections I have provided the conceptual references for understanding the food environment and outlined that the common domains across the food environment frameworks are availability, affordability and prices, food characteristics and promotion. I have used existing systematic reviews and literature to highlight available evidence. Following the previous structure, I will briefly highlight what gaps exist in terms of conceptual approaches and empirical evidence to motivate the research conducted here.

2.4.1. Conceptual gaps

A major shortcoming of existing food environment research is that it often does not account for individual factors at the same time as external factors. It remains therefore unclear to what degree findings on the food environment may be due to confounding from individual factors such as wealth or socio-economic status. It could be possible that the observed association of the food environment with dietary practices disappears once the individual-level drivers are sufficiently accounted for. If this were the case, the food environment could even be considered as an outcome of the (aggregate) individual-level factors, not necessarily as an exposure in its own right.

Additionally, much of the research on prices focusses on consumption of one specific type of item on the obesogenic pathway (ultra-processed foods, sweets or industrial diets). This gap in research is likely influenced by the initial focus of the food environment as a contributor to high levels of obesity in HICs. The role of the food environment in ensuring adequate nutrition, also reflecting on dimensions of micronutrient deficiencies and undernutrition, remains less clearly established.

It is important to address this research gap for several reasons: One, the physiological mechanism with which unfavourable foods may bring about negative health impacts is not clearly understood [100,101]. Two, it is empirically unclear to what degree the consumption of (some) unfavourable foods deteriorates overall diet quality. Three, focussing on one type or set of foods does not capture the balance of the diet, i.e. whether higher consumption of unfavourable foods may be offset by an even higher intake of favourable foods.

2.4.2. Evidence gaps

Based on the classification I introduced in the previous chapter and the existing literature discussed in the previous section the following evidence gaps remain:

Regarding availability, it is unclear how relative availability (i.e. between unhealthy or health foods) changes over time and whether total availability (i.e. density of foods available) is different across contexts.

Food prices, and relatedly, affordability, are overall fairly well researched and economic barriers are considered among the key determinants for a healthy diet. However, it remains underexplored how food prices influence dietary intake directly, i.e. for specific food commodities. This is the case for absolute price of commodities, but also for food prices of specific items with regard to prices of other foods. Evidence shows that relative caloric price (expressing food prices of fresh commodities relative to staple foods) explains consumption better than absolute price [67]. No studies could be found that analyse how prices of favourable food groups affect the consumption of unfavourable food groups and vice versa.

It is also unclear at the individual level what budgetary factors influence consumption. While this is very well researched for households – e.g. share of food expenditure to total expenditure as a key metric for food security [102,103] – it is not well understood for individuals and different eating occasions. Lastly, little research investigates the role of prices and availability if they are included in the same model. For example, a recent study of food environments in Malawi reports their findings on market availability, but the conclusions are drawn without considering food price [57].

2.4.3. Gaps in scope and research methods

In the previous paragraphs, I have provided a "common denominator" understanding of indicators of the food environment and given an overview of the existing evidence available. An additional useful way to categorize gaps in existing food environment research for this dissertation is along the dimension of *scope* of the food environment. By scope I specifically mean a) spatial distance, and b) target group(s) under scrutiny. Information about food environments can be usefully categorized along dimensions "where" the food environment is conceptualized and "who" engages in it.

For example, much of the early food environment research has been dedicated to understanding neighbourhood characteristics and their association with household consumption. Limited evidence exists on workplace, home and school food environments in LMICs [7,8]. These are often demarcated environments, where individuals cannot leave easily for certain periods of time and are therefore susceptible to consumption of convenience foods [72]. There is also a gap in understanding the variation within an area and how this variation affects diet quality.

Regarding existing evidence on the food environment for specific target groups, there is wide availability of studies looking at a variety of different individuals. Studies from LMICs have studied the association between the food environment and dietary intake of primary school children [54,65,96,104–109], (school going) adolescents [58,65,73,110–112], women of reproductive age (15-49 years) [43,64,113,114], adults or households. Several of these derive their consumption and background data from aggregate surveys, such as household questionnaires. Individuals within the household may have different consumption patterns. Standardized surveys assess diet quality of the household and young children, but adolescents' diet is rarely routinely captured [115]. This opens an important research gap because it has been documented that adolescent dietary patterns track into adulthood [116].

This aspect also relates to consumption of food away from home for specific individuals. This information is rarely available from household surveys and additionally almost never answered for specific individuals [117]. For example, it is unclear whether and how consumption away from home differs from consumption at home for adolescents.

Lastly, from a methodological perspective, many studies use straightforward measures of spatial dimensions, such as count data, which are not accounting for spatial autocorrelation [118,119] or considering the modifiable area unit problem. Interestingly, some early studies, especially from Brazil, pioneered the use of (more) sophisticated spatial measures, but this was not widely copied [42,106,120,121]. Three systematic reviews were identified that dealt specifically with the measures, assessments and tools used in food environment research (Table 3). These emphasize that very little consistent methodology is used throughout the literature.

Table 3: Existing systematic reviews on food environment measurements

Citation	Focus/ Typology	Key Finding
Kirkpatrick et al. 2014	Dietary assessments in food environment research	"There is a tendency toward the use of brief dietary assessment instruments with low cost and burden rather than more detailed instruments that capture intake with less bias. Use of error-prone dietary measures may lead to spurious findings and reduced power to detect associations." [122]
Lytle et al. 2017	Measures of the food environment	"The most common methodology used to study the food environment was geographic analysis (65% of articles) and the domination of this methodology has persisted since the last review. Only 25.9% of studies in this review reported the reliability of measures and 28.2% reported validity, but this was an improvement as compared to the earlier review. [...] Studies reporting measures of the school or worksite environment have decreased since the previous review." [123]
Lane et al. 2020	Existing observational tools to measure food and physical activity in schools	"In terms of comprehensiveness, tools ranged in their coverage of domains associated with policies and best practices related to food and/or physical activity. Two specific domains assessed by the majority of tools were the cafeteria and outdoor play areas. There are a few domains that could benefit from additional measures development, including indoor play areas and classrooms."[124]

3. Research Objectives

Children and adolescents are at a critical age for nutrition and adequate diet intake. As described in the previous chapter, existing data emphasize the importance that food environments have in shaping individuals' access to diets. A precise understanding on its role for specific food groups, dietary balance and interaction with individual factors is still lacking. This information would be extremely valuable for target group-adequate interventions and public health policies.

Given the existing gaps in the conceptual frameworks and outlined evidence, this research focuses on the concepts of availability, affordability and prices at the individual-level. Its aim is to contribute to the existing literature by providing evidence along the following conceptual lines: 1) **External factors**, especially affordability and price, availability and accessibility; 2) **Individual factors**, especially budget, cognitive and aspirational factors and socio-economic characteristics; and 3) **Spatial variation**, especially the differences of food environment indicators over varying levels of scale. To address the highlighted gaps in terms of scope, study I uses subnational data for the food environment as well as dietary intake. The other three publications in this dissertation deal with the food environment at the neighbourhood or inner-city level (studies II, III, IV). Common to all chapters is the focus on specific individuals across the lifecycle, ranging from early childhood (age 6-23 months, study I), children and adolescents (age 6-18 years, study II) and adolescents (12-15 years, studies III and IV).

The main goal of this dissertation is to characterize food environments in terms of food price and availability and measure their influence on diet quality of children and adolescents. As individual factors carry relevant explanatory weight in the dietary intake, I also explore the importance of food environments indicators *relative* to individual factors for understanding drivers of diet quality. A secondary goal is to describe the food environment and its variation at different spatial distances.

To reach the described overarching research aim, we define the following research aims and corresponding research questions:

Research Aim 1: Identify associations between food environment indicators dietary intake of young children across low and lower-middle income countries.

Research Question 1: Are food environment indicators in low-middle income countries associated with the quality of diet intake of young children (6-23 months old)?

Research Aim 2: Identify spatial variation of dietary intake within the German inner-city environment.

Research Question 2: Are there differences in diet intake among adolescents within the City of Dortmund after we account for socio-economic background characteristics?

Research Aim 3: Capture associations between individual level factors and diet quality within the Ghanaian school food environment.

Research Question 3: (How) Are individual factors associated with food choices and eating patterns of adolescents in Accra, Ghana?

Research Aim 4: Measure and identify association between external and individual factors of adolescents and diet quality within the Ghanaian school food environment.

Research Question 4: What does the food environment around Junior High Schools in Accra, Ghana look like and does it influence the diet intake of students while at school?

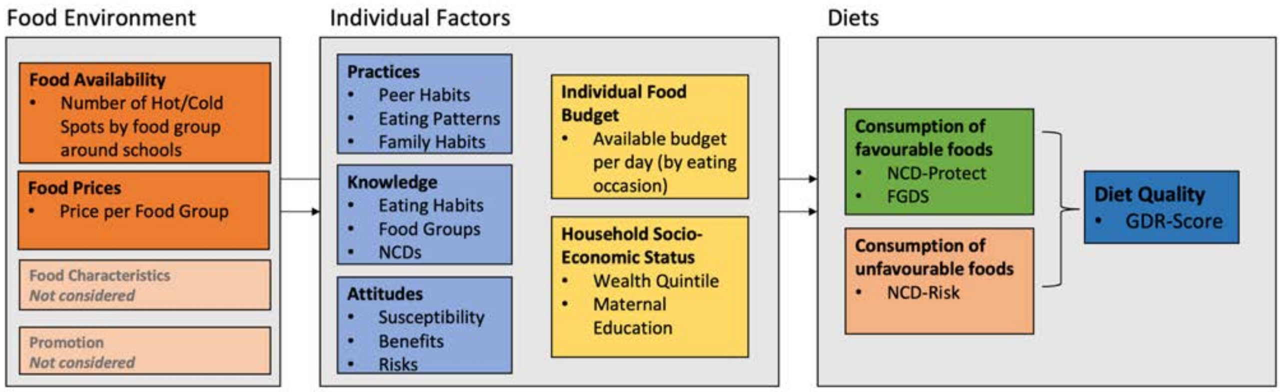
4. General Methods

This section provides an overview of the general methods and approach used in this dissertation. Note that detailed description of study design, definitions of indicators and statistical analyses including formulae are provided in each of the relevant manuscripts (listed in Chapter 5). Section 4.1. gives an overview of the framework and corresponding indicators. Study design and participants are summarized in section 4.2.; an overview of indicators and assessment methods used in each individual study is given in section 4.3. This chapter ends with a summary of the statistical approach taken (4.4).

4.1. Conceptual Framework

As outlined in the introduction, this dissertation follows an adapted version of the HLPE food systems framework. Figure 1 shows each of the main three conceptual blocks that are structuring this research, as well as the indicator groups and indicators used for these in study III and study IV, which both include indicators from all dimensions (cf. Table 4).

Figure 2:Conceptual overview of the food environment domains and indicators used in study III and IV of this dissertation (adapted from the Food Systems Dashboard and HLPE framework).



Note: GDR – Global Dietary Recommendation, NCD – Non-Communicable Disease, FGDS – Food Group Diversity Score

4.2. Study design and participants

This dissertation uses a total of three different datasets. One source is secondary data from the World Food Programme (WFP), Demographic and Health Surveys (DHS) and UNICEF (study I). The other two sources are primary data, collected in Dortmund (study II) Ghana (studies III and IV). This section provides an overview of the methods used in the analysis of each of the datasets. Detailed methodical information for each research aim and study are described in the respective publications (Chapter 5) and their supplementary data, which are reported in the annex A-D to this dissertation. I will refer to these datasets as "WFP data", "Ghana data" or "DONALD data", respectively. Table 4 provides an overview of the most relevant characteristics from each dataset/study design, following the conceptual structure outlined by Figure 1.

Table 4: Characteristics and indicators used in the different studies reported here

	WFP	**Dortmund**	**Ghana**
Study Design			
Study Type	Cross-sectional	Cross-sectional[3]	Cross-sectional
Study Participants	247 subnational areas from 20 countries	360 students	12 heads of schools, 409 students, 1,340 vendors
Age Group	6-23 months	6-18 years	12-15 years
Data and Methods			
Individual Characteristics	N/A	Household characteristics – parental employment and education	Socio-economic status, household wealth, Psychological and behavioural factors
Indicators of individual characteristics	N/A	Adjusted Winkler-Koch Score for Socio-Economic Status	Wealth Quintile, Daily Food Budget, Knowledge, Attitudes and Practices
Diets (Health and Nutrition)	Self-reported, DHS and UNICEF household module	Self-reported, 3 day weighing protocol, anthropometric measurements	Self-reported, 24 hr food group recall (DQQ)
Indicators of diet quality	MDD, Vitamin A-rich foods, Iron-rich foods	Consumption of food groups (g/1000kcal)	GDR score, NCD-Risk, NCD-Protect, FGDS, MDD

[3] Note that while the DONALD study is longitudinally in design, the research carried out here did only use a cross-sectional sample of the total database and is therefore considered cross-sectional for the purpose of this assessment.

	WFP	Dortmund	Ghana
Food Environment	Aggregated market surveys, price, relative caloric price and availability of food groups	N/A	(Geocoded) vendor survey, prices and availability of ready to eat foods
Indicators of food environment	Minimum and Median Price/100kcal, Relative Caloric Price, Market assortment	N/A	Price (in GHS)/ commodity, Hot/Coldspots of food groups
Analysis			
Spatial Variation	Subnational variation (intra-country and across WB income groups)	North/South of Dortmund using geocoded address data	Moran's I (global spatial autocorrelation), Getis-Ord G (local clustering)
Statistical Analysis	Individual random effects regressions	Multivariate fixed effects regression	Linear regression, logistic regression, spatial clustering

Note: GDR – Global Dietary Recommendation, NCD – Non-Communicable Disease, FGDS – Food Group Diversity Score, MDD – Minimum Dietary Diversity, GHS – Ghana Cedi, DQQ – Dietary Quality Questionnaire, WFP – World Food Programme, UNICEF – United Nations Childrens Fund, DHS – Demographic and Health Survey

The data for the WFP data comes from a database of consolidated datasets. It includes food price data and nutrition data for 247 subnational (i.e. Admin 1 or 2 level) areas from 20 countries. It includes price information on 12 food groups and matching information for diets of young children (age 6-23 months), namely % of children that consumed a minimally diverse diet, % of children that consumed iron-rich foods and % of children that consumed Vitamin A-rich foods (all in the preceding 24 hours).

The data for Dortmund comes from a subset of the DONALD study [125]. We selected 360 individuals that were between the age of 6-18 during the years 2014-2019 and had at least one dietary record on file. Of these, 296 had at least one anthropometric measurement recorded in the five-year study period.

The Ghana data used in this dissertation comes from primary data collection carried out in Accra, Ghana between November 2022 and February 2023. Cross-sectional in design, it includes data from 12 school administrations, 409 students from the same schools and 1,340 vendors around these schools. School administration was either head or deputy head teacher (n = 12), students were individuals enrolled in junior high school grade 1 or

2 (aged 12-15, median 14 years) and vendors were eligible to participate if they sold foods within a 300m perimeter around school.

4.3. Indicators and assessments

4.3.1. Individual Factors

No individual factors are included as covariates in the WFP data. DONALD-data routinely includes individual and household level information on parental employment and education, which were used to estimate household socio-economic status (SES) following Winkler-Koch [126].

Data from Ghana include detailed information on individual factors, among them socio-economic background data and household wealth. It also captures knowledge, attitude and practices as well as individual out-of-pocket expenditures on food throughout the day. Knowledge, attitudes and practices were collected according to established protocols [127,128], using a five point likert scale (full questionnaire in annex C and D).

4.3.2. Diet quality and nutritional status

All three data sources include self-reported data on diets. Data from the WFP dataset includes observations from DHS and UNICEF surveys that ask caregivers to report on the diet of children in the previous 24 hours [129,130]. On an individual level, this is reported as a binary indicator (did or did not consume a minimum diverse diet, Vitamin A-rich foods or iron-rich foods) which is aggregated at subnational level to the percentage of children, aged 6-23 months, that displayed the relevant consumption pattern.

The DONALD study asks participants to carry out a three-day-weighing protocol, in which consumed food items are documented and weighed over three days [131]. This allows to capture diet quality in great detail and is here assessed by grams consumed per food group (Vegetables, fruit group) per 100kcal. In addition, weight and height measurements are taken and body mass index as well as age-standardized body mass index (SDS-BMI) are calculated.

The dataset from Ghana followed established protocols for the DQQ methodology, which captures food groups consumed in the preceding 24 hours [132]. Information on food group consumption can be used to calculate a variety of diet quality indicators, of which we focus on four: Global Dietary Recommendations (GDR) score (0-18), which measures adherence to WHO recommended diet guidelines. NCD-Risk score (0-9), which measures the consumption of foods that should be consumed in moderation and are associated with heightened risk of NCDs. NCD-Protect score (0-9), which measures the consumption of foods that should be consumed regularly and are considered protective of NCDs. Food Group Diversity Score (FGDS), which measures how diverse (of ten favourable food groups) a diet is. Using cut-offs derived from minimum diversity, we define three categorical groups that relate to dietary diversity of different food groups. Individuals with high diversity of healthy foods and low diversity of unhealthy foods were classified as "Nutrition Champions", those with high diversity of unhealthy foods and low diversity of healthy foods as "Nutrition Challengers" and those with low diversity throughout as "Nutrition Strugglers".

4.3.3. Market assessments

The WFP dataset includes exhaustive market data that include food price data from one of three sources: WFP market monitoring data, Government consumer price index (CPI) data or food price data derived from household surveys. Data were collected at food level and absolute price (price per 100kcal), relative caloric price (ratio of commodity price to the price of staple) and assortment (count of foods per food group) calculated. No market data exist in the Dortmund dataset.

Data collected in Ghana include information on vendors within 300m perimeter of participating schools. Vendors were asked for the cheapest price per commodity group, with the exception of fruits and vegetables, where all prices were taken, and a simple count of commodities was conducted. Data were only collected on foods that can be directly consumed, i.e. do not require additional cooking processes. Additionally, the geolocation (accuracy <5m) was stored as well as vendor type and whether the vendor sold to students and if so, to how many (self-reported).

4.3.4. Spatial measures and assessment

In the WFP data, no geospatial information is collected, but spatial variation within country is reflected through information on subnational level. The DONALD data reflects spatial dimension within city boundaries, focussing on the North and South of Dortmund as main spatial dimensions. The spatial measures in the Ghana dataset take place at neighbourhood/ school level, i.e. below city administrative boundaries. We include geocoded vendor data as well as polygons of school campus sites.

4.4. Statistical analyses

The analysis of the role of the food environment (and individual factors) on diet quality is conducted mainly through linear regressions, although the exact specifications vary. The WFP data were analysed using individual multivariate effects regression with random effects at the country level. Results were adjusted for multiple testing using Benjamini-Hochberg [133]. Analysis of spatial differences in Dortmund was carried out using individual (i.e. one model per outcome) multivariate fixed effects regression, also adjusted for multiple testing using Benjamini-Hochberg procedure. Linear regression and logistic regression are used on the Ghana data as well as analyses of spatial clustering. Global spatial variation is assessed using Moran's I measure of autocorrelation [118] and local spatial variation is assessed using Getis-Ord G statistic [119].

5. Publications

Study I: The role of the food environment for dietary intake in LMICs

Exploring the relationship between food environment indicators and dietary intake of children 6-23 months; findings from 20 low and lower-middle income countries.

Janosch Klemm, Christopher Coffey, Mysbah Balagamwala, Zuzanna Turowska, Sabrina Kuri, Saskia de Pee

Global Food Security 2024, 42, 5. Epub: 2 September 2024

DOI 10.1016/j.gfs.2024.100795

Global Food Security 42 (2024) 100795

Contents lists available at ScienceDirect

Global Food Security

journal homepage: www.elsevier.com/locate/gfs

Exploring the relationship between food environment indicators and dietary intake of children 6–23 months old; findings from 20 low and lower-middle income countries

Janosch Klemm[a,b,*], Christopher Coffey[a], Mysbah Balagamwala[a], Zuzanna Turowska[a], Sabrina Kuri[a], Saskia de Pee[a,c]

[a] United Nations World Food Programme, Rome, Italy
[b] Center for Development Research (ZEF), Bonn University, Bonn, Germany
[c] Tufts University, Massachusetts, USA

ARTICLE INFO

Keywords:
Food environment
Food prices
Dietary intake
Children 6–23 months of age
Fill the Nutrient Gap

ABSTRACT

Understanding food environments and how they shape dietary and nutrition outcomes is key to ensuring that food systems can support healthy and sustainable diets for the most vulnerable. Using subnational data from 20 low and lower-middle income countries, we explored how assortment, relative and absolute food prices relate to the dietary intake of children aged 6–23 months. We found that greater assortment of nutrient-dense foods in the market showed a positive association with dietary intake (foods rich in iron or vitamin A) of children 6–23 months of age at the subnational level. Higher relative price of nutrient-dense foods compared to starchy staples was negatively associated with intake of foods rich in iron or vitamin A and minimum dietary diversity. We also found negative association between minimum price of nutrient-dense foods and the same dietary intake indicators. This provides evidence on the degree to which assortment and the relative price of foods influence household food choices. The variability in assortment and price within countries highlights the importance of collecting information on food environments at the subnational level, as they determine which foods households can access, and by extension, how diverse and nutritious the diets of children aged 6–23 months in the household, can be.

1. Introduction

Food security is contingent upon reliable access to sufficient, safe, and nutritious foods to meet dietary needs. Evidence on the importance of food environments in low and lower-middle income countries is emerging rapidly, but an understanding of its role in achieving and maintaining food and nutritional security still requires further research, particularly at a subnational level (Turner et al., 2020).

The food environment encompasses food availability, physical and economic access, promotion, advertising, information, and food quality and safety (High Level Panel of Experts on Food Security and Nutrition (HLPE), 2017). It is influenced by, and influences, the wider food system in which it is situated (Herforth and Ahmed, 2015). Measuring the food environment is key to understanding how it interacts with individual circumstances such as spending power and preferences to impact dietary and nutrition outcomes. Novel methods and metrics to improve understanding of complex interactions among dimensions of food environments are needed to generate evidence-informed actions to improve food and nutrition security (Turner et al., 2018).

The link between food prices and child malnutrition has been established in numerous studies (Ecker and Qaim, 2011; Headey and Ruel, 2023; Muhammad et al., 2017), including several analyses of price shocks (Arndt et al., 2016; Cornelsen et al., 2015; Green et al., 2013; Headey and Ruel, 2022; Yu and Shimokawa, 2016). Much of the evidence on the role of the food environment on dietary and nutrition outcomes is derived from high income countries (Beydoun et al., 2011; Black et al., 2014; Gittelsohn and Trude, 2017; Laska et al., 2010; Martin et al., 2012; Ziso et al., 2022), with findings from low and middle income countries rapidly emerging (Carducci et al., 2020; O'Meara et al., 2023; Toure et al., 2021; Turner et al., 2020; Westbury et al., 2021). These studies provide evidence that availability of fresh products is positively associated with dietary intake (Martin et al., 2012; Westbury et al.,

* Corresponding author. Center for Development Research (ZEF), Bonn University, Genscherallee 3, 53113, Bonn, Germany.
E-mail address: jklemm@uni-bonn.de (J. Klemm).

https://doi.org/10.1016/j.gfs.2024.100795
Received 1 June 2023; Received in revised form 25 July 2024; Accepted 13 August 2024
Available online 2 September 2024

2021; Ziso et al., 2022), that food prices are positively associated with dietary quality (Beydoun et al., 2011) and that these need to be considered among key socio-economic determinants of diets (Darmon and Drewnowski, 2015). Results from low and middle income countries document that increased availability of healthy food options is associated with improvements in child nutrition in some contexts (O'Meara et al., 2023; Westbury et al., 2021). These results also emphasize the ubiquity of ultra-processed foods (Colozza, 2022; Monteiro et al., 2013), consumption of which is associated with higher risk of non-communicable diseases (Chen et al., 2020; MacHado et al., 2019).

Despite emerging data, the overall evidence on the role of the food environment on nutrition status is still considered inconclusive (Turner et al., 2020) and several research gaps remain. Of the 74 studies reviewed by Westbury et al. (2021), only four included food prices as a variable, three of which took place in Brazil. Although some studies utilize comprehensive price data and focus on dietary intake and nutrition outcomes in children (Headey and Alderman, 2019) or dietary intake of adults and adolescents (Westbury et al., 2021), outside of this little evidence exists that links analysis of food group prices with the dietary intake of children 6–23 months old.

The Fill the Nutrient Gap (FNG) analysis is a nutrition situation analysis led by the United Nations' World Food Programme (WFP) which provides empirical evidence of the cost and affordability of nutrient-adequate diets in low and middle income countries (Bose et al., 2019). FNG analyses have been carried out in 37 countries between 2016 and 2021, taking on a food systems lens to examine barriers faced in accessing and consuming nutritious foods, focusing on individual countries' context.

However, the underlying market food price data used to calculate the cost of a nutrient-adequate diet in the FNG has never been systematically reviewed or analysed across countries to examine patterns among characteristics of the food environment. This exploratory study aims to gain insight into the relationship between market assortment and prices (independent variables) and dietary intake (outcome) on subnational and food group level. We cover roughly one quarter (20 out of 80) of all low and low-middle income countries and leverage unique granularity in the dataset to address important research gaps. Using subnational data (n = 247) from FNG assessments in 20 countries, we explore how food environment indicators relate to dietary intake of children aged 6–23 months and provide commentary on how data collection methods may influence indicators of food availability and price.

2. Methods

2.1. Data sources and standardization

The FNG analyses presented in this paper utilize one of three datatypes as a source for food prices. The primary and most common datatype is market food price data collection, referred to here as "market survey data". This is where the World Food Programme (WFP) or a partner organization collects prices in surveyed markets, using open food lists (i.e., collecting all foods available at the market). The second datatype used is "price monitoring data", which includes Consumer Price Index (CPI) data or agricultural market monitoring, which is often carried out by respective national agencies. This data is typically collected as part of national inflation or food price monitoring efforts covering a closed food list – a predefined set of foods in representative markets. "Household consumption data" is the third type of data source, deriving food prices from household food consumption modules in income and expenditure surveys. These are usually collected with predefined closed food lists of varying length (FAO & World Bank 2018) and provide the weight and value of the actual food items either bought by households from markets or home produced, allowing for the calculation of prices. In this paper we stratified and adjusted our analysis by datatype to account for potential variations arising from different price collection methodologies.

Food prices gathered in 20 FNG analyses were imported into R, removing 17 analyses from the overall dataset (n = 37) that are not nationally representative, have a time difference of more than three years between food prices and dietary intake (see next section) or were finalized after October 2021. Prices were standardized to January 2020 international US Dollars (i.e., purchasing power parity – PPP – adjusted USD) using World Bank PPP conversion. Averages (mean and median) and variation (standard deviation and variance) were calculated per food group for each subnational assessment. Seasonal averages were calculated using simple means and urban-rural stratification was aggregated using population weights. Foods were grouped according to the following groups: eggs, fish, pulses, grains, meat, dairy, green leafy vegetables, orange flesh vegetables, other vegetables, orange flesh fruits, other fruit, and roots. For the preparation of descriptive statistics, orange flesh fruits and other fruits were combined into a generic "fruits" group.

We included information on World Bank income level and datatype. Secondary data on dietary intake at subnational level were extracted from UNICEF Multiple Indicator Cluster Surveys (UNICEF et al., 2021) and DHS (The Demographic and Health Surveys (DHS) Program, 2022) online databases. A list of data sources used for both price and dietary intake by country is presented in the supplementary materials.

2.2. Selection of data for this paper

The analysis was carried out on 247 subnational regions of the 20 countries available in the dataset. Each subnational assessment constitutes our unit of analysis (referred to from here on as an "assessment"). One estimate for each of the food environment indicators, namely market assortment, price per 100 kcal and relative caloric price, was calculated per assessment (definitions of these indicators are provided in section 2.3). Where multiple (up to four) seasons were available for a single assessment area, an unweighted average was calculated to estimate a single unit of analysis comprising all time points. Where regional disaggregation of food price data beyond administrative level was available, a population-weighted average of the administrative zone was calculated. Where initial analysis was conducted in non-administrative units, market data was re-aggregated to match administrative zones.

2.3. Calculation and analysis of indicators

Data from price monitoring and market surveys consisted of a list of foods found in markets and retail outlets; datasets taken from household consumption surveys included estimated prices for purchased foods and foods produced at home. Information for each food included its average price per 100g and its nutrient composition (Deptford et al., 2017).

We utilized the HLPE 2017 food systems framework adapted by Fanzo et al., (2020) to categorize our data along two food system components: "food environment" and "diets". We considered market assortment, price per 100 kcal and relative caloric prices as "food environment" indicators. The percentage of children aged 6–23 months consuming iron-rich foods, vitamin A-rich foods and with minimum dietary diversity (MDD), as reported in secondary survey data, comprise the "diets" indicators.

2.3.1. Market assortment

To calculate market assortment as an indicator of availability, we counted the number of unique food commodities per food group by assessment. This reflects the number of unique food items within each food group (e.g., variations of green leafy vegetables), but it does not reflect how many units per food item or food group are available. We only included foods and food types that are used as part of the FNG analyses, excluding packaged foods of low nutritional value, condiments, herbs, spices, coffee, tea or alcohol.

2.3.2. Price per 100 kcal

We calculated price per 100 kcal of all commodities, as well as median and minimum price per 100 kcal per food group (retaining the same groups as used in calculating market assortment). To estimate caloric content per commodity, we used food composition table information included in the Cost of the Diet software (Deptford et al., 2017). The median was used instead of the mean to avoid bias from outliers. In this article "food prices" refers to median international USD per 100 kcal of each food group for all price references except where specified to be minimum price per 100 kcal.

2.3.3. Relative caloric price

We calculated relative caloric price (RCP) of selected food groups by dividing their cost (in terms of caloric price) by the cost of commonly consumed starchy staples (grains, roots, tubers). This approach builds upon the method used by Headey and Alderman (2019) in which RCPs for different food categories were calculated at the national level. Similar to Headey and Alderman (2019), we used the average of the three cheapest items within a food group to obtain the cost of the food group.

We deviated from their method in one aspect: they utilized preferred staples using national food balance sheet data to construct a weighted index of median prices. We also calculated a weighted index of staple prices but selected preferred starchy staples at subnational level, using information from the FNG, which uses secondary data and consults national stakeholders to determine the most commonly consumed staples in each assessment.

2.3.4. Dietary intake indicators

The most comprehensive dietary intake indicators available in secondary data (UNICEF Multiple Indicator Cluster Surveys (UNICEF et al., 2021) and DHS (The Demographic and Health Surveys (DHS) Program, 2022)) were diets of children 6–23 months of age, and, therefore, we focused on this age group to reflect consumption in a given food environment. Availability of dietary intake indicators for this age group varied from 150 (out of 247) subnational assessments for intake of foods rich in vitamin A and iron to 214 for MDD. In interpreting these indicators, we did not assume that dietary intake of children 6–23 months old is a proxy indicator for household consumption, but we did assume that there are shared purchasing and consumption patterns within a household.

2.4. Aggregation and analysis of indicators

Assortment, price per 100 kcal and RCP were calculated for each subnational assessment. For summary statistics by World Bank income group and datatype, we calculated and reported the mean and standard deviation using subnational estimates. These estimates were, in some cases, aggregated from more granular estimates of urban/rural or across seasons (Turowska et al., 2024). Except for calculating administration level estimates from urban rural stratified data, population weights were not applied to reflect the food environment in less densely populated areas.

To assess associations between independent food environment indicators and dependent dietary intake indicators, we performed individual linear regressions (full model specification in supplementary materials) for each combination of independent and dependent variables, accounting for country level effects and datatype. Independent variables were indicators that measure the food environment at subnational level, namely, market assortment, price per 100 kcal and RCPs. The assortment indicator was calculated for a combination of food groups and the two price indicators are measured for individual food groups, as explained further in this section. Dependent variables were dietary intake, measured as the percentage of children aged 6–23 months who, in the 24 h preceding the survey, consumed 1) iron-rich foods, 2) vitamin A-rich foods, and 3) foods from five or more food groups (i.e., achieved MDD) for each subnational level. We accounted for datatype and country-level effects using random effects.

We focused on food items available for each of the survey definitions of foods rich in vitamin A and iron, and minimum dietary diversity (Croft et al., 2018; UNICEF, 2017). This means for the percentage of children who consumed vitamin A-rich foods (dependent variable), we tested the association with the RCP, minimum and median price per 100 kcal of meat, fish, eggs, green leafy vegetables, orange flesh vegetables, orange flesh fruit, and the assortment of all these foods combined. For iron-rich foods we tested associations with the RCP, minimum and median price per 100 kcal of meat, fish, and eggs, and the combined

Table 1
Summary statistics for the variables used in this study, n refers to subnational assessment areas.

Variable	n	Mean	SD	Median	IQR
Child diets (children 6-23 mo), % consumed in the last 24hr					
Iron-rich foods	150	46.2	23.1	46.6	36.3
Vitamin A-rich foods	150	63.2	20.1	66.9	28.3
More than 5 food groups (MDD)	214	32.4	21.2	28.1	25.5
Assortment					
Eggs	245	1.6	1.2	1.0	1.0
Fish	247	7.8	6.6	6.0	9.5
Meat	246	11.0	10.2	7.3	6.8
Dairy	241	4.3	2.2	4.0	2.5
Green leafy vegetables	237	4.5	4.3	3.0	5.0
Orange flesh vegetables	223	1.9	0.7	2.0	1.0
Other vegetables	247	17.5	10.9	14.5	12.0
Orange flesh fruits	245	5.5	2.9	5.5	3.3
Other fruits	247	12.4	7.1	12.0	9.0
Pulses	243	7.7	4.9	7.0	7.5
Roots and tubers	246	4.4	2.2	4.0	4.0
Grains	247	10.4	6.6	10.0	8.3
Median Price/ 100 kcal					
Eggs	245	0.6	0.2	0.5	0.2
Fish	247	1.2	0.7	1.1	0.8
Meat	246	0.9	0.3	1.0	0.6
Dairy	241	0.4	0.2	0.4	0.3
Green leafy vegetables	237	1.3	1.5	0.8	1.1
Orange flesh vegetables	223	0.9	0.5	0.8	0.7
Other vegetables	247	0.9	0.4	0.9	0.6
Orange flesh fruits	245	0.7	0.4	0.6	0.4
Other fruits	247	0.7	0.4	0.7	0.4
Pulses	243	0.2	0.1	0.2	0.2
Roots and tubers	246	0.3	0.2	0.2	0.2
Grains	247	0.1	0.0	0.1	0.0
Minimum Price/100 kcal					
Eggs	245	0.5	0.2	0.5	0.2
Fish	247	0.6	0.5	0.4	0.6
Meat	246	0.4	0.3	0.4	0.4
Dairy	241	0.2	0.1	0.2	0.2
Green leafy vegetables	237	0.9	1.3	0.4	0.6
Orange flesh vegetables	223	0.8	0.5	0.6	0.6
Other vegetables	247	0.2	0.2	0.2	0.2
Orange flesh fruits	245	0.3	0.2	0.2	0.1
Other fruits	247	0.2	0.2	0.1	0.1
Pulses	243	0.1	0.1	0.1	0.0
Roots and tubers	246	0.1	0.1	0.1	0.1
Grains	247	0.04	0.0	0.04	0.0
Relative Caloric Price					
Eggs	245	12.2	7.1	10.5	9.5
Fish	247	17.1	12.7	12.4	14.4
Meat	246	13.3	8.8	12.1	11.1
Dairy	241	8.6	7.4	7.4	6.5
Green leafy vegetables	237	21.9	28.2	13.2	14.9
Orange flesh vegetables	223	21.6	13.9	19.5	16.4
Other vegetables	247	9.1	7.3	7.7	4.7
Orange flesh fruits	245	10.3	6.4	8.9	5.3
Other fruits	247	6.3	4.8	5.0	3.7
Pulses	243	2.9	2.7	2.4	1.1

assortment of these foods, and for MDD we test associations with the RCP, minimum and median price per 100 kcal of meat, fish, eggs, dairy, green leafy vegetables, orange flesh vegetables, other vegetables, orange flesh fruit, other fruit, and the combined assortment of these foods. This resulted in a total of 57 unique tests. We adjusted for multiple testing using Benjamini-Hochberg False Discovery Rate (q-values in the supplementary materials) (Benjamini and Hochberg, 1995).

To assess how best to account for potential country level effects within our models, we undertook Hausman tests comparing random and fixed effect models. Based on results and considering the characteristics of our data more broadly, we treated our data as panel data with random effects at the country level using Stata's xtset and xtreg commands. The results from these random effect models incorporated both *within* and *between* country effects. Datatype was treated as factor variable and included as a covariate in each model. To account for potential heteroskedasticity, we calculated robust standard errors using Stata's vce (robust) option. All data curation and visualization were carried out using R version 4.1.1 and Rstudio Software 1.4.1717. Statistical tests were carried out using STATA version 17.

3. Results

Table 1 provides an overview of all indicators available in the dataset used for this analysis, grouped by category. High variation, measured by the standard deviation, was found across dietary intake and food environment indicators. A detailed breakdown of per-country data sources is reported in Appendix Table A1 as well as supplementary materials.

3.1. Food environment indicators

3.1.1. Market assortment

Fig. 1 shows the average number of food items in each food group disaggregated by country, income group and datatype. There are visible differences across the different datatypes, with market survey data having a higher number of items per food group for both income groups compared to price monitoring and household consumption data. With the exception of dairy and fruit, household consumption data show relatively consistent number across both income groups, with low-income countries being only slightly below lower-middle income countries. This may be because of standardized survey methodology or because households typically consume a relatively fixed number of different foods.

Table 1 also shows lower assortment of foods in low-income countries for both household consumption and market survey data. Notable exceptions are pulses and grains in the price monitoring category, which may reflect a greater perceived importance of these commodities in these contexts. For low-income countries, the standard deviation (represented by whiskers in Fig. 1) of nutritious foods is smaller across datatypes, indicating that there is also comparatively less of a range within countries for assortment.

3.1.2. Price per 100 kcal

Fig. 2a shows median food prices for each food group by income group and datatype. Lower-middle income countries have higher prices for most nutrient-dense foods (eggs, fish, meat, dairy, green leafy vegetables) than low-income countries in household consumption and market survey data. This is not the case for price monitoring data, where low-income countries have higher prices than lower-middle income countries for animal source foods, but not for staples and dried foods such as grains, pulses and roots (see Limitations section for a discussion on differences in data collection methods). This pattern is also visible in Fig. 2b, which shows minimum price for food groups, although it is reversed for some food groups (e.g., eggs in low-income countries with market survey data).

3.1.3. Relative caloric price

The RCP for each food group by income group is shown in Fig. 3. We found RCPs to be higher for most nutrient-dense food groups in low-income countries compared to the lower-middle income countries in price monitoring and market survey data. Results are mixed for household consumption data, where estimates are closer and not systematically higher in one context than another. Nearly all animal source foods (eggs, fish, meat and dairy) have higher RCPs in low-income countries compared to lower-middle income countries across datatypes (Fig. 3).

Eggs, fish, meat, dairy, green leafy vegetables and orange flesh vegetables are consistently among the food groups with the highest RCPs (Fig. 3). These food groups also had a lower market assortment compared to other food groups (Fig. 1). This indicates that high RCP and low assortment of fresh, nutritious foods are a feature of food environment in low- and lower-middle income countries.

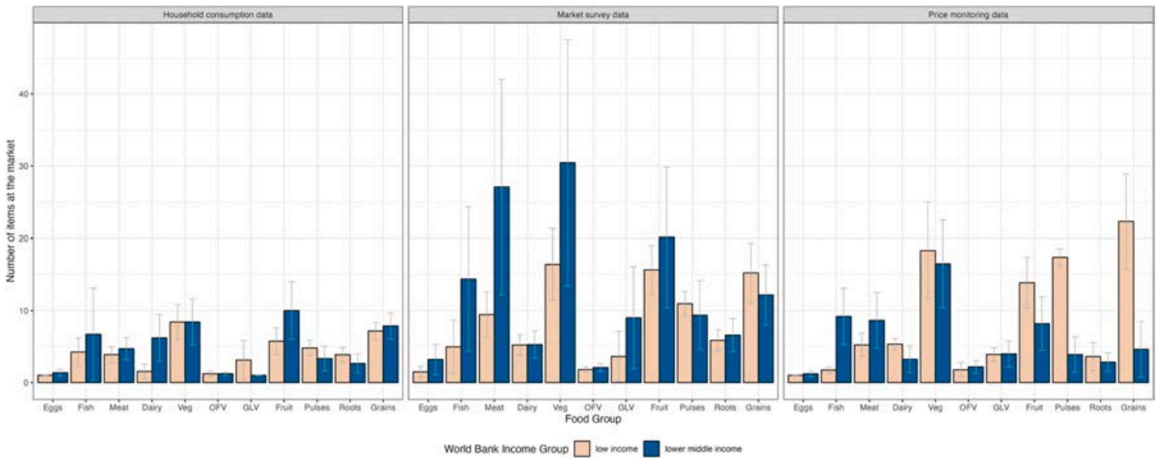


Fig. 1. Market assortment (number of items per food group) by datatype and income group.
Note: Data shown are means and standard deviations across subnational areas, for median number of items in each food group shown. Number of subnational areas (total n = 247) per subgroup varies as follows: price monitoring in low income countries n = 18 and lower-middle income n = 76; household consumption in low income countries n = 26 and lower-middle income countries n = 22; market survey in low income countries n = 61 and low-middle income countries n = 44.

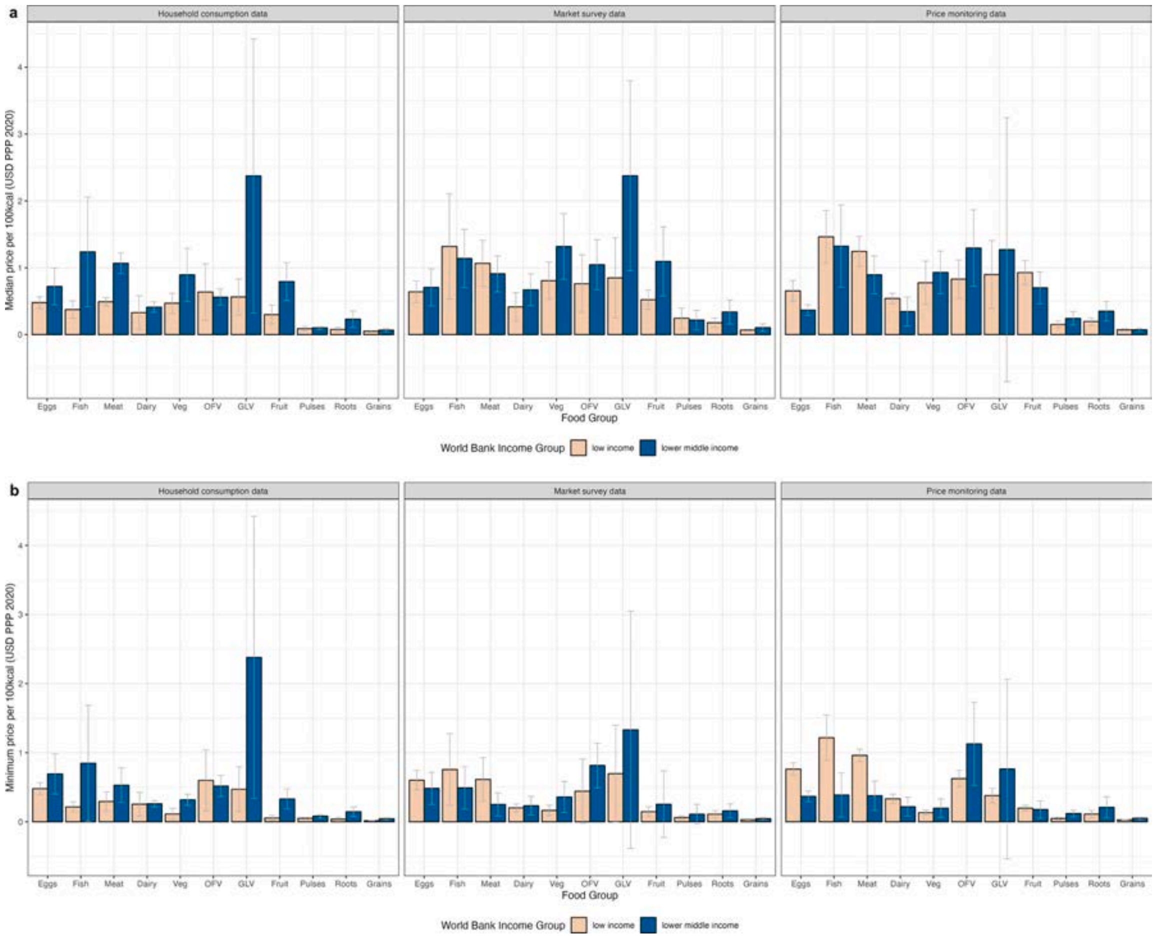


Fig. 2. a–b: Price per 100 kcal for selected food groups in international USD by datatype and income group.
Note: Data shown are means and standard deviations across subnational areas, for median (2a) and minimum (2b) price per 100 kcal for each food group shown. Number of subnational areas (total n = 247) per subgroup varies as follows: price monitoring in low income countries n = 18 and lower-middle income n = 76; household consumption in low income countries n = 26 and lower-middle income countries n = 22; market survey in low income countries n = 61 and low-middle income countries n = 44.

Table 2 reports the mean and standard deviation of RCP for key nutritious food groups (RCP for all food groups in Supplementary Table 3) by country and income group. It shows that the variation within a country can be as high as the variation within an income group. In other words, even where countries have, on average, favourable food environments (available and affordable nutrient-dense foods), there may be intra-country inequities with some subnational areas displaying very high RCPs of nutritious foods. Table 2 also shows that animal-source foods have a higher RCP in low-income countries compared to lower-middle income countries. The RCP of green leafy and orange flesh vegetables is lower or almost equal in low-income countries compared to lower-middle income countries.

3.2. Relationship between the food environment and child dietary intake indicators

Table 3 reports regression results for the associations between market assortment and corresponding dietary intake, adjusted for country level random effects and datatype. It shows that higher market assortment, i.e., a higher number of different foods per food group, was significantly associated with the percentage of children who consumed these food groups. Results indicate that increase of one additional food item was associated with a 0.855 and 0.390 percentage point (pp) increase in the intake of iron-rich foods and vitamin A-rich foods (significant at $p < 0.05$), respectively.

Table 4 reports the regression results for associations between minimum price (i.e., the cheapest food item per food group) or median price and dietary intake indicators. Minimum price of eggs and meat were negatively associated with iron and Vitamin A intake, and minimum price of eggs, meat and GLV show negative association with MDD. Results indicate that a one cent increase in the minimum price for eggs and meat was associated with a 0.487 and 0.199 pp decrease in children consuming iron-rich foods, a 0.410 and 0.262 pp decrease in children consuming vitamin A-rich foods (significant at $p < 0.05$). A one cent increase in the minimum price for eggs, meat and GLV was also associated with a 0.360, 0.156 and 0.017 pp decrease in the percentage of children consuming MDD. Higher median meat price was negatively associated with intake of vitamin A-rich foods (significant at $p < 0.05$).

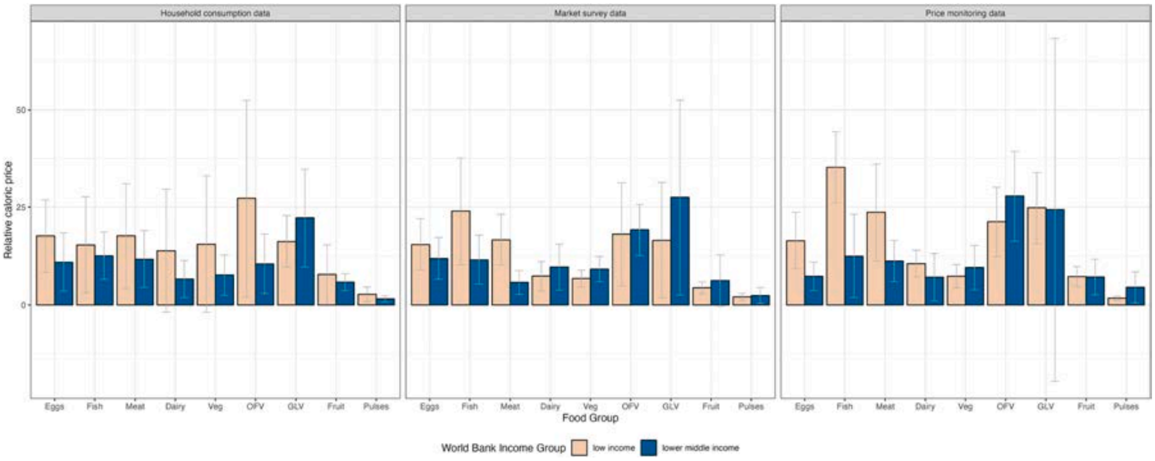


Fig. 3. Relative caloric price (RCP) by datatype and income group.
Note: Data shown are means and standard deviations across subnational areas, for relative caloric price for each food group shown. Number of subnational areas (total n = 247) per subgroup varies as follows: price monitoring in low income countries n = 18 and lower-middle income n = 76; household consumption in low income countries n = 26 and lower-middle income countries n = 22; market survey in low income countries n = 61 and low-middle income countries n = 44.

Table 2
Mean and standard deviation for RCP of selected nutritious food groups by country and country-type.

	Country	*n*	Eggs		Fish		Meat		Orange flesh vegetables		Green leafy vegetables	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
	Low-income	*105*	16.2	7.4	23.8	14.1	18.1	9.9	20.8	16.6	17.9	12.6
	Lower-middle income	*142*	9.3	5.3	12.2	8.8	9.7	5.7	22.3	11.2	25.1	35.9
Low-Income	Afghanistan	*34*	11.4	3.1	30.8	11.2	21.4	3.8	14.1	5.8	21.1	10.1
	Burkina Faso	*12*	24.4	5.8	12.2	4.0	11.5	3.2	30.1	24.9	5.3	1.6
	Burundi	*7*	16.9	3.4	26.2	18.3	7.9	2.4	12.3	3.9	6.2	1.7
	Ethiopia	*11*	19.7	7.5	35.2	10.4	31.4	9.4	16.4	7.8	26.0	10.3
	Mali	*8*	18.1	5.7	10.6	5.7	12.2	3.9	24.7	10.6	23.5	29.9
	Mozambique	*11*	23.9	10.2	19.5	15.6	28.7	14.1	52.5	17.4	17.8	6.9
	Nepal	*7*	11.5	2.1	35.2	7.8	11.5	0.9	28.8	3.6	22.9	7.2
	Uganda	*15*	12.9	4.9	12.4	8.4	9.5	3.1	9.2	8.7	15.2	6.3
Lower-middle Income	Bangladesh	*8*	16.7	2.0	12.5	2.4	19.1	4.7	17.7	4.4	10.4	3.4
	Cambodia	*19*	13.9	4.9	9.2	2.6	4.6	1.4	21.8	5.9	13.6	5.4
	El Salvador	*8*	5.8	0.6	19.7	6.2	3.7	0.7	10.3	3.2	28.6	6.2
	Ghana	*5*	13.1	10.7	4.9	5.5	9.6	6.6	NA		NA	
	Kyrgyz Republic	*9*	4.6	0.4	17.0	4.2	6.2	2.5	4.1	0.7	32.7	6.3
	Laos	*5*	12.9	7.5	11.0	3.3	3.7	1.0	19.9	5.3	7.6	2.3
	Lesotho	*10*	6.1	0.7	27.4	15.4	6.4	1.2	14.4	5.4	156.7	22.0
	Mauritania	*12*	12.5	3.7	10.0	7.2	10.2	2.2	20.5	4.6	63.0	27.0
	Myanmar	*15*	6.4	1.2	9.1	2.3	13.8	2.4	NA		6.9	2.4
	Philippines	*17*	6.6	2.1	3.1	1.1	3.9	1.1	28.2	8.2	11.6	4.1
	Sri Lanka	*25*	5.8	0.5	10.2	1.9	15.8	1.8	29.9	3.8	9.6	2.2
	Zambia	*9*	15.9	4.1	25.7	8.3	13.7	4.1	36.5	21.2	15.7	7.5

Higher median price of other fruits (i.e., fruits not included in the yellow or orange flesh fruit group, e.g., grapes, guava, or apple) showed positive association with the consumption of a minimum diverse diet.

Table 5 reports the association between relative caloric price and dietary intake of children aged 6–23 months. It shows that the relative caloric price of eggs, fish and meat were significantly associated (at $p < 0.05$) with the percentage of children who consume these foods. They indicate that a one unit increase in RCP of eggs, fish and meat, which expresses how much more expensive these iron-rich foods are compared to staple foods, was associated with a decrease in the percentage of children who consumed iron-rich foods in the last 24 h by 0.901, 0.279 and 0.756 pp respectively. We found higher RCP of meat and green leafy vegetables (significant at $p < 0.05$) to be associated with a lower prevalence of children who consumed vitamin A-rich foods in the 24 h preceding the survey. Similarly, an inverse association was found for RCP of eggs, meat, or green leafy vegetables with the percentage of children who consumed more than five food groups in the last 24 h (significant at $p < 0.05$).

4. Discussion

Based on our dataset of 247 subnational assessments from 20 countries, we found that minimum price and relative caloric price of nutrient-dense foods such as egg, fish, meat, or green leafy vegetables were negatively associated with dietary intake of children 6–23 months old. We also found that market assortment was positively associated with dietary intake indicators. Lastly, we showed that variation of assortment and prices of food groups within a country can be as high as variation

Table 3
Results from individual regression models showing associations between market assortment and dietary intake of children 6–23 months old in the last 24hrs.

Dependent variable	Independent variables	β	SE	R^2o	n
% consumed iron-rich foods	Assortment iron	0.855***	0.124	0.583	150
% consumed vit A-rich foods	Assortment vit. A	0.390**	0.191	0.36	150
% with minimum dietary diversity	Assortment MDD	0.180*	0.096	0.073	214

Note for Table 3: All regressions are adjusted for country level random effects and datatype. Standard errors are robust standard errors. ***p < 0.01, **p < 0.05, *p < 0.1. R^2o: R-squared overall. 'Assortment iron' refers to the total number of meat, fish, and eggs at the subnational level; 'Assortment vitamin A' refers to total number of meat, fish, eggs, green leafy vegetables, orange flesh vegetables and orange flesh fruits found at the subnational level and 'Assortment MDD' refers to total number of meat, fish, eggs, dairy, all vegetables (green leafy vegetables, orange flesh vegetables, other vegetables) and all fruits (orange flesh fruits and other fruits) found at the subnational level.

across countries in different income groups.

Cross-country comparisons of the relative costs of nutrient-adequate diets and relative caloric prices have previously been undertaken; however, to our knowledge, analysis has been restricted to the national level. Of particular relevance to our analysis are a study by Bai et al. (2021), which compared food prices and costs of a nutrient-adequate diet across 177 countries, and a study by Headey and Alderman (2019), which compared relative caloric prices of various non-staple food groups across countries. We differ in three important aspects: 1) datatype, 2) level of analysis, and 3) definition of price units.

For datatype, both relevant studies use food price data from the World Bank's International Comparison Program (ICP). The ICP, as part of the main objective of producing purchasing power parities and price level indexes, collects prices for the most widely consumed food items globally and regionally and constructs national averages for a (country-specific) list of individual foods used for comparison across countries. In contrast, our data came from a mixture of price monitoring, household consumption surveys, and one-off market data collections. With the exception of grains and pulses in low-income countries, market monitoring data has a lower number of observations for assortment across most food groups, compared to exhaustive market surveys (cf. Fig. 1). This suggests an emphasis of market monitoring on prices of staple foods in those areas and the potential to expand regular market monitoring initiatives by including more fresh, nutritious foods.

Secondly, our study used subnational data rather than national data, and only from low and lower-middle income countries rather than countries across all income classifications.

Thirdly, for price comparisons of different food groups, Bai et al. (2021) compared the cost of the most affordable foods by food group included in nutrient-adequate diets in each country, at international USD (PPP), for 177 countries. In our price analysis, we included the minimum and median price for all foods for which prices are available in our dataset. In contrast to Bai et al. (2021) we did not find higher prices in low-income countries across the dataset. While animal source foods showed higher RCP in low-income countries, not all nutrient-dense foods were more expensive in low-income countries (see supplementary materials for prices by food group and country). When disaggregating by datatype, we found that in the price monitoring dataset for all animal source foods and fruits, low-income countries face higher prices than lower-middle income countries, consistent with Bai et al. (2021). This trend was not visible in household consumption and market survey data and may be due to a selection bias arising from different methods in data collection.

Beyond methodological differences, our findings on the role of higher RCP are in line with well documented evidence that nutrient-dense foods are typically more expensive than energy dense foods (Bai et al., 2021; Drewnowski, 2010; Headey and Alderman, 2019). Our results also align further with findings from Headey and Aldermann (2019), who report RCPs to be significant predictors of consumption

Table 4
Results from individual regression models showing associations between food minimum and median price per 100 kcal and dietary intake of children 6–23 months old in the last 24hrs.

Dependent variable	Independent variables	β	SE	R^2o	n
% consumed iron-rich foods	Minimum Price eggs	−0.487***	0.042	0.307	150
	Minimum Price fish	−0.014	0.042	0.043	150
	Minimum Price meat	−0.199***	0.064	0.163	150
	Median Price eggs	−0.147	0.159	0.02	150
	Median Price fish	−0.009	0.025	0.03	150
	Median Price meat	−0.153	0.1	0.069	150
% consumed vit A-rich foods	Minimum Price eggs	−0.410***	0.177	0.134	150
	Minimum Price fish	−0.072	0.053	0.19	150
	Minimum Price meat	−0.262***	0.078	0.388	150
	Minimum Price GLV	−0.012*	0.007	0.026	147
	Minimum Price OFV	−0.007	0.035	0.014	134
	Minimum Price OFF	−0.243*	0.13	0.049	150
	Median Price eggs	−0.138	0.173	0.003	150
	Median Price fish	−0.011	0.015	0.015	150
	Median Price meat	−0.220**	0.099	0.284	150
	Median Price GLV	−0.016	0.011	0.008	147
	Median Price OFV	−0.051	0.035	0.008	134
	Median Price OFF	−0.023	0.036	0.006	150
% with minimum dietary diversity	Minimum Price eggs	−0.360***	0.075	0.166	214
	Minimum Price fish	0.005	0.049	0.014	214
	Minimum Price meat	−0.156**	0.063	0.062	214
	Minimum Price dairy	0.173	0.219	0.027	213
	Minimum Price GLV	−0.017**	0.007	0	211
	Minimum Price OFV	−0.006	0.024	0.035	196
	Minimum Price OFF	−0.078	0.08	0.003	214
	Minimum Price other veg	0.018	0.111	0.005	214
	Minimum Price other fruit	0.017	0.024	0.023	214
	Median Price eggs	−0.133	0.128	0.042	214
	Median Price fish	0.006	0.018	0.003	214
	Median Price meat	−0.053	0.071	0.003	214
	Median Price dairy	0.112	0.072	0.021	213
	Median Price GLV	−0.020*	0.012	0.001	211
	Median Price OFV	−0.014	0.029	0.06	196
	Median Price OFF	0.005	0.016	0.007	214
	Median Price other veg	0.085*	0.045	0.106	214
	Median Price other fruit	0.065***	0.025	0.000	214

All regressions are adjusted for country level random effects and datatype. Standard errors are robust standard errors. ***p < 0.01, **p < 0.05, *p < 0.1. R^2o: R-squared overall. GLV: green leafy vegetables. OFV: orange flesh vegetables. OFF: orange flesh fruits.

Table 5
Results from individual regression models showing association between relative caloric price and dietary intake of children 6–23 months old in the last 24hrs.

Dependent variable	Independent variables	β	SE	R^2o	N
% consumed iron-rich foods	RCP eggs	−0.901***	0.323	0.053	150
	RCP fish	−0.279***	0.103	0.189	150
	RCP meat	−0.756***	0.266	0.21	150
% consumed vit-A rich foods	RCP eggs	−0.475	0.318	0.007	150
	RCP fish	−0.112	0.102	0.062	150
	RCP meat	−0.667***	0.329	0.299	150
	RCP GLV	−0.110***	0.033	0.035	147
	RCP OFV	−0.018	0.134	0.016	134
	RCP OFF	−0.486*	0.273	0.023	150
% with minimum dietary diversity	RCP eggs	−0.598**	0.256	0.073	214
	RCP fish	−0.081	0.079	0.008	214
	RCP meat	−0.544**	0.227	0.05	214
	RCP dairy	−0.128	0.244	0.013	213
	RCP GLV	−0.112**	0.057	0.022	211
	RCP OFV	−0.023	0.111	0.028	196
	RCP OFF	−0.175	0.145	0.001	214
	RCP other veg	0.130	0.366	0.009	214
	RCP other fruit	−0.076	0.156	0.000	214

Note for Table 5: All regressions are adjusted for country level random effects and datatype. Robust standard errors in parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. R^2o: R-squared overall. RCP: Relative Caloric Price. GLV: green leafy vegetables. OFV: orange flesh vegetables. OFF: orange flesh fruits.

patterns of young children. Our analysis found that children aged 6–23 months have poorer dietary intake in areas with higher relative caloric price, higher minimum price and lower market assortment. In these food environments, even if some consumers may have higher spending power, their ability to exercise increased choice for nutritious foods will be hampered by the relative price and assortment of these foods.

This fits well with studies documenting that increases in food prices lead to greater reduction in food consumption, particularly of fresh, nutrient-dense foods, in low-income countries as compared to high-income countries (Green et al., 2013). This implies that high prices pose a substantial barrier in these contexts. Previous work on food price elasticities (Cornelsen et al., 2015) is consistent with our observation that minimum and relative prices – costs of one food group compared to another food group – are associated with dietary intake in children 6–23 months old in low and lower-middle income countries.

Existing literature on food environments in high-income countries and for other population groups finds that greater variety of fresh products is associated with a higher likelihood of these products being purchased (Martin et al., 2012), and that higher availability of fresh foods is associated with better dietary intake (Sawyer et al., 2021; Westbury et al., 2021; Ziso et al., 2022). Our analysis expands this body of work by providing evidence on the negative association between higher relative prices and dietary intake of children 6–23 months of age for low and lower-middle income countries.

Although well-documented in observational research, reducing economic barriers for improved dietary intake has not been widely included in intervention or policy design. A systematic review found no impact of food environmental interventions on child nutrition outcomes (anthropometrics, weight-status, and food group intake), but most of the 17 studies included focused on behavioural interventions or school nutrition policies, and none included a financial stimulus or targeted prices (Carducci et al., 2020). Likewise, another policy review has shown that while many low-income countries have some form of policy aimed at increasing fruit and vegetable consumption, only two of 49 countries (Botswana and Philippines) were identified as having allocated funds for subsidies for fruits and vegetables (Darfour-Oduro et al., 2019).

The results of this research, alongside other evidence, have important implications for policy, programme, and further research. Increasing consumer spending power is a key pathway to improving dietary intake and nutrition in low- and middle-income countries (Durao et al., 2020; Vaivada et al., 2020). Consumers with the same level of food expenditure can be faced with different incentives and opportunities in price and assortment of foods, depending on the food environment they are living in, which can ultimately result in varying purchase and consumption of fresh, nutritious foods. Accounting for subnational differences in cost and understanding the implications of higher prices of animal source foods and vegetables compared to those of staples is essential for the design of nutrition-sensitive social assistance programmes.

Our results provide evidence that where the relative additional cost of nutritious foods is higher, the consumption of the same foods is lower. This could indicate that these are both inversely correlated features of settings with lower income, but it could also indicate that consumers are influencing assortment and prices through their demand, i.e., what they are or are not buying. RCP reflects both staple and non-staple food prices, and, while a lower RCP may be driven by relatively cheaper non-staple foods, it may also (in theory) be driven by higher prices of staple foods. Where staple prices rise, households, especially poor ones, will have to dedicate more of their household resources towards them, just to maintain intake of the staple food (Cornelsen et al., 2015; Green et al., 2013; Seale Jr et al., 2003; Yu and Shimokawa, 2016). In these cases, a decline in the RCP would not necessarily provide any incentive towards consumption of non-staple foods. In some situations, staples can also act as so-called "Giffen goods", for which demand increases with price, possibly driven by "maximizing utility subject to subsistence concerns" (Jensen and Miller, 2008). Exploring the production and demand factors that lead to low market assortment and high relative caloric prices of foods is beyond the scope of this analysis, but requires further attention.

The higher relative cost of nutritious foods is likely driven by a combination of factors, including low consumer spending power and related lower demand for non-staple foods (Cornelsen et al., 2015; Green et al., 2013), greater food loss (Bartezzaghi et al., 2022; Ray, 2022; Ül Kirci et al., 2022), similar times of availability across fresh foods (Bonuedi et al., 2022), and greater risks for producers (Ül Kirci et al., 2022). Identifying context-specific drivers is an important study area for future research to explore.

5. Limitations

A main limitation in our analysis relates to different methodologies of food price data collection and country income levels. Different data collection methodologies were chosen in different contexts, which can introduce bias. For example, market survey data were predominantly collected in low-income countries, whereas price monitoring data were more readily available for lower-middle income countries. We find that food prices are typically higher in lower-middle income countries for which market survey data were collected, whereas the opposite is true for market data collected for price monitoring (e.g., here lower-middle income countries have lower average food prices than low-income countries). This may be due to the latter being collected with curated closed food lists, introducing a selection bias into the foods that are tracked.

To explore the relationship between food environment and child dietary intake indicators, we fit individual regression models for each combination of independent and dependent variables for which data was available, adjusting for country level effects and datatype. We did not include any other potentially confounding factors. Fitting a relatively large number of regression models increases the likelihood of spurious findings. With 57 individual tests for association in our analysis, even with the reported adjustments for multiple testing, some of the reported associations may be due to chance.

A "random effects" modelling approach was used to incorporate both *within* and *between* country effects, based on Hausman tests for model specification. Nonetheless, it is possible that not all assumptions underlying linear regression with a random effects model have been met in every model (Clark and Linzer, 2015).

Estimates were derived from country groupings with very different numbers of observations, and data that is largely not normally distributed. Although the median was calculated to reduce the impact of outliers, a varying number of observations may impact the estimates generated for each group.

It is important to highlight that timing of price data collection did not align with the time of dietary intake collection, which may represent different time periods, with the difference being as high as 3 years, and the median difference being 0.5 years (see supplementary material for overview of dates by country). This temporal gap between food environment and dietary intake is a key limitation of this study. Given the explorative nature of this paper we consider our results useful to contribute to evidence discussed in the previous section. Further research, aligning data collection of food environment and dietary intake indicators, is crucial to arrive at conclusive evidence.

Our data only reflected the dietary intake of children aged 6–23 months. While we assume that there are shared patterns of dietary intake within the households, this does not necessarily mean the relationship can be generalized to other household members. Factors such as individual prohibitions, nutrition awareness, intra-household sharing behaviours and breastfeeding may make small children different from other household members. In addition, dietary intake data was not available for all subnational assessments, leading to the exclusion of ca. 100 (vitamin A and iron intake) and 30 (MDD) assessments, respectively. Our data only included information on whether a certain item was found at a market, not the quantities available or the number of vendors who sold this item. It also does not reflect preferences of the population or origin of product. Finally, our estimates were based on FNG assessments carried out on a subnational level in 20 countries. The patterns we see may therefore be applicable only to those specific contexts and could vary in other countries and contexts.

6. Conclusion

We analysed a novel dataset containing information of 247 subnational observations from 20 countries. While these results were limited to this dataset, they provide evidence that within-country variation of food environment indicators can be as large as the variation within World Bank country income groups. Data that monitor food systems, access to healthy diets, and related targets are primarily available and discussed at national level only. This allows for comparison across countries, but it masks disparities within a country. While overall national progress towards these goals is desirable, improvement of national level food environment indicators may not change the food environment of the most vulnerable and hardest to reach. Monitoring food environments on a subnational level is an essential building block in tackling health and nutrition inequalities (Béné et al., 2022; Marshall et al., 2021).

We provide further evidence that living in food environments that have elevated barriers towards making healthy food choices is associated with poorer dietary intake of children aged 6–23 months. Specifically, we report associations between market assortment, minimum price, relative caloric price and minimum dietary diversity as well as the intake of iron and vitamin-A rich foods in children 6–23 months old. This suggests that focusing policies and programmes on lowest-cost nutritious foods (minimum price) and considering the opportunity cost of nutrition (relative caloric price) – the premium a consumer has to pay for nutritious foods as compared to staple foods – are important factors in the quality of the diet of children 6–23 months old.

As food systems continue to be transformed, local food environments play a crucial role in making nutritious diets available to everyone. Targeted interventions and policies to increase assortment and decrease prices of nutrient-dense foods could help improve their consumption, especially for vulnerable groups in low and lower-middle income countries.

Funding & role of funding organization

FNG analyses are funded by different organizations, which are acknowledged and declared in country specific reports. The UN World Food Programme country offices, the German Federal Ministry for Economic Cooperation and Development (BMZ) and the United States Agency for International Development (USAID). have funded multiple FNG analyses of which data were used for the analysis reported in this paper. None of the funders have had a role in the design, data collation and analysis reported in this paper, or in the decision to publish. The preparation of this manuscript and its open-access publication has been made possible by BMZ (grant numbers: 700022554 and 70002255).

CRediT authorship contribution statement

Janosch Klemm: Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Data curation, Conceptualization. **Christopher Coffey:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis. **Mysbah Balagamwala:** Writing – review & editing, Validation, Data curation. **Zuzanna Turowska:** Writing – review & editing, Methodology, Data curation, Conceptualization. **Sabrina Kuri:** Writing – review & editing, Validation, Data curation. **Saskia de Pee:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

The authors would like to acknowledge government partners, colleagues in WFP Country Offices and all national stakeholders for their leadership, contributions and extensive support for each FNG analysis. We would like to thank the donors that enabled WFP Country Offices to carry out the FNG analysis. We are grateful to colleagues from the Systems Analysis for Nutrition team at WFP Headquarters for their efforts in providing the data which makes up the FNGSTAT, inputs during the standardization process and ideas for this paper. Special thanks to Jane Badham and Alex Brito for their support in the publication process. We thank the anonymous reviewers for their comments and suggestions.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gfs.2024.100795.

Appendix

Table A1
Data sources by indicators used for the analysis, per country. N = number of subnational assessments, MDD, VITA, IRON indicate whether the respective intake indicator was available in reference document.

Country	N	Prices Year	Prices Type	Intake Year	Intake Reference	MDD	VITA	IRON
Afghanistan	34	2019	Primary – WFP and Partners	2018	Afghanistan Health Survey 2018	x	x	x
Bangladesh	8	2016	Household Survey - Household Income and Expenditure Survey (HIES) 2016	2019	Bangladesh Multiple Indicator Cluster Survey 2019, Survey Findings Report. Dhaka, Bangladesh: Bangladesh Bureau of Statistics (BBS)	x	x	x
Burkina Faso	12	2019	Primary – WFP and Partners	2019	Enquete Nutritionnelle Nationale, Burkina Faso 2019	x	N/A	N/A
Burundi	7	2018	Primary – WFP and Partners	2018	Enquete Nationale sur la Situation Nutritionnelle et la Securite Alimentaire au Burundi (ENSNSAB), Decembre 2018	x	x	x
Cambodia	19	2017	Primary – WFP and Partners	2014	Cambodia Demographic and Health Survey 2014. Phnom Penh, Cambodia, and Rockville, Maryland, USA: National Institute of Statistics, Directorate General for Health, and ICF International.	x	x	x
El Salvador	8	2014	Primary – WFP and Partners	2014	Encuesta nacional de salud 2014 - Encuesta de indicadores multiples por conglomerados 2014, Resultados principales. San Salvador, El Salvador: Ministerio de Salud e Instituto Nacional de Salud.	x	N/A	N/A
Ethiopia	11	2019	CPI/Market Monitoring – Central Statistical Agency of Ethiopia	2019	Ethiopia Mini Demographic and Health Survey 2019: Key Indicators. Rockville, Maryland, USA: EPHI and ICF.	x	x	x
Ghana	5	2015	CPI/Market Monitoring –Ministry of Food and Agriculture	2017	Multiple Indicator Cluster Survey (MICS2017/18), Survey Findings Report. Accra, Ghana: GSS	N/A	N/A	N/A
Kyrgyz Republic	9	2017	Household Survey - Kyrgyzstan Integrated Household Survey 2017	2018	Kyrgyzstan Multiple Indicator Cluster Survey 2018, Survey Findings Report. Bishkek, Kyrgyzstan: National Statistical Committee of the Kyrgyz Republic and UNICEF.	x	x	x
Laos	5	2017	Primary – WFP and Partners	2017	Lao Social Indicator Survey II 2017, Survey Findings Report. Vientiane, Lao PDR: Lao Statistics Bureau and UNICEF	x	N/A	N/A
Lesotho	10	2019	CPI/Market Monitoring – Ministry of Development Planning Lesotho, Bureau of Statistics	2017	Lesotho Multiple Indicator Cluster Survey 2018, Survey Findings Report. Maseru, Lesotho: Bureau of Statistics.	x	x	x
Mali	8	2019	Primary – WFP and Partners	2019	Enquête Nationale Nutritionnelle Anthropométrique et de Mortalité rétrospective suivant la méthodologie SMART, Mali 2019	x	x	x
Mauritania	12	2019	Primary – WFP and Partners	2018	Rapport de l`enquête nutritionnelle nationale SMART Aout 2018	x	N/A	N/A
Mozambique	11	2015	Household Survey - Inquérito do Orçamento Familiar (IOF) Household Budget Survey	2015	Relatório final do Inquérito ao Orçamento Familiar - IOF, 2014/15	x	N/A	N/A
Myanmar	15	2017	CPI/Market Monitoring – Central Statistics Organisation	2018	Myanmar Micronutrient and Food Consumption Survey (MMFCS) 2017–2018	x	x	x
Nepal	7	2019	CPI/Market Monitoring – Central Bureau of Statistics	2019	Nepal Multiple Indicator Cluster Survey 2019, Survey Findings Report. Kathmandu, Nepal: Central Bureau of Statistics and UNICEF Nepal.	x	x	x
Philippines	17	2015	CPI/Market Monitoring – Philippine Statistics Authority	2015	Philippine Nutrition Facts and Figures 2015: Anthropometric Survey. Food and Nutrition Research Institute.	x	N/A	N/A
Sri Lanka	25	2016	CPI/Market Monitoring – HARTI (Hector Kobbekaduwa Agrarian Research and Training Institute)	2016	Sri Lanka Demographic and Health Survey 2016	x	N/A	N/A
Uganda	15	2015	Household Survey - Uganda National Panel Survey Wave 5	2016	Uganda Demographic and Health Survey 2016. Kampala, Uganda and Rockville, Maryland, USA: UBOS and ICF. 2018	x	x	x
Zambia	9	2017	CPI/Market Monitoring – Zambia Statistics Agency	2018	Zambia Demographic and Health Survey 2018. Lusaka, Zambia, and Rockville, Maryland, USA: Zambia Statistics Agency, Ministry of Health, and ICF	x	x	x

References

Arndt, C., Hussain, M.A., Salvucci, V., Østerdal, L.P., 2016. Effects of food price shocks on child malnutrition: the Mozambican experience 2008/2009. Econ. Hum. Biol. 22, 1–13. https://doi.org/10.1016/j.ehb.2016.03.003.

Bai, Y., Alemu, R., Block, S.A., Headey, D., Masters, W.A., 2021. Cost and affordability of nutritious diets at retail prices: evidence from 177 countries. Food Pol. 99 https://doi.org/10.1016/j.foodpol.2020.101983.

Bartezzaghi, G., Cattani, A., Garrone, P., Melacini, M., Perego, A., 2022. Food waste causes in fruit and vegetables supply chains. In: Transportation Research Procedia. Elsevier B.V., pp. 118–130. https://doi.org/10.1016/j.trpro.2022.12.042

Béné, C., Fanzo, J., Achicanoy, H.A., Lundy, M., 2022. Can economic development be a driver of food system sustainability? Empirical evidence from a global sustainability index and a multi-country analysis. PLOS Sustainability and Transformation 1 (5), e0000013. https://doi.org/10.1371/journal.pstr.0000013.

Benjamini, Y., Hochberg, Y., 1995. Controlling the False Discovery Rate: a practical and powerful approach to multiple testing. J. Roy. Stat. Soc. 57 (1), 289–300. https://www.jstor.org/stable/2346101.

Beydoun, M.A., Powell, L.M., Chen, X., Wang, Y., 2011. Food prices are associated with dietary quality, fast food consumption, and body mass index among U.S. children and adolescents. J. Nutr. 141, 304–311. https://doi.org/10.3945/jn.110.132613.

Black, C., Moon, G., Baird, J., 2014. Dietary inequalities: what is the evidence for the effect of the neighbourhood food environment? Health Place. https://doi.org/10.1016/j.healthplace.2013.09.015.

Bonuedi, I., Kornher, L., Gerber, N., 2022. Agricultural seasonality, market access, and food security in Sierra Leone. Food Secur. 14, 471–494. https://doi.org/10.1007/s12571-021-01242-z.

Bose, I., Baldi, G., Kiess, L., de Pee, S., 2019. The "Fill the Nutrient Gap" analysis: an approach to strengthen nutrition situation analysis and decision making towards multisectoral policies and systems change. Matern. Child Nutr. 15 (3), 1–11. https://doi.org/10.1111/mcn.12793.

Carducci, B., Oh, C., Keats, E.C., Roth, D.E., Bhutta, Z.A., 2020. Effect of food environment interventions on anthropometric outcomes in school-aged children and adolescents in low- and middle-income countries: a systematic review and meta-analysis. Curr. Dev. Nutr. https://doi.org/10.1093/cdn/nzaa098.

Chen, X., Zhang, Z., Yang, H., Qiu, P., Wang, H., Wang, F., Zhao, Q., Fang, J., Nie, J., 2020. Consumption of ultra-processed foods and health outcomes: a systematic review of epidemiological studies. Nutr. J. https://doi.org/10.1186/s12937-020-00604-1.

Clark, T.S., Linzer, D.A., 2015. Should I use fixed or random effects? Political Science Research and Methods 3 (2), 399–408. https://doi.org/10.1017/PSRM.2014.32.

Colozza, D., 2022. A qualitative exploration of ultra-processed foods consumption and eating out behaviours in an Indonesian urban food environment. Nutr. Health. https://doi.org/10.1177/02601060221133897.

Cornelsen, L., Green, R., Turner, R., Dangour, A.D., Shankar, B., Mazzocchi, M., Smith, R. D., 2015. What happens to patterns of food consumption when food prices change? Evidence from a systematic review and meta-analysis of food price elasticities globally. Health Econ. 24, 1548–1559. https://doi.org/10.1002/hec.3107.

Croft, T.N., Marshall, A.M.J., Allen, C.K., Arnold, F., Assaf, S., Balian, S., 2018. Guide to DHS Statistics, vol. 645. ICF, Rockville.

Darfour-Oduro, S.A., Andrade, J.E., Grigsby-Toussaint, D.S., 2019. Review of policies to increase fruit and vegetable consumption and physical activity in 49 low- and middle-income countries. J. Publ. Health 41, 119–129. https://doi.org/10.1093/pubmed/fdy039.

Darmon, N., Drewnowski, A., 2015. Contribution of food prices and diet cost to socioeconomic disparities in diet quality and health: a systematic review and analysis. Nutr. Rev. 73, 643–660. https://doi.org/10.1093/nutrit/nuv027.

Deptford, A., Allieri, T., Childs, R., Damu, C., Ferguson, E., Hilton, J., Parham, P., Perry, A., Rees, A., Seddon, J., Hall, A., 2017. Cost of the Diet: a method and software to calculate the lowest cost of meeting recommended intakes of energy and nutrients from local foods. BMC Nutrition 3 (1), 1–17. https://doi.org/10.1186/s40795-017-0136-4.

Drewnowski, A., 2010. The nutrient rich foods index helps to identify healthy, affordable foods. American Journal of Clinical Nutrition 91. https://doi.org/10.3945/ajcn.2010.28450D.

Durao, S., Visser, M.E., Ramokolo, V., Oliveira, J.M., Schmidt, B.M., Balakrishna, Y., Brand, A., Kristjansson, E., Schoonees, A., 2020. Community-level interventions for improving access to food in low- and middle-income countries. Cochrane Database Syst. Rev. 2020 (7) https://doi.org/10.1002/14651858.CD011504.PUB2.

Ecker, O., Qaim, M., 2011. Analyzing nutritional impacts of policies: an empirical study for Malawi. World Dev. 39, 412–428. https://doi.org/10.1016/j.worlddev.2010.08.002.

Fanzo, J., Haddad, L., McLaren, R., Marshall, Q., Davis, C., Herforth, A., Jones, A., Beal, T., Tschirley, D., Bellows, A., Miachon, L., Gu, Y., Bloem, M., Kapuria, A., 2020. The Food Systems Dashboard is a new tool to inform better food policy. Nature Food 1 (5), 243–246. https://doi.org/10.1038/s43016-020-0077-y. Springer Nature.

FAO, World Bank, 2018. Food Data Collection in Household Consumption and Expenditure Surveys Guidelines for Low-And Middle-Income Countries (Rome).

Gittelsohn, J., Trude, A., 2017. Diabetes and obesity prevention: changing the food environment in low-income settings. Nutr. Rev. 75, 62–69. https://doi.org/10.1093/nutrit/nuw038.

Green, R., Cornelsen, L., Dangour, A.D., Honorary, R.T., Shankar, B., Mazzocchi, M., Smith, R.D., 2013. The effect of rising food prices on food consumption:systematic review with meta-regression. Br. Med. J. 347 https://doi.org/10.1136/bmj.f3703.

Headey, D.D., Alderman, H.H., 2019. The relative caloric prices of healthy and unhealthy foods differ systematically across income levels and continents. J. Nutr. 149 (11), 2020–2033. https://doi.org/10.1093/jn/nxz158.

Headey, D., Ruel, M., 2023. Food inflation and child undernutrition in low and middle income countries. Nat. Commun. 14 https://doi.org/10.1038/s41467-023-41543-9.

Headey, D.D., Ruel, M.T., 2022. Economic shocks predict increases in child wasting prevalence. Nat. Commun. 13 https://doi.org/10.1038/s41467-022-29755-x.

Herforth, A., Ahmed, S., 2015. The food environment, its effects on dietary consumption, and potential for measurement within agriculture-nutrition interventions. Food Secur. 7 (3), 505–520. https://doi.org/10.1007/S12571-015-0455-8/TABLES/1.

High Level Panel of Experts on Food Security and Nutrition, 2017. Nutrition and food systems. A report by the high level panel of Experts on food security and nutrition of the committee on World food security. In: HLPE Report 12 |Policy Support and Governance| Food and Agriculture Organization of the United Nations. September 2017. https://www.fao.org/policy-support/tools-and-publications/resources-details/en/c/1155796/.

Jensen, R.T., Miller, N.H., 2008. Giffen behavior and subsistence consumption. Am. Econ. Rev. 98 (4), 1553–1577. https://doi.org/10.1257/aer.98.4.1553.

Laska, M.N., Hearst, M.O., Forsyth, A., Pasch, K.E., Lytle, L., 2010. Neighbourhood food environments: are they associated with adolescent dietary intake, food purchases and weight status? Publ. Health Nutr. 13, 1757–1763. https://doi.org/10.1017/S1368980010001564.

MacHado, P.P., Steele, E.M., Levy, R.B., Sui, Z., Rangan, A., Woods, J., Gill, T., Scrinis, G., Monteiro, C.A., 2019. Ultra-processed foods and recommended intake levels of nutrients linked to non-communicable diseases in Australia: evidence from a nationally representative cross-sectional study. BMJ Open 9. https://doi.org/10.1136/bmjopen-2019-029544.

Marshall, Q., Bellows, A.L., McLaren, R., Jones, A.D., Fanzo, J., 2021. You say you want a data revolution? Taking on food systems accountability. Agriculture 11 (5), 422. https://doi.org/10.3390/agriculture11050422.

Martin, K.S., Havens, E., Boyle, K.E., Matthews, G., Schilling, E.A., Harel, O., Ferris, A.M., 2012. If you stock it, will they buy it? Healthy food availability and customer purchasing behaviour within corner stores in Hartford, CT, USA. Publ. Health Nutr. 15, 1973–1978. https://doi.org/10.1017/S1368980011003387.

Monteiro, C.A., Moubarac, J.C., Cannon, G., Ng, S.W., Popkin, B., 2013. Ultra-processed products are becoming dominant in the global food system. Obes. Rev. https://doi.org/10.1111/obr.12107.

Muhammad, A., D'Souza, A., Meade, B., Micha, R., Mozaffarian, D., 2017. How income and food prices influence global dietary intakes by age and sex: evidence from 164 countries. BMJ Glob. Health 2 (3). https://doi.org/10.1136/BMJGH-2016-000184.

O'Meara, L., De Bruyn, J., Dominguez-Salas, P., Hope, T., Turner, C., Stoynova, M., Wellard, K., Ferguson, E., 2023. Characteristics of food environments that influence food acquisition and diets of women in low- and middle-income countries: a scoping review protocol. JBI Evid Synth. https://doi.org/10.11124/JBIES-22-00299.

Ray, R.C., 2022. Fruits and vegetable wastes. In: Valorization to Bioproducts and Platform Chemicals. Springer, Singapore. https://doi.org/10.1007/978-981-16-9527-8.

Sawyer, A.D.M., van Lenthe, F., Kamphuis, C.B.M., Terragni, L., Roos, G., Poelman, M.P., Nicolaou, M., Waterlander, W., Djojosoeparto, S.K., Scheidmeir, M., Neumann-Podczaska, A., Stronks, K., 2021. Dynamics of the complex food environment underlying dietary intake in low-income groups: a systems map of associations extracted from a systematic umbrella literature review. Int. J. Behav. Nutr. Phys. Activ. https://doi.org/10.1186/s12966-021-01164-1.

Seale Jr, J.L., Regmi, A., Bernstein, J., 2003. *International evidence on food consumption patterns*. Economic Research Service/USDA. In: Technical Bulletin 1904. https://www.ers.usda.gov/webdocs/publications/47429/14755_tb1904_1_.pdf. (Accessed 16 July 2024).

The Demographic and Health Surveys (DHS) Program, 2022. StatComplier, the DHS Program indicator data API. https://api.dhsprogram.com/#/index.html.

Toure, D., Herforth, A., Pelto, G.H., Neufeld, L.M., Mbuya, M.N., 2021. An emergent framework of the market food environment in low-and middle-income countries. Curr. Dev. Nutr. https://doi.org/10.1093/cdn/nzab023.

Turner, C., Aggarwal, A., Walls, H., Herforth, A., Drewnowski, A., Coates, J., Kalamatianou, S., Kadiyala, S., 2018. Concepts and critical perspectives for food environment research: a global framework with implications for action in low- and middle-income countries. Global Food Secur. 18, 93–101. https://doi.org/10.1016/j.gfs.2018.08.003.

Turner, C., Kalamatianou, S., Drewnowski, A., Kulkarni, B., Kinra, S., Kadiyala, S., 2020. Food environment research in low- and middle-income countries: a systematic scoping review. Adv. Nutr. 11 (2), 387–397. https://doi.org/10.1093/ADVANCES/NMZ031.

Turowska, Z., Klemm, J., de Pee, S., 2024. (forthcoming). Analyzing Diet Cost and Affordability: A Dataset from Fill the Nutrient Gap Analyses (2015-2021).

Unicef, W.H.O., 2021. Joint Malnutrition Estimates Database. World Bank. https://data.unicef.org/topic/nutrition/malnutrition.

Ül Kirci, M., Isaksson, O., Seifert, R.. Managing Perishability in the Fruit and Vegetable Supply Chains. Sustainability (Switzerland). https://doi.org/10.3390/su14095378.

UNICEF, 2017. Multiple Indicator Cluster Surveys List of Indicators.

Vaivada, T., Akseer, N., Akseer, S., Somaskandan, A., Stefopulos, M., Bhutta, Z.A., 2020. Stunting in childhood: an overview of global burden, trends, determinants, and drivers of decline. Am. J. Clin. Nutr. 112 (Suppl. 2), 777S https://doi.org/10.1093/AJCN/NQAA159.

Westbury, S., Ghosh, I., Jones, H.M., Mensah, D., Samuel, F., Irache, A., Azhar, N., Al-Khudairy, L., Iqbal, R., Oyebode, O., 2021. The influence of the urban food environment on diet, nutrition and health outcomes in low-income and middle-income countries: a systematic review. BMJ Glob. Health 6. https://doi.org/10.1136/bmjgh-2021-006358.

World Food Programme, 2022. Fill the Nutrient Gap. https://www.wfp.org/publications/2020-fill-nutrient-gap.

Yu, X., Shimokawa, S., 2016. Nutritional impacts of rising food prices in African countries: a review. Food Secur. 8, 985–997. https://doi.org/10.1007/s12571-016-0605-7.

Ziso, D., Chun, O.K., Puglisi, M.J., 2022. Increasing access to healthy foods through improving food environment: a review of mixed methods intervention studies with residents of low-income communities. Nutrients. https://doi.org/10.3390/nu14112278.

Study II: The association between residence and dietary intake in a HIC

Place of Residence Is Associated with Dietary Intake and BMI-SDS in Children and Adolescents: Findings from the DONALD Cohort Study.

Janosch Klemm, Ines Perrar, Christian Borgemeister, Ute Alexy, Ute Nöthlings

Int. J. Environ. Res. Public Health 2024, 21, 46. Epub 28 December 2023

DOI 10.3390/ijerph21010046

International Journal of
Environmental Research and Public Health

MDPI

Article

Place of Residence Is Associated with Dietary Intake and BMI-SDS in Children and Adolescents: Findings from the DONALD Cohort Study

Janosch Klemm [1,*], Ines Perrar [2], Christian Borgemeister [1], Ute Alexy [2] and Ute Nöthlings [2]

[1] Center for Development Research (ZEF), University of Bonn, Genscherallee 3, 53113 Bonn, Germany; cb@uni-bonn.de
[2] Institute of Nutrition and Food Sciences (IEL), Nutritional Epidemiology, University of Bonn, Friedrich-Hirzebruch-Allee 7, 53115 Bonn, Germany; iperrar@uni-bonn.de (I.P.); alexy@uni-bonn.de (U.A.); noethlings@uni-bonn.de (U.N.)
* Correspondence: jklemm@uni-bonn.de

Abstract: We aimed to determine whether place of residence in the German urban food environment is associated with habitual dietary intake (energy, macronutrients, and food groups) and body mass index (standard deviation score of BMI and BMI-SDS). Our hypothesis was that place of residence may explain some variation in dietary intake and nutritional outcomes. For the cross-sectional analyses of DONALD study data, we grouped participants according to their geocoded residence in the north or south of Dortmund. We applied robust multi-level mixed effects regression models using residence as a predictor and (1) BMI-SDS or (2) dietary data (daily intake of energy (kcal), macronutrients (energy percentage), or food groups (g/1000 kcal)) as the outcome. Models were adjusted for age, sex, and household socio-economic status. An analysis was carried out on 1267 anthropometric measurements collected annually from 360 participants aged 6–18 years (935 3-day weighed dietary records from 292 participants) between 2014 and 2019. In the fully adjusted models, residence in the south was associated with a lower BMI-SDS (β = −0.42, p = 0.02), lower intake of sugar-sweetened beverages (β = −47.00, p = 0.04), and higher intake of vegetables (β = 11.13, p = 0.04). Findings suggest that the place of residence, beyond individuals' socio-economic statuses, may be a contributing factor to dietary quality.

Keywords: dietary intake; children; adolescents; urban settings; spatial trends

check for updates

Citation: Klemm, J.; Perrar, I.; Borgemeister, C.; Alexy, U.; Nöthlings, U. Place of Residence Is Associated with Dietary Intake and BMI-SDS in Children and Adolescents: Findings from the DONALD Cohort Study. *Int. J. Environ. Res. Public Health* **2024**, *21*, 46. https://doi.org/10.3390/ijerph21010046

Academic Editor: Paul B. Tchounwou

Received: 10 November 2023
Revised: 13 December 2023
Accepted: 23 December 2023
Published: 28 December 2023

1. Introduction

Dietary risk factors are a major cause of global illness [1,2]. Understanding the role of external factors, such as the food environment around the individual (here determined by place of residence), is important regarding dietary intake: Spatial patterns of dietary intake can be the first point of investigation to understand how variation occurs in different target groups [3–5] and identify potential pathways to making healthy, sustainable diets more widely consumed. School-aged children and adolescents are a critical age group for this, as they require healthy diets for proper growth and development [6]. Additionally, adult dietary patterns are shaped during childhood [7], making this a key target group for possible interventions. Existing analyses on spatial patterns have yielded strong insights into the role of the built environment on dietary intake and health outcomes [8–10], establishing the concepts of food environment [11,12], food deserts [13,14], and food swamps [10,15] in nutrition and food security research.

Recent evidence on the spatial variation in dietary intake has highlighted specifically the role of neighborhood socio-economic statuses for BMI and dietary intake [16–22], but little to no research has been carried out on this topic in Germany. It is not established whether residence and location are relevant factors for dietary intake within the German population [23]. While research is available for the supply of (nutritious) foods within the urban context [24,25], in one case including demand for drivers for elderly age groups [26], no study was found that systematically assessed if spatial variation in demand, i.e., of dietary patterns, is detectable within the German context, or whether dietary patterns are spatially homogenous.

Due to the limited understanding of spatial variation in dietary patterns in the German population, we aimed to better understand variations in food group intake and standard deviation scores of BMIs (BMI-SDS) of 6- to 18-year-old individuals in the Dortmund Nutritional and Anthropometric Longitudinally Designed (DONALD) cohort study. Therefore, we analyzed macronutrients and food groups, such as fruits and vegetables, as these food groups have been shown to reduce the risk of chronic disease, including in children and adolescents [27–30], and the consumption of sugar-sweetened beverages, as a higher intake of these is linked to a higher risk of a range of non-communicable diseases [31,32]. The objective of this study was to determine whether place of residence plays a role in the participants' diets and BMI-SDS within the DONALD study.

2. Methods

2.1. Study Sample

The ongoing DONALD study is an open cohort study that was initiated in 1985 in Dortmund, the eighth largest city in Germany, located in the Ruhr area. The DONALD study's design has been extensively described elsewhere [33]. In summary, each year, 35–40 healthy infants are recruited in or near Dortmund and undergo repeated examinations. Eligible are healthy German infants (i.e., infants free of diseases affecting growth and/or dietary intake) whose parents are willing to participate in a long-term study and of whom at least one has sufficient knowledge of the German language. Among 6–18 year olds, data on dietary intake, anthropometry, biomarkers, lifestyle, and early life parameters are collected each year. Parental examinations occur every four years. The DONALD study was approved by the Ethics Committee of the University of Bonn, according to the Declaration of Helsinki. Written consent of the study participants and/or parents was obtained prior to all investigations.

2.2. Study Population

For the present analysis, data of participants of the DONALD study, who were 6–18 years old between 2014–2019, were examined. The age range 6–18 was set to align with school-going age in Germany, meaning that these individuals are, to some degree, making individual decisions regarding their dietary intake. We selected the five years prior to the COVID-19 pandemic to exclude dietary intake that was potentially affected by national lockdowns, school closures, and an overall change in the food environment. We only selected participants with at least one anthropometric measurement.

In total, 360 participants who matched those requirements were identified. For dietary records, only 292 of those 360 participants had at least one observation and were included in the analysis of dietary intake. The median number of dietary records available for the 5-year period per participant was 3 (25. percentile: 2; 75. percentile: 5).

2.3. Dietary Assessment

Dietary intake information in the DONALD study is based on 3-day weighed dietary records. All food and drinks consumed by the participants, including leftovers, were weighed and recorded by the parents or the participants themselves, if old enough. Semi-quantitative recording (spoons, cups) was allowed if accurate weighing was not possible. Information on recipes, brands, and types of commercial foods was also required. Energy and nutrient intake were calculated based on the food composition database LEBTAB (LEBensmittelTABelle). Composition of staple foods is based on the German food composition table BLS (Bundeslebensmittelschlüssel) 3.02. Energy and nutrient contents of commercial food products were estimated by recipe simulation using labeled ingredients and nutrient contents. Commodity-level information was aggregated to food group level and standardized relative to individual energy intake (in g food group per 1000 kcal). Total energy intake (TEI), macronutrients (calculated as % of TEI), and food group intake were calculated as individual means of three days of recording. Food groups analyzed include grains, dairy, meat and fish, vegetables, fruits, sweets, and sugar-sweetened beverages (SSB) (Table 1).

Table 1. Description and components of food groups utilized for this analysis.

Food Group	Components
Meat and Fish	• Beef, veal, pork, game, lamb, goat, horse • Poultry • Organ meats and offal • Sausages, cold cuts • Meat dishes • Fish, fresh or frozen • Processed fish
Dairy	• Dairy products, fermented and unfermented • Fresh, soft, (semi)hard and processed cheese • Dairy powder • Instant milk beverages (e.g., cocoa)
Fruits	• Fruit, fresh and frozen • Fruit, canned • Fruit, dried
Vegetables	• Vegetables and mushrooms, fresh and frozen • Vegetables and mushrooms, canned • Vegetables and mushrooms, dried
Sweets	• Sugar, sweeteners • Sweet parfait (jam, honey, hazelnut spread) • Candy (wine gums, drops) • Chocolate, bars • Ice cream, water ice • Sweet sauces • Non-milk-desserts
Grain	• Flour, mixed and plain • Bread • Grain, cooked and raw • Dough • Pasta • Ready to eat cereals
SSB	• Sweetened fruit juice drinks and nectars, • Soft drinks/sodas, • Sweetened teas and waters, • Instant beverages (except dairy drinks), sweetened sport drinks

2.4. Anthropometrics

For the DONALD study, height and weight were measured by trained nurses according to standard procedures, with the participants dressed in underwear only and barefoot. Standing height was measured to the nearest 0.1 cm using a digital stadiometer (Harpenden, Crymych, UK). Bodyweight was measured to the nearest 100 g using an electronic scale (Seca 753E; Seca Weighing and Measuring System, Hamburg, Germany). BMI was calculated using body weight (kg) divided by the square of the body height (m^2). For an age- and sex-independent consideration of BMI, we calculated BMI–SDS using German reference percentiles for children and adolescents [34].

2.5. Place of Residence

Using GIS mapping, we assigned each individual reported place of residence to the respective administrative districts of Dortmund (Stadtbezirke). As the sample sizes in the northern districts were very small, we further grouped our data following a binary north (n = 52 for individuals with at least one anthropometric measurement) and south (n = 308) divide (Figure 1) to serve as proxy for neighborhood socio-economic status. We selected north/south rather than east/west as this divide aligns with reported differences in statistics on social status and wealth. These include unemployment, dependency on social assistance among the elderly, or enrolment in social protection scheme (SGB II, a social assistance mechanism by the federal employment agency, with the aim to cover subsistence costs for jobseekers and their dependents [35]): The latter being 34.7% in the north and 20.7% in the south for children, 21.2% in the north and 12.0% in the south for adults, respectively [36].

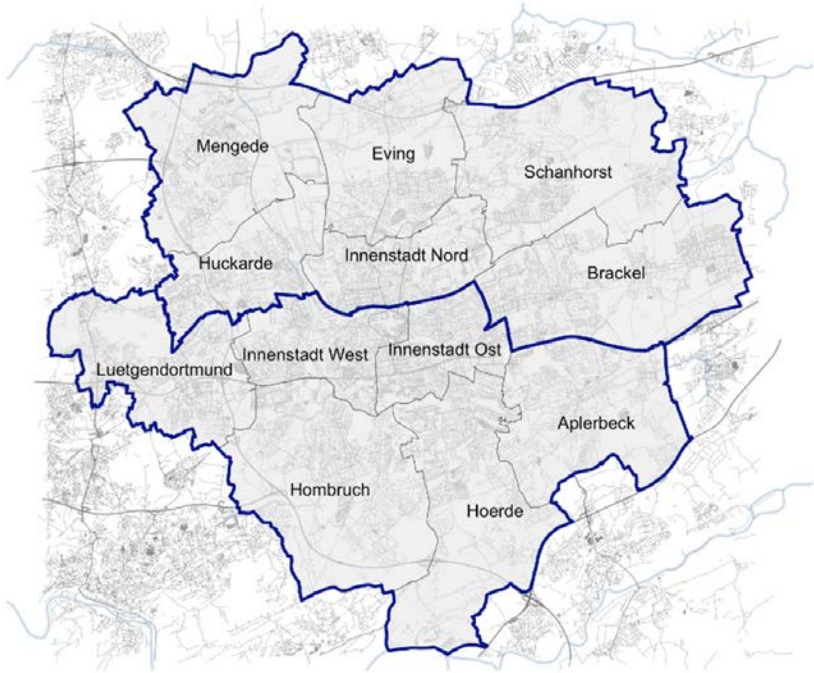


Figure 1. Dortmund city districts per analysis area (north and south).

2.6. Assessment of Covariates

We included physical activity as covariate for BMI-SDS models to account for differences in energy balance [37]. We included socio-economic status of the household as covariate to account for differences that may influence the quality of the diet at household level [38]. Age and sex, taken from the annual participant questionnaire, were included to account for variation that may be due to lifecycle-specific eating habits [39]. Physical activity was expressed as Metabolic Equivalent of Task (MET)-minutes in organized, unorganized, and total settings. Data on physical activity were assessed using an interviewer-based, validated questionnaire (Adolescent Physical Activity Recall Questionnaire [40]), which included questions on duration and frequency of organized (e.g., training in a sports club) and unorganized (leisure sports, e.g., playing football with friends) activities.

Socio-economic data were collected using standardized questionnaires [32]. Socio-economic score (SES) was calculated adapted from [41], reflecting (a) educational and professional qualification of the parents and b) occupation level of parents, each receiving a score from 0–7, resulting in a total score from 0–14 per parent. No data on household income were available and, therefore, are not included in the calculation. Averages across both parents, where applicable, were calculated to estimate total household SES. Where only one score was available, this was taken as household SES.

2.7. Statistical Analysis

Data were processed, and descriptive statistics were prepared using RStudio 2022.07.1. All regression models were carried out using STATA version 16. The significance level was set at $p < 0.05$. A two-sample *t*-test with unequal variances was used to estimate whether a significant difference in SES exists between the two administrative groupings.

A robust multi-level mixed effects regression using STATA's mixed command was used to analyze the effect of location of residence on nutrition and health outcomes. We define residence as the categorical independent variable and the dependent variable as per the following groups:

1. BMI-SDS
2. Food Group Dietary Intake (Grains, Vegetables, Fruits, Meat, Sweets, Dairy, SSB)
3. Macronutrient Intake (Energy, Protein, Fat and Sugar).

Each indicator within these health and nutrition outcome groups was analyzed separately. We included individual's unique ID and year as random effects to reflect varying numbers of observations per individual and changes due to specific years. We selected north as the reference area, i.e., coefficients are differences in the south relative to the north. For the first model (Model A), we included age (years) and sex (boy/girl) as covariables to account for the impact of these variables according to TEI. In the second model (Model B), we additionally included SES as a third covariable to account for possible effects that household SES may have (e.g., knowledge about healthy eating or resources available for food). For BMI-SDS as dependent outcome, we further included physical activity (measured in total MET-minutes) as a covariable (Model B*). We plotted and visually inspected histograms of residuals of the robust mixed effects model for normal distribution. We performed Breusch–Pagan/Cook–Weisberg test for heteroscedasticity using STATA's hettest command and specified robust standard errors where heteroscedasticity is present (using STATA's VCE command). Incomplete records were omitted from the respective models (Missing are $n = 14$ for SES-adjusted models and $n = 3$ for Activity-adjusted models). To account for multiple testing, Benjamini–Hochberg procedure for false discovery rate (FDR) was carried out within each model and outcome group, setting FDR at 0.20. The relatively high false discovery rate was selected due to the exploratory nature of this research and to avoid false negatives.

3. Results

Table 2 shows median values of background characteristics, anthropometric data, and dietary intake in this sample. SES is high overall in the study sample [33] but higher in the southern part of Dortmund than in the north. The range in SES, expressed by the 25th and 75th percentiles, was comparable in both areas, with the south having slightly higher values. Results from the *t*-test show that there is a small but significant difference in means of socio-economic status between the north relative to the south (diff = −0.70, $p = 0.01$).

Table 2. Characteristics of DONALD study participants (age 6–18) between 2014 and 2019, stratified by place of residence.

Place of Residence:	North		South	
n participants	52	(14.4)	308	(85.6)
$n_{anthropometry}$ [a]	184	(14.5)	1083	(85.5)
$n_{3\text{-day-dietary-records}}$ [a]	149	(15.9)	786	(84.1)
n female participants (%)	27	(51.9)	134	(43.5)
Age (in years)	14	(9.8; 16.5)	11	(7.6; 15.1)
SES [b]				
Household SES	9.4	(7.8; 10.8)	10.3	(9.1, 11.3)
Anthropometry				
BMI (kg/m^2)	19.8	(16.7; 23.4)	17.4	(15.5; 20.4)
BMI-SDS	0.4	(−0.6; 1.2)	−0.2	(−0.8; 0.4)
Height (cm)	164.9	(139.6; 172.9)	148.7	(129.1; 168.0)
Weight (kg)	52.3	(33.7; 67.9)	38.1	(26.8; 57.9)
Macronutrients [c]				
TEI (kcal/day)	1795.2	(1519.8; 2057.8)	1694.6	(1481.4; 1978.0)
Carbohydrates (%E)	50.6	(47.5; 53.2)	51.1	(47.5; 54.2)
Fat (%E)	33.6	(32.2; 37.7)	34.4	(31.9; 37.7)
Protein (%E)	13.2	(12.5; 14.8)	13.4	(11.8; 14.9)
Sugar (%E)	23.8	(20.1; 26.3)	22	(18.8; 26.0)
Food Group [c]				
Dairy (g/1000 kcal)	136.1	(102.6; 188.5)	124.4	(88.5; 182.6)
Fruit (g/1000 kcal)	59.7	(25.9; 92.5)	61.1	(37.7; 97.6)
Grains (g/1000 kcal)	85.4	(67.2; 96.9)	83.7	(64.4; 103.1)
Meat and Fish (g/1000 kcal)	55.9	(42.2; 72.0)	46.1	(31.8; 69.2)
SSB (g/1000 kcal)	68.5	(17.4; 158.3)	39.5	(6.5; 80.8)
Sweets (g/1000 kcal)	29.1	(23.1; 42.2)	33.3	(19.7; 47.1)
Vegetables (g/1000 kcal)	64.1	(38.0; 83.1)	56.3	(33.5; 84.2)
Physical Activity [d]				
MET Minutes	967.8	(560.9; 1304.1)	1014	(708.4; 1427.0)

Values are medians (25th; 75th percentile in parenthesis) of the mean of repeated measurements by participant, or frequencies (% in parenthesis). SES Socio-Economic Score, SSB Sugar-Sweetened Beverages, BMI Body Mass Index, BMI-SDS Body Mass Index Standard Deviation Score, TEI total energy intake, MET Metabolic Equivalent of Task. [a] Due to repeated measurements per participant. [b] Missing 14 (participants), north = 3, south = 11. [c] Missing 68 (participants), north = 6, south = 62. [d] Missing 3 (participants), north = 0, south = 3.

In the fully-adjusted multi-level mixed-effects models using place of residence as the explanatory variable, we found that residence in the south was associated with lower BMI-SDS ($\beta = -0.417$, $p = 0.017$), lower intake of sugar-sweetened beverages ($\beta = -47.00$, $p = 0.044$) and higher intake of vegetables ($\beta = 11.13$, $p = 0.043$) in g per 1000 kcal after controlling for household SES (Table 3, unstandardized coefficients). No significant differences between north and south were found for the intake of fruit, meat, dairy, grains, or sweets. Additionally, no significant results were found for macronutrients, nor did adjustment for multiple testing change the significance of the findings (at FDR = 0.20, detailed results in Supplementary Material).

Table 3. Spatial trends between south and north (reference) Dortmund for selected indicators.

			β	*p*-Value	Lower CI	Upper CI
BMI	SDS	Model A	−0.489	**0.005**	−0.827	−0.151
		Model B	−0.425	**0.016**	−0.769	−0.081
		Model B*	−0.417	**0.017**	−0.759	−0.075
Food Groups	SSB	Model A	−47.661	**0.039**	−92.821	−2.501
		Model B	−47.000	**0.044**	−92.642	−1.359
	Vegetables	Model A	12.133	**0.027**	1.377	22.889
		Model B	11.129	**0.043**	0.351	21.906
	Fruit	Model A	7.829	0.302	−7.030	22.688
		Model B	9.876	0.196	−5.094	24.847
	Meat	Model A	−4.468	0.252	−12.122	3.185
		Model B	−4.746	0.239	−12.640	3.148
	Sweets	Model A	1.602	0.545	−3.592	6.796
		Model B	2.327	0.397	−3.057	7.712
	Grain	Model A	3.905	0.277	−3.141	10.952
		Model B	1.646	0.637	−5.200	8.492
	Dairy	Model A	−8.138	0.465	−29.946	13.671
		Model B	−6.237	0.565	−27.492	15.017

Significant *p*-values ($p < 0.05$) in the adjusted model are bolded; Model A is adjusted for age and sex. Model B is adjusted for age, sex and socio-economic status. Model B* (BMI-SDS only) is adjusted for age, sex, socio-economic status and physical activity. β-coefficients are unstandardized. BMI Body Mass Index, SDS Standard Deviation Score, SSB Sugar-Sweetened Beverages, CI Confidence Intervall.

4. Discussion

This study investigated associations between place of residence and dietary intake and anthropometrics among children and adolescents enrolled in the DONALD study. This is the first time that data from this cohort were analyzed for spatial differences. Two main aspects stood out from the results: Firstly, we provided evidence that even when accounting for the overall high SES, spatial differences among participants of this rather homogeneous study population can be observed. Secondly, we presented an explorative analysis and starting point for further investigation into the enabling factors of the urban (food) environment in Germany. While spatial analysis of the urban food environment has been undertaken in several countries [3,42,43], no study could be identified that focused on the spatial differences in dietary intake within a German city or within the German population beyond urban/rural disaggregation. The association between SES and a healthy diet or health more generally has been documented for children and adolescents in the German context [41,44], with one study additionally finding that obesity contributes to the loss of SES [45]. The present analysis provided further nuance to the role of SES, for example, by distinguishing between neighborhood (spatial) and household levels of SES. We found that residence in the south, which is considered to have higher neighborhood socio-economic status [36,46], was significantly associated with lower BMI-SDS, lower intake of SSB, and higher intake of vegetables in the study population, even when accounting for household SES.

We observed a 0.417 difference in BMI-SDS between the north and south. With a completely random spatial distribution, the median value for both the north and south would be expected to be around 0 for each. However, predicted values for the south were −0.11 and for the north 0.30 for Model B*, respectively (a detailed overview of predicted values by the model is presented in the Supplementary Materials). This pattern in BMI-SDS matched the general trends reported for overweight or obesity on the city district level among 6-year-olds in Dortmund [46].

For SSB, the estimated difference between the two regions was 47 g per 1000 kcal consumed—estimated consumption is around 65% higher in the north than it was in the south. Intakes of SSB reported in the KiGGS Study were at 300 mL per day for girls

(11–13 and 14–17 years), nearly 330 mL per day for boys (11–13 years), and almost 500 mL per day for boys (14–17 years) [47]. The same study reported a significant discrepancy between socio-economic groups in the frequency of drinking SSBs. Although we did not analyze consumption frequencies in this paper, our data also show a higher intake of SSB in adolescent boys than in girls. The comparatively lower intakes per day reported in the DONALD study (compared to KiGGS, cf. Table 2) could be explained by the overall relatively high socio-economic status of the household. Despite the role that the SES of the household appears to play [48], differences between the two areas still occur when controlling for household SES. This indicated that factors beyond the household may also influence the intake of SSBs.

While the absolute differences between (adjusted) estimated intake of vegetables in north versus south Dortmund were small, estimates were 17% lower in the north. It is also noteworthy that the combined reported median quantity of fruits and vegetables consumed per day (123.85 g/1000 kcal for the north and 117.39 g/1000 kcal for the south) were far below the recommended daily intakes (roughly 190 g/1000 kcal, based on 400 g for both fruits and vegetables for the average individual (2100 kcal/day) according to the WHO). Hence, while the differences reported here were statistically significant, the actual difference between the two areas may be negligible, given that both areas would require large increases in intake to meet WHO targets.

As our results were adjusted for household socio-economic status in a spatial context, they, however, indicate the possibility that in some areas, even individuals that have relatively high levels of SES are limited in their ability to consume a healthy diet. Our findings, therefore, support the hypotheses that several determinants of dietary intake are outside the control of the individual [49]. Existing literature provides a variety of possible explanations why neighborhood socio-economic statuses could influence dietary patterns, including lack of availability [50–53], high relative prices of healthy foods [53], abundant and convenient access to unhealthy foods vis-à-vis healthier options [10,15], or peer effects within neighborhoods [54–57]. Further research is needed to identify specific drivers for the city of Dortmund, as well as the role of migration, which is higher in the north [36].

A growing body of research on the food environment exists, analyzing spatial variation in nutrition indicators generally [3,4,58,59], examining the influence of the food environment on dietary intake or health [8,60], the relationship between the socio-economic status of the neighborhood and food availability [15,51–53,61–63] and the influence of vendors on consumption [15]. Based on our data and analysis, our study belongs to the first group, as it focused on spatial variation in nutrition indicators. Specifically, our study added to the existing body of evidence on the food environment insofar as we showed (1) significant variation between two city areas, which aligned with global findings that highlight the role of the socio-economic status of the neighborhood, and (2) that the impact of individual or household socio-economic status may not be sufficiently strong to counteract the role that the food environment had.

While most research includes features of the built environment (such as store density or assortment), our study did not include such characteristics. Still, our findings are in line with evidence from other countries, which suggest that the physical area of residence may have a strong influence on eating patterns and, consequently, nutrition and health status, even when the background characteristics of the individual are accounted for. In a systematic review of 15 studies on obesity in children and adolescents and urban built environments carried out in the USA between 2001 and 2008, Dunton et al. reported that neighborhood pattern was the only feature that showed an association with obesity [9]. In another study conducted with data from Los Angeles, USA, researchers found that living in a neighborhood with a very low SES residence score was significantly associated with higher BMI, even when accounting for the education and income of the individual [60]. In a similar study focusing on dietary patterns of female adolescents in Baltimore, USA, Hager et al., argued that "without health-promoting opportunities from higher-ranking systems (i.e., the neighbourhood), individuals (i.e., adolescents) have difficulty pursuing and maintaining healthy behaviours" [15]. They found that neighborhood SES was associated with the consumption of snacks and desserts but not with the number of servings of fruits and vegetables of the individual. As they did not investigate the portion size of food groups, it remains unclear whether there was a (small) difference in intake amounts, as was found in our study.

Beyond its exploratory value, the present evaluation showed three specific strengths: Firstly, the longitudinal design: we accounted for dietary intake over 5 years and used multiple observations per individual (median n = 3). Secondly, we included a quantitative household SES indicator: we included information on educational and professional qualifications as well as the actual professional status of the parents. Thirdly, our dataset allowed us to analyze the weight of consumed food groups, whereas many studies focused on overweight, aggregated groups ("snacks and desserts") or frequencies ("servings of fruit and vegetables").

Yet, some empirical, methodological, and conceptual limitations remain: Despite variation in the group, the study sample still had relatively high socio-economic status (mean value 10 [from 0–14]), which has been noted and discussed elsewhere [33]. This analysis is, therefore, not generalizable beyond the study sample and only allows limited conclusions for a wider population. The calculated SES consisted only of two out of three indicator groups used by the reference literature: education and employment, not factoring in the actual income as this is not available in the dataset. It may, therefore, be possible for residual socio-economic confounding to occur. Although we used robust standard errors, accounted for possible confounders, and the fact that low numbers of observations in the north are generally reflected in wider confidence intervals, the uneven geographic distribution of participants may have impacted our findings. Furthermore, geographic location was included as a two-area variable (north/south) in the statistical models, which may not reflect the diversity of locations in Dortmund. It is, therefore, possible that statistically significant clusters exist that were not identified by this analysis and equally possible that clusters documented here are not visible in a different definition or aggregation of area units. Additionally, differences in genders and age groups, which are not spread equally across the two areas, could also have influenced findings. However, we did account for these parameters statistically by including age and sex as covariates. Lastly, we did not provide any evidence on how the reported differences could arise. We documented that there is significant spatial variation in dietary intake and nutrition status between the two areas, but investigation of why was beyond the scope of this analysis.

5. Conclusions

To our knowledge, this is the first study that looked at the association between nutrition indicators (dietary intake and BMI-SDS) and the location of inner-city residences in Germany. We found that even when adjusting for age, sex, socio-economic status (and physical activity for BMI-SDS), there was a significant difference between the north and the south of Dortmund for BMI-SDS and intake of SSB and vegetables. Results for grains, dairy, animal protein sources, fruits, or sweets are statistically insignificant and therefore warrant further investigation.

Overall, our results add to existing evidence that factors affecting dietary intake are in part outside of the immediate control of the individual. Further research is therefore required to arrive at conclusive evidence on whether place of residence is a significant variable in determining dietary intake or whether inner-city spatial clusters are driven by individual or household socio-economic factors alone. This should include both further (spatial) analysis of existing datasets and the collection of primary data on the urban food environment itself.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/ijerph21010046/s1, Figure S1: Chloropleth maps of mean dietary intake and nutrient status indicators of Donald study participants (age 6–18) between 2014 and 2019 by city districts (Stadtbezirk) of Dortmund. Figure S2: Predicted values for North and South

Dortmund, respectively, by model specification. Table S1: Regression results for macronutrients by model specification.

Author Contributions: All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by J.K., I.P., C.B., U.A. and U.N. The first draft of the manuscript was written by J.K. and I.P. and all authors commented on previous versions of the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: The DONALD Study is financially supported by the Ministry of Science and Research of North Rhine-Westphalia, Germany. Work on this analysis was additionally funded by the University of Bonn, the University of Applied Sciences Bonn-Rhein-Sieg, and the Ministry of Culture and Science of North Rhine-Westphalia, Germany, through the Forschungskolleg "One Health and Urban Transformation". The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Institutional Review Board Statement: The DONALD study was approved by the Ethics Committee of the University of Bonn, Germany (Approval Number 185/20) and have therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments.

Informed Consent Statement: All assessments in the DONALD study were performed with parental and later on participants' written informed consent.

Data Availability Statement: Data of the DONALD study is available upon request.

Acknowledgments: The participation of all children and their families in the DONALD study is gratefully acknowledged. We also thank the DONALD staff for carrying out the anthropometric measurements, for administering the questionnaires, and for collecting and coding the dietary records. We thank Samuel Muli for his comments and help with the statistical design of the analysis.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Afshin, A.; Sur, P.J.; Fay, K.A.; Cornaby, L.; Ferrara, G.; Salama, J.S.; Mullany, E.C.; Abate, K.H.; Abbafati, C.; Abebe, Z.; et al. Health effects of dietary risks in 195 countries, 1990–2017: A systematic analysis for the Global Burden of Disease Study 2017. *Lancet* **2019**, *393*, 1958–1972. [CrossRef] [PubMed]
2. Qiao, J.; Lin, X.; Wu, Y.; Huang, X.; Pan, X.; Xu, J.; Wu, J.; Ren, Y.; Shan, P. Global burden of non-communicable diseases attributable to dietary risks in 1990–2019. *J. Hum. Nutr. Diet.* **2022**, *35*, 202–213. [CrossRef] [PubMed]
3. Dekker, L.H.; Rijnks, R.H.; Strijker, D.; Navis, G.J. A spatial analysis of dietary patterns in a large representative population in the north of The Netherlands—The Lifelines cohort study. *Int. J. Behav. Nutr. Phys. Act.* **2017**, *14*, 166. [CrossRef]
4. Block, J.P.; Scribner, R.A.; Desalvo, K.B. Fast food, race/ethnicity, and income: A geographic analysis. *Am. J. Prev. Med.* **2004**, *27*, 211–217. [CrossRef] [PubMed]
5. Morland, K.; Wing, S.; Roux, A.D.; Poole, C. Neighborhood Characteristics Associated with the Location of Food Stores and Food Service Places. *Am. J. Prev. Med.* **2002**, *22*, 23–29. [CrossRef] [PubMed]
6. Norris, S.A.; Frongillo, E.A.; Black, M.M.; Dong, Y.; Fall, C.; Lampl, M.; Liese, A.D.; Naguib, M.; Prentice, A.; Rochat, T.; et al. Nutrition in adolescent growth and development. *Lancet* **2022**, *399*, 172–184. [CrossRef]
7. Nicklaus, S. Development of food variety in children. *Appetite* **2009**, *52*, 253–255. [CrossRef] [PubMed]
8. Schafft, K.A.; Jensen, E.B.; Hinrichs, C.C. Food Deserts and Overweight Schoolchildren: Evidence from Pennsylvania. *Rural Sociol.* **2009**, *74*, 153–177. [CrossRef]
9. Dunton, G.F.; Kaplan, J.; Wolch, J.; Jerrett, M.; Reynolds, K.D. Physical environmental correlates of childhood obesity: A systematic review. *Obes. Rev.* **2009**, *10*, 393–402. [CrossRef]
10. Cooksey-Stowers, K.; Schwartz, M.B.; Brownell, K.D. Food swamps predict obesity rates better than food deserts in the United States. *Int. J. Environ. Res. Public Health* **2017**, *14*, 1366. [CrossRef]
11. Glanz, K.; Sallis, J.F.; Saelens, B.E.; Frank, L.D. Nutrition Environment Measures Survey in Stores (NEMS-S). Development and Evaluation. *Am. J. Prev. Med.* **2007**, *32*, 282–289. [CrossRef] [PubMed]
12. McInerney, M.; Csizmadi, I.; Friedenreich, C.M.; Uribe, F.A.; Nettel-Aguirre, A.; McLaren, L.; Potestio, M.; Sandalack, B.; McCormack, G.R. Associations between the neighbourhood food environment, neighbourhood socioeconomic status, and diet quality: An observational study. *BMC Public Health* **2016**, *16*, 984. [CrossRef]
13. Shaw, H.J. Food deserts: Towards the development of a classification. *Geogr. Ann. Ser. B* **2006**, *88*, 231–247. [CrossRef]
14. Beaulac, J.; Kristjansson, E.; Cummins, S. A Systematic Review of Food Deserts, 1966–2007. *Prev. Chronic Dis.* **2009**, *6*, A105. [PubMed]

42. Rose, D.; Bodor, J.N.; Swalm, C.M.; Rice, J.C.; Farley, T.A.; Hutchinson, P.L. *Deserts in New Orleans? Illustrations of Urban Food Access and Implications for Policy*; University of Michigan: Ann Arbor, MI, USA, 2009.
43. Cummins, S.C.J. The Local Food Environment and Health: Some Reflections from the United Kingdom. *Am. J. Public Health* **2003**, *93*, 521. [CrossRef]
44. Kuntz, B.; Waldhauer, J.; Zeiher, J.; Finger, J.D.; Lampert, T. Soziale Unterschiede im Gesundheitsverhalten von Kindern und Jugend lichen in Deutschland—Querschnittergebnisse aus KiGGS Welle 2. *J. Health Monit.* **2018**, *3*, 45–63. [CrossRef]
45. Mader, S.; Rubach, M.; Schaecke, W.; Röger, C.; Feldhoffer, I.; Thalmeier, E.-M. Healthy nutrition in Germany: A survey analysis of social causes, obesity and socioeconomic status. *Public Health Nutr.* **2020**, *23*, 2109–2123. [CrossRef]
46. Stadt Dortmund. *Stadt Dortmund Bericht zur Sozialen Lage in Dortmund 2018*; Dezernat für Arbeit, Gesundheit, Soziales, Sport und Freizeit: Dortmund, Germany, 2018.
47. Mensink, G.; Schienkiewitz, A.; Rabenberg, M.; Borrmann, A.; Richter, A.; Haftenberger, M. Konsum zuckerhaltiger Erfrischungsgetränke bei Kindern und Jugendlichen in Deutschland-Querschnittergebnisse aus KiGGS Welle 2 und Trends. *J. Health Monit.* **2018**, *3*, 32–39. [CrossRef]
48. Schneider, S.; Mata, J.; Kadel, P. Relations between sweetened beverage consumption and individual, interpersonal, and environmental factors: A 6-year longitudinal study in German children and adolescents. *Int. J. Public Health* **2020**, *65*, 559–570. [CrossRef] [PubMed]
49. WBAE—Wissenschaftlicher Beirat für Agrarpolitik Ernährung und Gesundheitlichen Verbraucherschutz beim BMEL. *Politik für eine Nachhaltigere Ernährung: Eine Integrierte Ernährungspolitik Entwickeln und Faire Ernährungsumgebungen Gestalten*; BMEL (Bundesministerium für Ernährung und Landwirtschaft): Berlin, Germany, 2020.
50. Franco, M.; Diez Roux, A.V.; Glass, T.A.; Caballero, B.; Brancati, F.L. Neighborhood Characteristics and Availability of Healthy Foods in Baltimore. *Am. J. Prev. Med.* **2008**, *35*, 561–567. [CrossRef] [PubMed]
51. Powell, L.M.; Slater, S.; Mirtcheva, D.; Bao, Y.; Chaloupka, F.J. Food store availability and neighborhood characteristics in the United States. *Prev. Med.* **2007**, *44*, 189–195. [CrossRef] [PubMed]
52. Morland, K.; Filomena, S. Disparities in the availability of fruits and vegetables between racially segregated urban neighbourhoods. *Public Health Nutr.* **2007**, *10*, 1481–1489. [CrossRef] [PubMed]
53. Block, D.; Kouba, J. A comparison of the availability and affordability of a market basket in two communities in the Chicago area. *Public Health Nutr.* **2006**, *9*, 837–845. [CrossRef]
54. Gwozdz, W.; Sousa-Poza, A.; Reisch, L.A.; Bammann, K.; Eiben, G.; Kourides, Y.; Kovács, E.; Lauria, F.; Konstabel, K.; Santaliestra-Pasias, A.M.; et al. *Peer Effects on Obesity in a Sample of European Children*; Forschungsinstitut zur Zukunft der Arbeit: Bonn, Germany, 2015.
55. Kalavana, T.V.; Maes, S.; De Gucht, V. Interpersonal and Self-regulation Determinants of Healthy and Unhealthy Eating Behavior in Adolescents. *J. Health Psychol.* **2010**, *15*, 52. [CrossRef]
56. Finnerty, T.; Reeves, S.; Dabinett, J.; Jeanes, Y.M.; Vögele, C. Effects of peer influence on dietary intake and physical activity in schoolchildren. *Public Health Nutr.* **2010**, *13*, 376–383. [CrossRef]
57. Bruening, M.; Eisenberg, M.; MacLehose, R.; Nanney, M.S.; Story, M.; Neumark-Sztainer, D. Relationship between Adolescents' and Their Friends' Eating Behaviors: Breakfast, Fruit, Vegetable, Whole-Grain, and Dairy Intake. *J. Acad. Nutr. Diet.* **2012**, *112*, 1608–1613. [CrossRef]
58. Morrison, K.T.; Nelson, T.A.; Ostry, A.S. Mapping spatial variation in food consumption. *Appl. Geogr.* **2011**, *31*, 1262–1267. [CrossRef]
59. Alemu, T.G.; Techane, M.A.; Wubneh, C.A.; Assimamaw, N.T.; Belay, G.M.; Tamir, T.T.; Muhye, A.B.; Kassie, D.G.; Wondim, A.; Terefe, B.; et al. Spatial variation and determinates of dietary diversity among children aged 6–23 months in Ethiopia: Spatial and multilevel analysis using Ethiopian Demography Health Survey (EDHS) 2019. *Arch. Public Health* **2022**, *80*, 152. [CrossRef] [PubMed]
60. Inagami, S.; Cohen, D.A.; Finch, B.K.; Asch, S.M. You Are Where You Shop. Grocery Store Locations, Weight, and Neighborhoods. *Am. J. Prev. Med.* **2006**, *31*, 10–17. [CrossRef] [PubMed]
61. Hendrickson, D.; Smith, C.; Eikenberry, N. Fruit and vegetable access in four low-income food deserts communities in Minnesota. *Agric. Hum. Values* **2006**, *23*, 371–383. [CrossRef]
62. Walker, R.E.; Keane, C.R.; Burke, J.G. Disparities and access to healthy food in the United States: A review of food deserts literature. *Health Place* **2010**, *16*, 876–884. [CrossRef]
63. Smith, C.; Morton, L.W. Rural Food Deserts: Low-income Perspectives on Food Access in Minnesota and Iowa. *J. Nutr. Educ. Behav.* **2009**, *41*, 176–187. [CrossRef]

15. Hager, E.R.; Cockerham, A.; O'Reilly, N.; Harrington, D.; Harding, J.; Hurley, K.M.; Black, M.M. Food swamps and food deserts in Baltimore City, MD, USA: Associations with dietary behaviours among urban adolescent girls. *Public Health Nutr.* **2017**, *20*, 2598–2607. [CrossRef] [PubMed]
16. Mason, K.E.; Pearce, N.; Cummins, S. Do neighbourhood characteristics act together to influence BMI? A cross-sectional study of urban parks and takeaway/fast-food stores as modifiers of the effect of physical activity facilities. *Soc. Sci. Med.* **2020**, *261*, 113242. [CrossRef] [PubMed]
17. de Bont, J.; Márquez, S.; Fernández-Barrés, S.; Warembourg, C.; Koch, S.; Persavento, C.; Fochs, S.; Pey, N.; de Castro, M.; Fossati, S.; et al. Urban environment and obesity and weight-related behaviours in primary school children. *Environ. Int.* **2021**, *155*, 106700. [CrossRef]
18. Zhou, P.; Li, R.; Liu, K. The Neighborhood Food Environment and the Onset of Child-Hood Obesity: A Retrospective Time-Trend Study in a Mid-sized City in China. *Front. Public Health* **2021**, *9*, 688767. [CrossRef]
19. van Erpecum, C.P.L.; van Zon, S.K.R.; Bültmann, U.; Smidt, N. The association between the presence of fast-food outlets and BMI: The role of neighbourhood socio-economic status, healthy food outlets, and dietary factors. *BMC Public Health* **2022**, *22*, 1432. [CrossRef]
20. Prados, M.J.; Nicosia, N.; Datar, A. Impact of built, social, and economic environments on adolescent obesity and related health behaviors. *Obesity* **2023**, *31*, 1085–1094. [CrossRef]
21. Wasserman, J.A.; Suminski, R.; Xi, J.; Mayfield, C.; Glaros, A.; Magie, R. A multi-level analysis showing associations between school neighborhood and child body mass index. *Int. J. Obes.* **2014**, *38*, 912–918. [CrossRef] [PubMed]
22. Atanasova, P.; Kusuma, D.; Pineda, E.; Frost, G.; Sassi, F.; Miraldo, M. The impact of the consumer and neighbourhood food environment on dietary intake and obesity-related outcomes: A systematic review of causal impact studies. *Soc. Sci. Med.* **2022**, *299*, 114879. [CrossRef] [PubMed]
23. Augustin, H. *Stadt, Ernährung und Soziale Ungleichheit*; Artec Forschungszentrum Nachhaltigkeit: Bremen, Germany, 2014.
24. Kühn, G.; Junker, R. *Nahversorgung in Großstädten*; Deutsches Institut für Urbanistik: Berlin, Germany, 2006.
25. Lexis, C. Nahversorgung durch City-Märkte des Lebensmitteleinzelhandels—Ein neues Konzept zur Stärkung wohnnaher Versorgung in Städten? *Berichte Arbeitskreises Geogr. Handel.* **2012**, *32*, 34–38.
26. Hoffmann, S. Lebensmitteleinkauf der Generation 50plus. Analyse von Angebot und Nachfrage im Stadtgebiet Würzburg. *Berichte Arbeitskreises Geogr. Handel.* **2008**, *23*, 5–9.
27. Boeing, H.; Bechthold, A.; Bub, A.; Ellinger, S.; Haller, D.; Kroke, A.; Leschik-Bonnet, E.; Müller, M.J.; Oberritter, H.; Schulze, M.; et al. Critical review: Vegetables and fruit in the prevention of chronic diseases. *Eur. J. Nutr.* **2012**, *51*, 637–663. [CrossRef] [PubMed]
28. Mellendick, K.; Shanahan, L.; Wideman, L.; Calkins, S.; Keane, S.; Lovelady, C. Diets rich in fruits and vegetables are associated with lower cardiovascular disease risk in adolescents. *Nutrients* **2018**, *10*, 136. [CrossRef]
29. Nyanchoka, M.A.; van Stuijvenberg, M.E.; Tambe, A.B.; Zuma, M.K.; Mbhenyane, X.G. Fruit and Vegetable Consumption Patterns and Risk of Chronic Diseases of Lifestyle among University Students in Kenya. *Int. J. Environ. Res. Public Health* **2022**, *19*, 6965. [CrossRef]
30. Macknin, M.; Stegmeier, N.; Thomas, A.; Worley, S.; Li, L.; Hazen, S.L.; Tang, W.H.W. Three Healthy Eating Patterns and Cardiovascular Disease Risk Markers in 9 to 18 Year Olds with Body Mass Index >95%: A Randomized Trial. *Clin. Pediatr.* **2021**, *60*, 474–484. [CrossRef]
31. Malik, V.S.; Hu, F.B. The role of sugar-sweetened beverages in the global epidemics of obesity and chronic diseases. *Nat. Rev. Endocrinol.* **2022**, *18*, 205–218. [CrossRef]
32. Alcaraz, A.; Pichon-Riviere, A.; Palacios, A.; Bardach, A.; Balan, D.J.; Perelli, L.; Augustovski, F.; Ciapponi, A. Sugar sweetened beverages attributable disease burden and the potential impact of policy interventions: A systematic review of epidemiological and decision models. *BMC Public Health* **2021**, *21*, 1460. [CrossRef]
33. Kroke, A.; Manz, F.; Kersting, M.; Remer, T.; Sichert-Hellert, W.; Alexy, U.; Lentze, M.J. The DONALD Study: History, current status and future perspectives. *Eur. J. Nutr.* **2004**, *43*, 45–54. [CrossRef] [PubMed]
34. Kromeyer-Hauschild, K.; Wabitsch, M.; Kunze, D.; Geller, F.; Geiß, H.C.; Hesse, V.; von Hippel, A.; Jaeger, U.; Johnsen, D.; Korte, W.; et al. Perzentile für den Body-mass-Index für das Kindes- und Jugendalter unter Heranziehung verschiedener deutscher Stichproben. *Monatsschrift Kinderheilkd.* **2001**, *149*, 807–818. [CrossRef]
35. Federal Employment Agency. *Unemployment Benefit II/Social Assistance*; Federal Employment Agency: Nuremberg, Germany, 2020.
36. Stadt Dortmund. *Statistikatlas Stadt Dortmund*; Stabsstelle Dortmunder Statistik: Dortmund, Germany, 2019.
37. Westerterp, K.R. Exercise, energy balance and body composition. *Eur. J. Clin. Nutr.* **2018**, *72*, 1246–1250. [CrossRef] [PubMed]
38. Darmon, N.; Drewnowski, A. Does social class predict diet quality? *Am. J. Clin. Nutr.* **2008**, *87*, 1107–1117. [CrossRef]
39. Kersting, M.; Sichert-Hellert, W.; Lausen, B.; Alexy, U.; Manz, F.; Schöch, G. Energy intake of 1 to 18 year old German children and adolescents. *Z. Ernährungswiss* **1998**, *37*, 47–55. [CrossRef] [PubMed]
40. Booth, M.L.; Okely, A.D.; Chey, T.; Bauman, A. The reliability and validity of the Adolescent Physical Activity Recall Questionnaire. *Med. Sci. Sports Exerc.* **1986**, *34*, 1986–1995. [CrossRef]
41. Lampert, T.; Müters, S.; Stolzenberg, H.; Kroll, L.E. Messung des sozioökonomischen Status in der KiGGS-Studie: Erste Folgebefragung (KiGGS Welle 1). *Bundesgesundheitsblatt Gesundheitsforschung Gesundheitsschutz* **2014**, *57*, 762–770. [CrossRef]

Study III: Individual-level drivers of diet quality in adolescents in Ghana

Individual-level drivers of food choices and diet quality among adolescents in urban West Africa: evidence from Accra, Ghana.

Janosch Klemm, Samuel Muli, Kolade Oluwagbemigun, Martin Parlasca, Aba Crentsil, Deda Ogum, Peter Quartey, Amos Laar, Anna Lartey, Christian Borgemeister, Ute Nöthlings

Accepted at Maternal & Child Nutrition [in print]

DOI doi.org/10.1111/mcn.13775

Maternal & Child Nutrition

WILEY

Maternal & Child Nutrition

ORIGINAL ARTICLE OPEN ACCESS

Individual-Level Drivers of Food Choices and Diet Quality Among Adolescents in Urban West Africa: Evidence From Accra, Ghana

Janosch Klemm[1] | Samuel Muli[2] | Kolade Oluwagbemigun[2] | Martin Parlasca[1] | Aba Crentsil[3] | Deda Ogum[4] | Peter Quartey[3] | Amos Laar[4] | Anna Lartey[5] | Christian Borgemeister[1] | Ute Nöthlings[2]

[1]Center for Development Research (ZEF), University of Bonn, Bonn, North Rhine-Westphalia, Germany | [2]Institute of Nutrition and Food Sciences (IEL) - Nutritional Epidemiology, University of Bonn, Bonn, North Rhine-Westphalia, Germany | [3]Institute of Statistical, Social and Economic Research, University of Ghana, Accra, Greater Accra, Ghana | [4]Department of Population, Family & Reproductive Health, School of Public Health, University of Ghana, Accra, Greater Accra, Ghana | [5]Department of Nutrition and Food Science, University of Ghana, Accra, Greater Accra, Ghana

Correspondence: Janosch Klemm (jklemm@uni-bonn.de)

Received: 24 May 2024 | **Revised:** 31 October 2024 | **Accepted:** 11 November 2024

Funding: The study was supported by the University of Bonn, the University of Applied Sciences Bonn-Rhein-Sieg, and the Ministry of Culture and Science of North Rhine-Westphalia, Germany, through the Forschungskolleg "One Health and Urban Transformation". The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Keywords: adolescents | diet diversity | diet quality | Ghana | Global Dietary Recommendation (GDR) Score | urban settings

ABSTRACT

Diet quality is influenced by multiple individual factors, but their relative strength and importance remain unclear. We investigate the associations between five domains of individual factors (economic, cognitive, aspirational, situational and consumer behaviour) and diet intake of adolescents in Accra, Ghana. A cross-sectional survey among Junior High School (JHS) students ($n = 409$, mean age 14.3 years ± 1.28 (SD)) in Accra, Ghana, was conducted. Data on diet intake, knowledge, attitude and practices (KAP) and socioeconomic background characteristics were collected. Adjusting for other factors, students' total budget was positively associated with food group diversity ($\beta = 0.12$, 95% confidence interval [CI] 0.09–0.15) but inversely associated with diet quality ($\beta = -0.07$, 95% CI −0.11 to −0.03). Positive attitude towards nutrition and healthy eating was inversely associated with unfavourable diversity ($\beta = -0.17$, 95% CI −0.31 to −0.03). Differences between negative deviants relative to positive deviants were determined by attitude towards healthy eating (odds ratio [OR] = 0.41; 95% CI 0.17–0.99) and family practices (OR = 0.48; 95% CI 0.23–1.00). We provide evidence that higher food budgets were associated with higher diet diversity, but not with improved diet quality. Attitude, but not knowledge, was linked to better diet quality. Future studies should focus on the specific contribution of aspirational, situational and behavioural factors in directing increased diversity towards favourable eating habits.

1 | Introduction

People's dietary choices have substantial impacts on individual health, public health and planetary health (Afshin et al. 2019; Qiao et al. 2022; Springmann et al. 2018). However, the determinants of these choices are not well understood, particularly for vulnerable demographic groups such as adolescents in low- and middle-income countries (LMICs) (Fanzo and Davis 2021; Kupka, Siekmans, and Beal 2020). Adolescence, a critical period in life, is marked by susceptibility to various forms of malnutrition (Norris et al. 2022), establishments of dietary patterns that often persist into adulthood, influencing

Summary

- Adolescents with higher budgets tended to consume more unfavourable food groups, relative to favourable food groups.
- No budget difference was found between positive deviants (Nutrition Champions) versus negative deviants (Nutrition Challengers). They differ mainly regarding attitudes and family practices.
- Attitudes, such as perceived benefits of healthy eating, were identified as the most relevant mitigating factor for the intake of *unfavourable* food groups. Practices, especially family practices such as regularly eating home-cooked meals, on the other hand, were associated with the intake of *favourable* food groups.
- These specific pathways of individual-level factors must be considered when informing policies or programmes for adolescent diet intake.

long-term health outcomes and predisposing individuals to chronic disease risk (ALjaraedah, Takruri, and Tayyem 2019; Contento et al. 2006; Cutler et al. 2011; Tabbakh and Freeland-Graves 2016).

As a typical sub-Saharan African metropolitan area, Accra, the capital of Ghana, is characterised by increasing urban sprawl, rising income and employment levels, increased demand for convenient shopping and high availability of ultra-processed foods (Mockshell et al. 2022), emphasising the potential health impact of this landscape. At the same time, Accra experiences the triple burden of malnutrition, characterised by high rates of overweight and obesity alongside undernutrition and persistent micronutrient deficiencies, such as anaemia in women of reproductive age (Ghana Statistical Service 2015; Wrottesley et al. 2023). The prevalence of overweight is around 47% in children aged 6–16 years (Ganle, Boakye, and Baatiema 2019) and 40% in women of reproductive age (Ghana Statistical Service 2015).

Previous studies of diets in and around schools in Ghana included analysis of school meals provided through feeding programmes (Fernandes et al. 2017), highlighting non-receipt of school meals as a predictor of bringing money to school to buy food, or focus on eating patterns of school children (Abizari and Ali 2019; Ogum-Alangea et al. 2020), but neither provide information on the relationship of individual characteristics (such as amount of money brought) and diet quality. While existing literature from Ghana also shows that individuals are exposed to a large variety of economic and behavioural factors that influence their diet quality (Holdsworth et al. 2020; Laar et al. 2023), the pathways and association between these are still unclear. In their review of industrial diets among adolescents in Ghana, Sambu et al. (2024) found that most research on adolescents addresses unhealthy diets as an isolated behavioural or nutritional issue and fails to connect domains of the food system. Qualitative studies conducted among adolescents in Ghana underscore the pivotal role of the physical food environment, economic constraints, and cognitive factors such as food preferences in shaping dietary decisions (Holdsworth et al. 2020; Liguori et al. 2022; Mockshell et al. 2022; Pradeilles et al. 2021), which supports the need for quantitative research in this domain. In summary, existing research on socioeconomic drivers of dietary intake tends to either focus on adults (Karanja et al. 2022; Kushitor et al. 2023; Weil et al. 2023), include limited drivers on adolescent diet quality (Abizari and Ali 2019; Fernandes et al. 2017; Ganle, Boakye, and Baatiema 2019; Madzorera et al. 2023; Sambu et al. 2024) or utilise qualitative methods (Iyassu et al. 2023; Liguori et al. 2022) and does not reflect the unique situation of adolescents (Karanja et al. 2022; Kushitor et al. 2023). It is particularly important to better understand adolescent diets given the role healthy diets play for critical physiological and neurocognitive development during adolescence and the elevated burden of nutrition in Ghana overall.

We address this research gap by tracking the relationship between individual and behavioural factors in adolescents and the outcome of diet quality, measured by diet scores. In particular, we investigate the influence of five domains of individual factors, namely economic, cognitive, aspirational and situational factors as well as consumer behaviour on diet intake of school-age adolescents in Accra. Thereby, this study aims to provide a comprehensive understanding of the factors associated with the food choices and eating patterns of school-going adolescents in Accra.

2 | Methods and Materials

2.1 | Study Design and Population

Cross-sectional in design, we used a two-stage proportional stratified random sampling strategy. Three areas within Greater Accra were identified as sample sites based on similar economic, infrastructure and public health indicators reported in the 2021 census (Ghana Statistical Service 2022): Ayawaso East Municipality, Ablekuma Central Municipality and Accra Metro. Within these areas, eight public and four private schools were randomly selected (serving as the Primary Sampling Unit), following the public/private ratio and representative of official enrolment statistics. We selected 12 out of 115 Junior High Schools (JHS) and determined a minimum sample of 379 students (Secondary Sampling Unit), using a 5% margin of error, 95% confidence level and 50% sample proportion on an estimated 24,000 students in the identified metropolitan areas. In each of the identified schools, 36 students from grades JHS1 and JHS2 who attended school on the preceding day (to match the recall timeframe) were randomly selected, except for one school, where only 34 students were enroled in both grades, yielding a total of 428 students. After data cleaning and plausibility checks, 19 students were excluded due to implausible consumption patterns.

JHSs, which are mostly day schools in Ghana, do not provide institutional school meals (as basic schools) or financial support mechanisms as would be found, for example, in Senior High Schools (Free Senior High School Policy). Foods consumed by JHS students during a school day are therefore either purchased by the students, brought from home or potentially gifted.

Indicators used in this study are aligned with the High Level Panel of Experts (HLPE) food systems framework (HLPE 2017) adapted for tracking global progress on the food systems dashboard (Fanzo et al. 2020). They are categorised according to five areas of individual and behavioural factors that influence diet choice: economic, cognitive, aspirational, situational and consumer behaviour (detailed mapping of the indicators to each factor is provided in Supporting Information: Material S1).

2.2 | Protocol

We obtained written informed consent from all study participants: parents or legal guardians of all eligible students before their selection ($n = 1510$, response rate of parents > 80%) and written assent from the students before conducting the survey. All eligible and randomly selected students ('participants' from here on) assented to and completed the survey.

2.3 | Data Collection

Participant data were collected in schools between the 7th and 28th of November 2022. This survey utilised five groups of variables collected as part of the questionnaire, which was pilot tested among 16 junior high students and conducted as described below (full survey questionnaires are reported in Supporting Information: Materials S2). Participant surveys were carried out Tuesdays to Fridays, so the dietary recall period (i.e., the previous day) would always refer to a school day.

2.3.1 | Anthropometric Variables

Anthropometric variables were collected as background information (not used in models) from participants, while dressed in school uniforms, without shoes. Height was measured using Leicester portable height measure (Marsden HM-250P, 1 mm graduations) and weight was measured using portable weighing scales (Ingco HESA 41802, 0.1 kg precision). Given that students wear standardised school uniforms, weighing approximately 550 g, which was subtracted from measured weight, we do not expect bias from this in our anthropometric measurements (Censi et al. 2013).

2.3.2 | Knowledge, Attitude and Practice Scores

A formative set of 28 Knowledge (8), Attitude (8) and Practice (12) (KAP) questions were collected from students to capture individuals' characteristics. Questions were based on established and validated protocols (Fautsch Macías, Glasauer, and Food and Agriculture Organization of the United Nations 2014; Moitra, Verma, and Madan 2021) and checked for face validity and applicability for the local context. Two researchers reviewed a set of 36 questions. Their feedback was integrated into the questionnaire and pilot tested with 16 students. After pilot testing, eight questions were removed from the survey. An overview of question per category and subcomponent is provided in Appendix Table A1. The maximum overall KAP Score that could be achieved was 36, with each of the individual components scored from 0 to 12. For knowledge and attitude, the individual subcategories were scored from 0 to 4, and for practices, the individual subcategories were scored from 0 to 3.

2.3.3 | Sociodemographic and Food Budget Information

Participants were asked to estimate their food budget for the previous 24 h. Specifically, we inquired how much money they had at their disposal for breakfast, lunch, snacks and total budget, in case food purchases occur outside of breakfast, lunch or snacks. Participants reported if they brought food from home for any of these eating occasions. They were additionally asked about other household characteristics, including maternal education, religion, ethnicity, maternal marital status and whether they live with their parents or a caretaker.

2.3.4 | Wealth Proxies

A collapsed 11-item asset index was collected using a validated questionnaire from the equity tool project (Chakraborty et al. 2016). It was designed to capture the availability of key assets and assign scores, identifying the equivalent national wealth quintile, for each individual, based on cutoffs from national household surveys. Based on Maternal Health Survey 2017, urban-specific cutoffs for wealth quintiles are available and were used to assign individuals to the appropriate quintiles.

2.3.5 | Diet Quality Questionnaire (DQQ)

A Ghana-specific DQQ was used following established protocols (Herforth et al. 2020; Uyar et al. 2023). The DQQ recalls consumption of 29 food groups during the preceding 24 h, that is, whether a food group was consumed (binary). A detailed description of this methodology can be found elsewhere, as well as its applicability for adolescents (Herforth et al. 2020; Uyar et al. 2023; Wang et al. 2022). DQQ allows calculating different indicators related to dietary intake. For this study, we focused on the *Food Group Diversity Score* (FGDS; 0–10), *Global Dietary Recommendations (GDR) Score* (0–18), *Non-Communicable Disease* (NCD) *Risk Score* (0–9) and *NCD-Protect Score* (0–9) (Herforth et al. 2020). GDR Score is a composite of NCD-Risk and NCD-Protect (calculated as 9 + NCD-Protect Score − NCD-Risk Score), but for ease of reference, we reported results for all three variables.

2.3.6 | Definition of Outcome Variables

Outcome variables of interest in this study were FGDS, GDR Score, NCD-Risk Score and NCD-Protect Score. To capture trade-offs between these linear scores, we defined categorical outcomes for our study cohort based on NCD-Protect and NCD-Risk Scores. These nutrition types were defined as: 'Nutrition Struggler' as the group that lacks diversity throughout (below 5 NCD-Risk foods and below 5 NCD-Protect foods). We defined

'Nutrition Champions' as our positive deviants: those who consumed 5 or more NCD-Protect foods and 5 or less NCD-Risk foods. 'Nutrition Challengers' were defined as negative deviants: those who consumed 5 or more NCD-Risk foods while consuming 5 or less NCD-Protect foods. Cutoffs for NCD-Protect were set at 5 so positive deviants exceed the minimum threshold for dietary diversity (Arimond et al. 2021). Cutoffs for NCD-Risk were also set at 5 to parallel NCD-Protect cutoffs. More formally, this can be expressed as:

$$\text{Nutrition Challenger} \rightarrow \text{NCD-Risk} \geq 5 \cap \text{NCD-Protect} \leq 5 \cap \text{NCD-Risk} > \text{NCD-Protect}$$

$$\text{Nutrition Champion} \rightarrow \text{NCD-Protect} \geq 5 \cap \text{NCD-Risk} \leq 5 \cap \text{NCD-Protect} > \text{NCD-Risk}$$

$$\text{Nutrition Struggler} \rightarrow \text{NCD-Protect} < 5 \cap \text{NCD-Risk} < 5.$$

2.4 | Definition of Predictors

Predictors used in this study were individuals' budgets measured in Ghanian Cedi (GHS) per day, as well as Knowledge, Attitude and Practice (KAP) scores. KAP scores were used in two different ways: (1) as aggregate scores for knowledge, attitude and practice, respectively, and (2) as expanded scores for all 10 Knowledge, attitude and practice subcategories (cf. previous section).

2.5 | Assessment of Covariates

In this study, we assessed potential confounding variables informed by the conceptual work of Fanzo et al. (2020), also cf. Supporting Information: Materials S1, including sex, age, ethnicity, religion and a school dummy. Household characteristics included maternal education, maternal marital status, household wealth quintile and whether the child resided with their parents or someone else.

2.6 | Statistical Analysis

Baseline characteristics of the study population were summarised as mean and standard deviation, disaggregated by sex to identify potential differences between sexes. To estimate the relationship between predictors and outcomes, we fitted the following multivariable linear regression models for each outcome:

$$DQ_i = \beta 1 * \text{DailyBudget}_i + \beta 2 * \text{Knowledge}_i + \beta 3 * \text{Attitude}_i + \beta 4 * \text{Practice}_i + \beta 5 * X_i + \varepsilon_i \quad (1)$$

where DQ_i represents different measures of diet quality, namely GDR Score, FGDS, NCD Protect or NCD Risk. The vector X_i contains socioeconomic background characteristics, namely sex, age, school, household wealth, religion, ethnicity, maternal education, maternal marital status and residence with parents.

We ran the model separately for each measure of diet quality DQ_i. For a more nuanced analysis of the role of the budget and of the KAP scores, we ran a second model (expanded). In this model, $DailyBudget_i$ is a vector of the daily budget consisting of breakfast, lunch and snack budget, $Knowledge_i$ is the vector of three subcomponent knowledge scores, $Attitude_i$ is the vector of three subcomponent Attitude Scores, $Practice_i$ is the vector of the three subcomponent Practice Scores and X_i is the vector of socioeconomic background characteristics, namely sex, age, school, household wealth, religion, ethnicity, maternal education, maternal marital status and residence with parent. We adjusted for multiple hypothesis testing using False Discovery Rate set at 0.05 following the Benjamini-Hochberg procedure (Benjamini and Hochberg 1995) and reported both p-values and q-values.

We also applied a multinomial logistic regression model on nutrition type and the previously described predictors:

$$NT_i = \gamma 1 * \text{DailyBudget}_i + \gamma 2 * \text{Knowledge}_i + \gamma 3 * \text{Attitude}_i + \gamma 4 * \text{Practice}_i + \gamma 5 * X_i + \varepsilon_i \quad (2)$$

where:

NT_i (Nutrition Type) represents three categories (Nutrition Champion, Nutrition Challenger and Nutrition Struggler), and X_i is the vector of socioeconomic background characteristics: sex, age, school, household wealth, religion, ethnicity, maternal education, maternal marital status and residence with parents. We set the Nutrition Champions as the reference group.

3 | Results

3.1 | Basic Characteristics of Study Population

Table 1 reports the characteristics of the study participants according to sex. The median age for all study participants was 14 years. Half of the participants were female. Nearly all (98%) of the students reported having purchased some foods with the budget available to them.

3.2 | Drivers of Diet Quality Scores

Table 2 reports the results of the multivariable linear regression model. We first considered students' budget. Adjusting for all other factors, students' total budget was positively associated with a more diverse diet as measured by the FGDS ($\beta = 0.12$, 95% confidence interval [CI] 0.09–0.15). A higher budget was associated with a higher consumption of NCD-Protect foods ($\beta = 0.10$, 95% CI 0.06–0.13). However, a higher budget was also associated with higher consumption of NCD-Risk foods ($\beta = 0.16$, 95% CI 0.13–0.20). Since the total budget had a stronger association with the consumption of NCD-Risk foods compared to NCD-Protect foods, the total budget was associated

TABLE 1 | Summary Characteristics of study population, by sex.

	All ($n = 409$)		Female ($n = 206$, 50.4%)		Male ($n = 203$, 49.6%)	
Variable	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Age (in years)	14.35	(1.28)	14.27	(1.13)	14.42	(1.41)
Body mass index (BMI)	19.70	(3.70)	20.73	(4.05)	18.65	(2.97)
BMI for age (z-score)	−0.18	(1.23)	0.13	(1.20)	−0.49	(1.19)
GDR score (0–18)	9.15	(2.07)	9.16	(2.10)	9.14	(2.04)
NCD-Protect score (0–9)	3.24	(1.67)	3.39	(1.73)	3.08	(1.61)
NCD-Risk score (0–9)	3.09	(2.01)	3.23	(2.04)	2.94	(1.96)
FGD score (0–10)	5.12	(1.63)	5.19	(1.62)	5.05	(1.63)
Achieved MDD-W (%)	N/A		65.0	(0.48)	N/A	
Budget total (GHS)	10.20	(5.42)	9.86	(5.05)	10.54	(5.76)
Budget breakfast (GHS)	2.80	(2.84)	2.68	(2.71)	2.92	(2.97)
Budget lunch (GHS)	4.24	(2.86)	4.15	(2.79)	4.33	(2.93)
Budget snacks (GHS)	2.24	(2.51)	2.21	(2.51)	2.27	(2.53)
Knowledge score (0–12)	6.36	(1.99)	6.40	(1.95)	6.31	(2.03)
Attitude score (0–12)	8.17	(1.30)	8.24	(1.37)	8.10	(1.22)
Practice score (0–12)	5.11	(1.63)	5.12	(1.71)	5.09	(1.54)

Note: All numbers are mean values, and parentheses show standard deviations (SD). 1 GHS ≈ 0.07 USD (2022).
Abbreviations: BMI, Body Mass Index; FGD, Food Group Diversity; GDR, Global Dietary Recommendation; GHS, Ghana Cedis; MDD-W, Minimum Dietary Diversity for Women; NCD, Non-Communicable Diseases.

with an overall decrease in diet quality as measured by the GDR Score ($\beta = -0.07$, 95% CI −0.11 to −0.03). Turning towards non-economic drivers of diet quality, we found that, while adjusting for other variables, both the attitude towards and practices of healthy eating are positively associated with the GDR Score (attitude $\beta = 0.23$, 95% CI 0.07–0.39; practices $\beta = 0.17$, 95% CI 0.04–0.30). Knowledge about healthy eating, on the other side, was negatively associated with FGDS and NCD-Protect ($\beta = -0.12$, 95% CI −0.19 to −0.04 and $\beta = -0.10$, 95% CI −0.18, −0.02), while practices were positively associated with these two outcomes ($\beta = 0.20$, 95% CI 0.11–0.29 and $\beta = 0.24$, 95% CI 0.14–0.34). Finally, attitude towards healthy eating was negatively associated with the consumption of NCD-Risk foods ($\beta = -0.17$, 95% CI −0.31 to −0.03). Only the associations between knowledge and NCD-Protect as well as attitude and NCD-Risk were not robust when accounting for multiple hypotheses testing.

Table 3 reports expanded results of the multivariable linear regression model, which showed that budget dedicated to snacks was inversely associated with GDR Score (GDR: $\beta = -0.14$, 95% CI −0.22 to −0.05) and positively associated with FGDS, NCD-Protect and NCD-Risk (FGDS: $\beta = 0.15$, 95% 0.09–0.21, NCD-Protect: $\beta = 0.13$, 95% 0.06–0.19, NCD-Risk: $\beta = 0.26$, 95% 0.19–0.34). Breakfast and lunch budgets were positively associated with FGDS, NCD-Protect and NCD-Risk but showed no association with GDR. Knowledge of NCDs was inversely associated with NCD-Protect ($\beta = -0.38$, 95% CI −0.63 to −0.13). Attitude towards the benefits of healthy eating showed positive associations with GDR Score ($\beta = 0.59$, 95% CI 0.20–0.98), as did family practice scores ($\beta = 0.53$, 95% CI 0.20–0.86). Readiness to change was positively associated with FGDS ($\beta = 0.28$, 95% CI 0.09–0.47) and NCD-Protect ($\beta = 0.37$, 95% CI 0.17–0.57).

3.3 | Drivers of Nutrition Types

In the next step, we assigned students to the three nutrition types. We found that almost two thirds (66%) of study participants belonged to the 'Struggler' group. Around 16% belonged to the 'Challenger' and 13% belonged to the 'Champion' group. About 5% were not assigned to any nutrition type.

Correlates of group assignment based on logistic regression models are shown in Table 4. Comparing Strugglers and Challengers to Champions, we found that a one-unit (GHS) increase in total budget was associated with lower relative odds of being a Struggler as compared to being a Champion (OR 0.88; 95% CI 0.82–0.95). A one-unit increase in attitude score was associated with lower relative odds of being a Challenger as compared to being a Champion (OR 0.63; 95% CI 0.45–0.90). A one-unit increase in practice score was associated with lower relative odds of being a Struggler as compared to being a Champion (OR 0.66; 95% CI 0.53–0.83).

For the expanded model, being in the Struggler group was inversely associated with the breakfast budget (OR: 0.85; 95% CI 0.74–0.97). The only difference between Challengers and Champions (Reference) was lower attitude towards the benefits of eating healthy (OR = 0.41; 95% CI −0.12 to 0.99) and family practices (OR = 0.48; 95% CI 0.23–1.00) (Table 5).

4 | Discussion

In our exploratory study on the influence of five domains of individual factors (economic, cognitive, aspirational, situational

TABLE 2 | Results of multiple linear regression.

Predictors	GDR score Estimate (95% CI)	GDR score *p*-value	GDR score *q*-value	FGDS Estimate (95% CI)	FGDS *p*-value	FGDS *q*-value	NCD protect Estimate (95% CI)	NCD protect *p*-value	NCD protect *q*-value	NCD risk Estimate (95% CI)	NCD risk *p*-value	NCD risk *q*-value
Total budget	−0.07* (−0.11 to −0.03)	**0.001**	**0.024**	0.12*** (0.09–0.15)	**< 0.001**	**< 0.001**	0.10*** (0.06–0.13)	**< 0.001**	**< 0.001**	0.16*** (0.13– 0.20)	**< 0.001**	**< 0.001**
Knowledge score	−0.04 (−0.15 to 0.06)	0.447	0.661	−0.12* (−0.19 to −0.04)	**0.003**	**0.026**	−0.1 (−0.18 to −0.02)	**0.014**	0.061	−0.06 (−0.16 to 0.03)	0.201	0.621
Attitude score	0.23* (0.07–0.39)	**0.005**	**0.043**	0.01 (−0.10 to 0.13)	0.813	0.959	0.06 (−0.06 to 0.18)	0.345	0.554	−0.17 (−0.31 to −0.03)	**0.021**	0.145
Practice score	0.17 (0.04–0.30)	**0.01**	0.067	0.20*** (0.11–0.29)	**< 0.001**	**< 0.001**	0.24*** (0.14–0.34)	**< 0.001**	**< 0.001**	0.07 (−0.05 to 0.18)	0.261	0.635
Observations	409			409			409			409		
R^2/R^2 adjusted	0.163/0.089			0.283/0.220			0.227/0.159			0.282/0.218		

Note: *p*, *p*-value; *q*-value, FDR adjusted *p*-value using the Benjamini–Hochberg procedure. Models were adjusted for age, sex, wealth quintile, religion, ethnicity, maternal education, marital status of the mother, residency of the child (e.g., living with parents or caretaker) and school.
Abbreviations: FGDS, Food Group Diversity Score; GDR, Global Dietary Recommendations; KAP, Knowledge, Attitude and Practices; NCD, non-communicable disease.
$^*p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

and consumer behaviour) on the diet intake of school-age adolescents in Accra, we report three key results.

First, a higher budget alone, keeping all other factors fixed, was associated with slightly more unfavourable food groups in the diet. This means that individuals with a higher budget tended to consume more NCD-Risk foods (e.g., sugar-sweetened beverages, sweets, processed meat or packaged, ultra-processed salty snacks) than NCD-Protect foods (e.g., whole grains, pulses, dark green leafy vegetables). This complements the established relationship at the household level between diet quality and food expenditure (Pechey and Monsivais 2016), income (Bouis, Eozenou, and Rahman 2011; Colen et al. 2018; French et al. 2019; Muhammad et al. 2017) or socioeconomic status (Cutler et al. 2011; Fitzgerald et al. 2013). Larger food budget was associated with higher intake of favourable group, but also unfavourable food groups, such as processed meat, sweets or packaged, salty snacks. Evidence on this well-documented phenomenon (Global Alliance for Improved Nutrition GAIN, 2020; Monteiro et al. 2013; Ogum-Alangea et al. 2020; Westbury et al. 2021), observed particularly alongside a growing urban middle-class in low- and middle-income countries (Colozza, 2022; Karanja et al. 2022; Landais et al. 2023; Li et al. 2020), parallels increased attention to indicators reflecting healthy and unhealthy elements of diets (Herforth et al. 2020). Our results suggest that for adolescents within the urban context, higher consumption of NCD-Risk foods was predominantly driven by snack budget, that is, having cash available to spend on food outside of specific meals.

Second, beyond food budget, the results show considerable differences between each of the two main pathways of the Healthy Diet recommended by the World Health Organization —*increasing* favourable food groups and *moderating* unfavourable food groups. A higher attitude score on nutrition (considering oneself susceptible to nutrition-related diseases and perceiving benefits from adequate dietary intake) was negatively associated with the consumption of NCD-Risk foods. Higher practice scores, in particular family practices and practices that reveal the readiness to change, were positively associated with NCD-Protect foods. Previous studies on obesity also show that attitudes and perceptions about risk factors for being overweight are associated with the prevalence of overweight (Bean et al. 2018; Manggabarani et al. 2020; Oyewande et al. 2019), and research on psycho-social and cognitive determinants, such as knowledge, attitudes and practices, has established that these traits can strongly influence dietary intake. But while cognitions—including risk perception, preferences, food characteristics or health and nutrition knowledge—are considered important determinants of individuals' diets (Karanja et al. 2022; Manggabarani et al. 2020; Patrick and Nicklas 2005; Peters et al. 2009; Shahi et al. 2023), the role of factual knowledge or pure competence in nutrition itself is unclear: Several studies from predominantly high-income countries show promising results of improved dietary habits after nutrition counselling or knowledge intervention (Amoore et al. 2023; Brennan et al. 2021; Kullen et al. 2022), but others find that knowledge in nutrition by itself is insufficient to improve diets (Campbell et al. 2013; Tabbakh and Freeland-Graves 2016). The association of beneficial family practices with improved dietary practices is supported by evidence from high-

TABLE 3 | Regression results of the expanded multivariable linear regression models.

	GDR score			FGDS			NCD protect			NCD risk		
Predictors	**Estimate (95% CI)**	***p*-value**	***q*-value**	**Estimate (95% CI)**	***p*-value**	***q*-value**	**Estimate (95% CI)**	***p*-value**	***q*-value**	**Estimate (95% CI)**	***p*-value**	***q*-value**
Breakfast budget	−0.01 (−0.08 to 0.06)	0.769	0.865	0.12*** (0.06–0.17)	**< 0.001**	**< 0.001**	0.09* (0.03–0.14)	**0.003**	**0.023**	0.10* (0.03–0.16)	**0.004**	**0.033**
Lunch budget	0.02 (−0.06 to 0.10)	0.683	0.819	0.12*** (0.06–0.18)	**< 0.001**	**0.001**	0.13** (0.07–0.19)	**< 0.001**	**0.001**	0.12* (0.04–0.19)	**0.002**	**0.016**
Snacks budget	−0.14* (−0.22 to −0.05)	**0.002**	**0.02**	0.15*** (0.09–0.21)	**< 0.001**	**< 0.001**	0.13** (0.06–0.19)	**< 0.001**	**0.003**	0.26*** (0.19–0.34)	**< 0.001**	**< 0.001**
Knowledge—Eating habits	−0.35 (−0.75 to 0.06)	0.095	0.283	−0.21 (−0.51 to 0.10)	0.181	0.543	−0.26 (−0.58 to 0.05)	0.101	0.266	0.08 (−0.28 to 0.45)	0.66	0.866
Knowledge—NCDs	−0.2 (−0.52 to 0.12)	0.228	0.478	−0.31 (−0.55 to −0.07)	**0.011**	0.076	−0.38* (−0.63 to −0.13)	**0.003**	**0.023**	−0.18 (−0.47 to 0.11)	0.223	0.52
Knowledge—Food groups	0.25 (−0.10 to 0.59)	0.165	0.384	0.03 (−0.23 to 0.28)	0.848	0.977	0.22 (−0.05 to 0.49)	0.116	0.287	−0.03 (−0.34 to 0.28)	0.855	0.921
Attitude—Benefits	0.59* (0.19 to 0.98)	**0.004**	**0.03**	0.01 (−0.28 to 0.31)	0.925	0.977	0.1 (−0.20 to 0.41)	0.501	0.702	−0.48 (−0.84 to −0.13)	**0.008**	0.054
Attitude—Barriers	0.16 (−0.15 to 0.47)	0.305	0.53	−0.03 (−0.26 to 0.20)	0.777	0.977	0.06 (−0.18 to 0.30)	0.626	0.796	−0.1 (−0.38 to 0.18)	0.474	0.82
Attitude—Susceptibility	0.16 (−0.05 to 0.37)	0.131	0.345	0 (−0.16 to 0.16)	0.999	0.999	0.03 (−0.14 to 0.19)	0.754	0.905	−0.13 (−0.32 to 0.05)	0.16	0.431
Practices—Eating	0.05 (−0.33 to 0.44)	0.782	0.865	−0.03 (−0.32 to 0.26)	0.824	0.977	−0.05 (−0.35 to 0.25)	0.738	0.905	−0.11 (−0.46 to 0.24)	0.551	0.864
Practices—Readiness	0.15 (−0.11 to 0.40)	0.257	0.491	0.28* (0.09–0.47)	**0.004**	**0.032**	0.37** (0.17–0.57)	**< 0.001**	**0.005**	0.22 (−0.01 to 0.45)	0.063	0.265
Practices—Peers	−0.12 (−0.54 to 0.30)	0.586	0.745	0.34 (0.03–0.66)	**0.031**	0.161	0.29 (−0.04 to 0.62)	0.084	0.247	0.4 (0.03–0.78)	**0.036**	0.188
Practices—Family	0.53* (0.20–0.86)	**0.002**	**0.02**	0.22 (−0.02 to 0.47)	0.077	0.293	0.29 (0.03–0.55)	**0.027**	0.115	−0.24 (−0.54 to 0.06)	0.122	0.427
Observations	409			409			409			409		
R^2/R^2 adjusted	0.202/0.113			0.286/0.206			0.260/0.177			0.311/0.234		

Note: p, *p*-value; *q*-value, FDR adjusted *p*-value using the Benjamini–Hochberg procedure. Models were adjusted for age, sex, wealth quintile, religion, ethnicity, maternal education, marital status of the mother, residency of the child (e.g., living with parents or caretaker) and school.

Abbreviations: FGDS, Food Group Diversity Score; GDR, Global Dietary Recommendations; KAP, Knowledge, Attitude and Practices; NCD, non-communicable disease.

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

TABLE 4 | Regression results for multinomial logistic regression models, ref = Champions (positive deviants).

	Challenger		Struggler	
Predictors	**Odds ratios (95% CI)**	***p*-value**	**Odds ratios (95% CI)**	***p*-value**
Total budget	1.07 (0.98–1.16)	0.145	0.88** (0.82–0.95)	0.001
Knowledge score	1.06 (0.85–1.32)	0.604	1.08 (0.90–1.28)	0.418
Attitude score	0.63* (0.45–0.90)	0.011	0.84 (0.64–1.12)	0.240
Practices score	0.76 (0.58–1.00)	0.050	0.66*** (0.53–0.83)	< 0.001
Observations	385			
R^2/R^2 adjusted	0.192/0.189			

Note: Parentheses show 95% confidence intervals (CI); *p*, *p*-value. Models were adjusted for age, sex, wealth quintile, religion, ethnicity, maternal education, marital status of the mother, residency of the child (e.g., living with parents or caretaker) and school.
$^*p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

TABLE 5 | Regression results for multinomial logistic regression models, ref = Champions (positive deviants).

	Challenger		Struggler	
Predictors	**Odds ratios (95% CI)**	***p*-value**	**Odds ratios (95% CI)**	***p*-value**
Breakfast budget	1.01 (0.86–1.17)	0.948	0.85* (0.74–0.97)	0.013
Lunch budget	1.11 (0.93–1.34)	0.241	0.90 (0.77–1.04)	0.153
Snacks budget	1.13 (0.95–1.34)	0.159	0.90 (0.77–1.04)	0.150
Knowledge—Eating habits	0.95 (0.40–2.24)	0.912	0.87 (0.43–1.75)	0.695
Knowledge—NCDs	1.96 (0.95–4.05)	0.068	2.19* (1.21–3.98)	0.010
Knowledge—Food groups	0.79 (0.39–1.61)	0.518	0.74 (0.42–1.31)	0.298
Attitude—Benefits	0.41* (0.17–0.99)	0.047	0.57 (0.28–1.16)	0.120
Attitude—Barriers	0.64 (0.32–1.26)	0.196	0.70 (0.40–1.20)	0.193
Attitude—Susceptibility	0.79 (0.50–1.25)	0.319	1.18 (0.81–1.72)	0.383
Practices—Eating	0.76 (0.32–1.78)	0.524	0.71 (0.37–1.39)	0.320
Practices—Readiness	0.76 (0.43–1.33)	0.338	0.59* (0.37–0.94)	0.027
Practices—Peers	1.23 (0.51–2.99)	0.647	0.67 (0.32–1.40)	0.281
Practices—Family	0.48* (0.23–1.00)	0.049	0.62 (0.33–1.14)	0.122
Observations	385			
R^2/R^2 adjusted	0.216/0.213			

Note: Parentheses show 95% confidence intervals (CI); *p*, *p*-value. Models were adjusted for age, sex, wealth quintile, religion, ethnicity, maternal education, marital status of the mother, residency of the child (e.g., living with parents or caretaker) and school.
Abbreviations: FGDS, Food Group Diversity Score; GDR, Global Dietary Recommendations; KAP, Knowledge, Attitude and Practices; NCD, non-communicable disease.
$^*p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

income-countries (Gillman, 2000; Neumark-Sztainer et al. 2008; Nicklas et al. 2001; Patrick and Nicklas 2005) and low-middle-income countries (Glanz et al. 2021; Sedibe et al. 2018; Sirasa et al. 2019). The role of peer practices was less pronounced, both in this study and in the literature. Conceptually, the food intake of adolescents is related to peer values or social norms (Contento et al. 2006; Stok et al. 2016). While empirical, qualitative studies on this subject highlight the importance of peer norms generally, they emphasise the budgetary constraint to be more dominant (Holdsworth et al. 2020; Liguori et al. 2022).

Of note is the reported negative association of knowledge of NCDs and favourable food groups (FGDS and NCD-Protect). Several factors could explain this counterintuitive finding: For one, individuals with lower scores in favourable food groups could be externally targeted by nutrition knowledge interventions. Additionally, individuals with lower scores in favourable food groups may also have to think about their food choices more thoroughly and regularly than those with high favourable food group intake, thereby increasing competency on nutrition. Finally, individuals with higher scores in favourable food groups could be 'ignorant' of some of the NCD-related facts, because consuming less unfavourable foods may lead to less domain knowledge of diet-related NCD risks.

Our third key finding is that Nutrition Champions—the positive deviants, who exhibited low intake of NCD-Risk and relatively higher intake of NCD-Protect food groups—did not have higher food budget than their counterparts (Nutrition Challengers) but differ in attitude and practice scores. These findings were driven by the higher sub-components of attitudes towards benefits of healthy eating and family practices, respectively. A study from France using a positive deviance approach has documented higher nutritional quality at no additional cost within a low-income group (Marty et al. 2015), suggesting that some improvement in diet quality can be achieved without increasing cost. Similar to a recent study from Nepal, which documented positive deviants (with a higher dietary diversity score) to be more engaged in joint family practices such as preparing meals (Shahi et al. 2023), we also found that positive deviants have higher family practice scores. Notably, the number of positive deviants was fairly low (13%), indicating that only a few students managed to strike a favourable balance in their food group intake.

This study has several strengths: We based our findings on a quantified analysis of both economic and behavioural drivers and used an extensive set of covariates (behavioural and socioeconomic). We also included dietary intake measurements for both favourable and unfavourable dietary patterns and focused on JHS students in Accra, who (have to) purchase much of their own food. However, despite these strengths, some limitations remain. The data on dietary intake, background characteristics and KAP details were all based on self-reported measurements, which could introduce some bias. Second, dietary intake was collected based on the DQQ methodology. This means that frequency dietary intake was only collected at the food group level and may not be analysed beyond that. Furthermore, we also did not collect any information on portion size, which may explain some variation in diet quality. However, existing evidence from other countries indicates that portion size adds limited information in explaining variation in diet quality (Nöthlings et al. 2003). As the suite of indicators derived from the DQQ do not require portion size, we consider it to be sufficiently granular enough for the purpose of our study. Finally, despite the number of covariates included in the study, some residual confounding could still occur.

The findings of this study coherently spell out a need for double-duty actions in Accra and comparable urban areas in sub-Saharan Africa: JHS students in Accra typically carry money with them and spend it mainly (both by majority of students and by majority of money spent) on foods that are considered risk factors for NCDs. At the same time, nearly one-third of the girls in the study cohort do not consume a diet that is minimally diverse (MDD-W) and will likely not meet requirements for micronutrient density.

Policy interventions could regulate foods sold and consumed on school grounds during school time, which falls under the mandate of the school health authorities (School Health Education Programme). Another opportunity lies in the current national effort to develop four double-duty food-based policy bundles – comprising a front-of-pack warning label, marketing restrictions, public food procurement and ultra-processed food taxation (Laar et al. 2023). Public food procurement (done by, or with oversight from government and other public sector agencies) in programmes such as school meals can help in creating a healthy school food environment, especially when they are aligned with Food Based Dietary Guidelines (Ministry of Food and Agriculture, & University of Ghana School of Public Health, 2023). Targeted subsidies and taxes for foods sold at schools could encourage a more favourable diversity in consumption. Identifying the best intervention and policy design may require localised research and testing different approaches. More research needs to be directed towards the decision making around food purchases of adolescents in their specific food environment (Pradeilles et al. 2021), to leverage the opportunity this age group has for public health over the course of their lifetime.

5 | Conclusion

Higher budget for food was associated with food group diversity but not with improved diet quality. Favourable and unfavourable dietary patterns were associated with different drivers. While beneficial practices were linked to increased intake of favourable food groups, positive attitudes towards nutrition are linked to moderation of unfavourable food groups. With these dynamics, it is paramount for policy makers and programme implementers to pursue double-duty actions regarding healthy diets. This means to ensure that favourable foods are more readily available, accessible and affordable for consumption while supporting moderation of unfavourable foods. Given the critical role that adolescents play in public health, ensuring healthy options tailored to their own budget are available should be the first step to improve their dietary intake.

Author Contributions

Janosch Klemm, Christian Borgemeister and Ute Nöthlings designed the research study and contributed to protocol development. Janosch Klemm led the data collection and management. Janosch Klemm analysed the data with support from Samuel Muli. Samuel Muli, Kolade Oluwagbemigun, Martin Parlasca, Aba Crentsil, Deda Ogum and Ute Nöthlings contributed to research methodology and validation. Janosch Klemm, Samuel Muli, Kolade Oluwagbemigun and Martin Parlasca wrote the first draft of the paper. Aba Crentsil, Deda Ogum, Peter Quartey, Amos Laar, Anna Lartey, Christian Borgemeister and Ute Nöthlings reviewed and critically revised the paper. All authors have read and approved the final manuscript.

Acknowledgements

The authors would like to thank all study participants and staff members of the Ghana Education Service for providing support to the study and granting access to the study sites, in particular: Dorcas Hushie, Ernest Amoah Ampah, Theresa Oppong Mensah, Patrick Banafo, Stephen Abanfo, Kwabena Bempah Tandoh, Cynthia Nyarko, Grace Homiah, and Philipina Tupper, as well as all teachers who supported the data collection at the schools visited. We would like to thank all enumerators active in the data collection and research assistant Kezia Dampare. Thank you to Linus Linnaeus Tannor for his guidance and help during the design phase of the survey. We are grateful to two anonymous reviewers for their comments and suggestions. This analysis was funded by the University of Bonn, the University of Applied Sciences Bonn-Rhein-Sieg and the Ministry of Culture and Science of North Rhine-Westphalia, Germany, through the Forschungskolleg 'One Health and Urban Transformation'. The funders had no role in study design, data collection and analysis, decision to publish or preparation of the manuscript. Open Access funding enabled and organized by Projekt DEAL.

Ethics Statement

Ethical approval for the study was received from the Ghana Health Service Ethics Review Committee (GHS-ERC 021/08/22), the University of Ghana, Legon (ECH 064/22-23), and the Center of Development Research Ethics Committee (15c_22).

Consent

Written consent of legal guardians was obtained for all participants under the age of 18. Written assent of all participants was obtained before being interviewed.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Data will be made available upon reasonable request. The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

References

Abizari, A. R., and Z. Ali. 2019. "Dietary Patterns and Associated Factors of Schooling Ghanaian Adolescents." *Journal of Health, Population, and Nutrition* 38, no. 1: 5. https://doi.org/10.1186/s41043-019-0162-8.

Afshin, A., P. J. Sur, K. A. Fay, et al. 2019. "Health Effects of Dietary Risks in 195 Countries, 1990–2017: A Systematic Analysis for the Global Burden of Disease Study 2017." *The Lancet* 393, no. 10184: 1958–1972. https://doi.org/10.1016/S0140-6736(19)30041-8.

ALjaraedah, T. Y., H. R. Takruri, and R. F. Tayyem. 2019. "Dietary Practices and Nutrient Intake Among Adolescents: A General Review." *Obesity Medicine* 16: 100–145. https://doi.org/10.1016/j.obmed.2019.100145.

Amoore, B. Y., P. K. Gaa, A. Amalba, and V. Mogre. 2023. "Nutrition Education Intervention Improves Medical Students' Dietary Habits and Their Competency and Self-Efficacy in Providing Nutrition Care: A Pre, Post and Follow-Up Quasi-Experimental Study." *Frontiers in Nutrition* 10: 1063316. https://doi.org/10.3389/fnut.2023.1063316.

Arimond, M., D. Wiesmann, and S. Rodríguez Ramírez, et al. 2021. *Food Group Diversity and Nutrient Adequacy: Dietary Diversity as a Proxy for Micronutrient Adequacy for Different Age and Sex Groups in Mexico and China*. Geneva: The Global Alliance for Improved Nutrition (GAIN). https://doi.org/10.36072/dp.9.

Bean, M. K., K. S. Ingersoll, P. Powell, et al. 2018. "Impact of Motivational Interviewing on Outcomes of an Adolescent Obesity Treatment: Results From the MI Values Randomized Controlled Pilot Trial." *Clinical Obesity* 8, no. 5: 323–326. https://doi.org/10.1111/cob.12257.

Benjamini, Y., and Y. Hochberg. 1995. "Controlling the False Discovery Rate: A Practical and Powerful Approach to Multiple Testing." *Journal of the Royal Statistical Society Series B: Statistical Methodology* 57, no. 1: 289–300. https://www.jstor.org/stable/2346101.

Bouis, H. E., P. Eozenou, and A. Rahman. 2011. "Food Prices, Household Income, and Resource Allocation: Socioeconomic Perspectives on Their Effects on Dietary Quality and Nutritional Status." *Food and Nutrition Bulletin* 32, no. 1: S14–S23. https://doi.org/10.1177/15648265110321S103.

Brennan, S. F., F. Lavelle, S. E. Moore, et al. 2021. "Food Environment Intervention Improves Food Knowledge, Wellbeing and Dietary Habits in Primary School Children: Project Daire, a Randomised-Controlled, Factorial Design Cluster Trial." *International Journal of Behavioral Nutrition and Physical Activity* 18, no. 1: 23. https://doi.org/10.1186/s12966-021-01086-y.

Campbell, K. J., G. Abbott, A. C. Spence, D. A. Crawford, S. A. McNaughton, and K. Ball. 2013. "Home Food Availability Mediates Associations Between Mothers' Nutrition Knowledge and Child Diet." *Appetite* 71: 1–6. https://doi.org/10.1016/j.appet.2013.07.006.

Censi, L., A. Spinelli, R. Roccaldo, et al. 2013. "Dressed or Undressed? How to Measure Children's Body Weight in Overweight Surveillance." *Public Health Nutrition* 17, no. 12: 2715–2720. https://doi.org/10.1017/S1368980013003030.

Chakraborty, N. M., K. Fry, R. Behl, and K. Longfield. 2016. "Simplified Asset Indices to Measure Wealth and Equity in Health Programs: A Reliability and Validity Analysis Using Survey Data From 16 Countries." *Global Health: Science and Practice* 4, no. 1: 141–154. https://doi.org/10.9745/GHSP-D-15-00384.

Colen, L., P. C. Melo, Y. Abdul-Salam, D. Roberts, S. Mary, and S. Gomez Y Paloma. 2018. "Income Elasticities for Food, Calories and Nutrients Across Africa: A Meta-Analysis." *Food Policy* 77: 116–132. https://doi.org/10.1016/j.foodpol.2018.04.002.

Colozza, D. 2024. "A Qualitative Exploration of Ultra-Processed Foods Consumption and Eating Out Behaviours in an Indonesian Urban Food Environment." *Nutrition and Health* 30: 613–623. https://doi.org/10.1177/02601060221133897.

Contento, I. R., S. S. Williams, J. L. Michela, and A. B. Franklin. 2006. "Understanding the Food Choice Process of Adolescents in the Context of Family and Friends." *Journal of Adolescent Health* 38, no. 5: 575–582. https://doi.org/10.1016/j.jadohealth.2005.05.025.

Cutler, G. J., A. Flood, P. Hannan, and D. Neumark-Sztainer. 2011. "Multiple Sociodemographic and Socioenvironmental Characteristics Are Correlated With Major Patterns of Dietary Intake in Adolescents." *Journal of the American Dietetic Association* 111, no. 2: 230–240. https://doi.org/10.1016/j.jada.2010.10.052.

Fanzo, J., and C. Davis. 2021. *Global Food Systems, Diets and Nutrition. Linking Science, Economics and Policy*. Geneva: Palgrave Studies in Agricultural Economics and Food Policy. https://doi.org/10.1007/978-3-030-72763-5.

Fanzo, J., L. Haddad, and R. McLaren, et al. 2020. "The Food Systems Dashboard Is a New Tool to Inform Better Food Policy." *Nature Food* 1: 243–246.

Fautsch Macías, Y., and P. Glasauer. 2014. *Guidelines for Assessing Nutrition-Related Knowledge, Attitudes and Practices: KAP Manual*. Geneva: Food and Agriculture Organization of the United Nations. https://www.fao.org/3/i3545e/i3545e00.htm.

Fernandes, M., G. Folson, E. Aurino, and A. Gelli. 2017. "A Free Lunch or a Walk Back Home? The School Food Environment and Dietary Behaviours Among Children and Adolescents in Ghana." *Food Security* 9, no. 5: 1073–1090. https://doi.org/10.1007/s12571-017-0712-0.

Fitzgerald, A., C. Heary, C. Kelly, E. Nixon, and M. Shevlin. 2013. "Self-Efficacy for Healthy Eating and Peer Support for Unhealthy Eating Are Associated With Adolescents' Food Intake Patterns." *Appetite* 63: 48–58. https://doi.org/10.1016/j.appet.2012.12.011.

French, S. A., C. C. Tangney, M. M. Crane, Y. Wang, and B. M. Appelhans. 2019. "Nutrition Quality of Food Purchases Varies by Household Income: The SHoPPER Study." *BMC Public Health* 19, no. 1: 231. https://doi.org/10.1186/s12889-019-6546-2.

Ganle, J. K., P. P. Boakye, and L. Baatiema. 2019. "Childhood Obesity in Urban Ghana: Evidence From a Cross-Sectional Survey of In-School Children Aged 5–16 Years." *BMC Public Health* 19, no. 1: 1561. https://doi.org/10.1186/s12889-019-7898-3.

Ghana Statistical Service. 2015. *Ghana Demographic and Health Survey 2014*. Ghana: DHS. https://dhsprogram.com/publications/publication-fr307-dhs-final-reports.cfm.

Ghana Statistical Service. 2022. *Ghana 2021 Population and Housing Census*. Ghana: DHS.

Gillman, M. W. 2000. "Family Dinner and Diet Quality Among Older Children and Adolescents." *Archives of Family Medicine* 9, no. 3: 235–240. https://doi.org/10.1001/archfami.9.3.235.

Glanz, K., J. J. Metcalfe, S. C. Folta, A. Brown, and B. Fiese. 2021. "Diet and Health Benefits Associated With In-Home Eating and Sharing Meals at Home: A Systematic Review." *International Journal of*

Environmental Research and Public Health 18, no. 4: 1–20. https://doi.org/10.3390/ijerph18041577.

Global Alliance for Improved Nutrition (GAIN). 2020. *Urban Food Environments in Low-and Middle-Income Countries*. Geneva: GAIN. https://www.gainhealth.org/sites/default/files/publications/documents/urban-governance-for-nutrition-programme-factsheet.pdf.

Herforth, A. W., D. Wiesmann, E. Martínez-Steele, G. Andrade, and C. A. Monteiro. 2020. "Introducing a Suite of Low-Burden Diet Quality Indicators That Reflect Healthy Diet Patterns at Population Level." *Current Developments in Nutrition* 4, no. 12: nzaa168. https://doi.org/10.1093/cdn/nzaa168.

HLPE. 2017. "Nutrition and Food Systems. A Report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security." www.fao.org/cfs/cfs-hlpe.

Holdsworth, M., R. Pradeilles, A. Tandoh, et al. 2020. "Unhealthy Eating Practices of City-Dwelling Africans in Deprived Neighbourhoods: Evidence for Policy Action From Ghana and Kenya." *Global Food Security* 26: 100452. https://doi.org/10.1016/j.gfs.2020.100452.

Iyassu, A., A. Laillou, K. Tilahun, et al. 2024. "The Influence of Adolescents' Nutrition Knowledge and School Food Environment on Adolescents' Dietary Behaviors in Urban Ethiopia: A Qualitative Study." *Maternal & Child Nutrition* 20, no. Suppl 5: 13527. https://doi.org/10.1111/mcn.13527.

Karanja, A., A. Ickowitz, B. Stadlmayr, and S. McMullin. 2022. "Understanding Drivers of Food Choice In Low- and Middle-Income Countries: A Systematic Mapping Study." *Global Food Security* 32: 100615. https://doi.org/10.1016/j.gfs.2022.100615.

Kullen, C., L. Mitchell, H. T. O'Connor, J. A. Gifford, and K. L. Beck. 2022. "Effectiveness of Nutrition Interventions on Improving Diet Quality and Nutrition Knowledge in Military Populations: A Systematic Review." *Nutrition Reviews* 80, no. 6: 1664–1693.

Kupka, R., K. Siekmans, and T. Beal. 2020. "The Diets of Children: Overview of Available Data for Children and Adolescents." *Global Food Security* 26: 100402. https://doi.org/10.1016/j.gfs.2020.100402.

Kushitor, S. B., D. O. Alangea, R. Aryeetey, and A. de-Graft Aikins. 2023. "Dietary Patterns Among Adults in Three Lowincome Urban Communities in Accra, Ghana." *PLoS One* 18, no. 11: 0293726. https://doi.org/10.1371/journal.pone.0293726.

Laar, A., J. M. Amoah, L. M. Massawudu, et al. 2023. "Making Food-Related Health Taxes Palatable in Sub-Saharan Africa: Lessons From Ghana." *BMJ Global Health* 8: e012154. https://doi.org/10.1136/bmjgh-2023-012154.

Landais, E., M. Miotto-Plessis, C. Bene, et al. 2023. "Consumption of Food Away From Home in Low- and Middle-Income Countries: A Systematic Scoping Review." *Nutrition Reviews* 81, no. 6: 727–754. https://doi.org/10.1093/nutrit/nuac085.

Li, L., N. Sun, L. Zhang, et al. 2020. "Fast Food Consumption Among Young Adolescents Aged 12–15 Years in 54 Low- and Middle-Income Countries." *Global Health Action* 13, no. 1. https://doi.org/10.1080/16549716.2020.1795438.

Liguori, J., R. Pradeilles, and A. Laar, et al. 2022. "Individual-Level Drivers of Dietary Behaviour in Adolescents and Women Through the Reproductive Life Course in Urban Ghana: A Photovoice Study." *Maternal & Child Nutrition* 18, no. 4: 1795438.

Madzorera, I., S. Bromage, and M. Mwanyika-Sando, et al. 2023. "Dietary Intake and Quality for Young Adolescents in Sub-Saharan Africa: Status and Influencing Factors." *Maternal & Child Nutrition* 4: e13463.

Manggabarani, S., I. Said, A. J. Hadi, R. Saragih, M. Cristandy, and N. E. Januariana. 2020. "The Effectivity of Peer Education Module on Knowledge, Attitude, and Fast Food Consumption in Adolescents." *Journal of Health Promotion and Behavior* 5, no. 1: 35–43. https://doi.org/10.26911/thejhpb.2020.05.01.05.

Marty, L., C. Dubois, M. S. Gaubard, et al. 2015. "Higher Nutritional Quality at No Additional Cost Among Low-Income Households: Insights From Food Purchases of 'Positive Deviants'." *The American Journal of Clinical Nutrition* 102, no. 1: 190–198. https://doi.org/10.3945/ajcn.114.104380.

Ministry of Food and Agriculture, and University of Ghana School of Public Health. 2023. "Food-Based Dietary Guidelines 2023." https://mofa.gov.gh/site/images/pdf/Ghana_Food_Based_Dietary_Guidelines_2023.pdf.

Mockshell, J., S. O. Ogutu, D. Álvarez, C. Asante-Addo, and F. A. Asante. 2022. "How Healthy and Food Secure Is the Urban Food Environment in Ghana." *World Development Perspectives* 26: 100427. https://doi.org/10.1016/j.wdp.2022.100427.

Moitra, P., P. Verma, and J. Madan. 2021. "Development and Validation of a Questionnaire Measuring Knowledge, Attitudes, and Practices (KAP) to Healthy Eating and Activity Patterns in School Children (Heaps)." *Nutrition and Health* 27, no. 2: 199–209. https://doi.org/10.1177/0260106020982356.

Monteiro, C. A., J. C. Moubarac, G. Cannon, S. W. Ng, and B. Popkin. 2013. "Ultra-Processed Products Are Becoming Dominant in the Global Food System." *Obesity Reviews* 14, no. S2: 21–28. https://doi.org/10.1111/obr.12107.

Muhammad, A., A. D'Souza, B. Meade, R. Micha, and D. Mozaffarian. 2017. "How Income and Food Prices Influence Global Dietary Intakes by Age and Sex: Evidence From 164 Countries." *BMJ Global Health* 2, no. 3: e000184. https://doi.org/10.1136/bmjgh-2016-000184.

Neumark-Sztainer, D., M. E. Eisenberg, J. A. Fulkerson, M. Story, and N. I. Larson. 2008. "Family Meals and Disordered Eating in Adolescents Longitudinal Findings From Project EAT." *Archives of Pediatrics and Adolescent Medicine* 162, no. 1: 17–22. https://doi.org/10.1001/archpediatrics.2007.9.

Nicklas, T. A., T. Baranowski, K. W. Cullen, and G. Berenson. 2001. "Eating Patterns, Dietary Quality and Obesity." *Journal of the American College of Nutrition* 20, no. 6: 599–608. https://doi.org/10.1080/07315724.2001.10719064.

Nöthlings, U., K. Hoffmann, M. M. Bergmann, and H. Boeing. 2003. "Portion Size Adds Limited Information on Variance in Food Intake of Participants in the EPIC-Potsdam Study." *The Journal of Nutrition* 133, no. 2: 510–515. https://doi.org/10.1093/jn/133.2.510.

Norris, S. A., E. A. Frongillo, M. M. Black, et al. 2022. "Nutrition in Adolescent Growth and Development." *The Lancet* 399, no. 10320: 172–184. https://doi.org/10.1016/S0140-6736(21)01590-7.

Ogum-Alangea, D., R. N. O. Aryeetey, H. L. Gray, A. K. Laar, and R. M. K. Adanu. 2020. "Basic School Pupils' Food Purchases During Mid-Morning Break in Urban Ghanaian Schools." *PLoS One* 15, no. 9: e0238308. https://doi.org/10.1371/journal.pone.0238308.

Oyewande, A., A. Ademola, T. Okuneye, F. Sanni, A. Hassan, and P. Olaiya. 2019. "Knowledge, Attitude and Perception Regarding Risk Factors of Overweight and Obesity Among Secondary School Students in Ikeja Local Government Area, Nigeria." *Journal of Family Medicine and Primary Care* 8, no. 4: 1391. https://doi.org/10.4103/jfmpc.jfmpc_160_19.

Patrick, H., and T. A. Nicklas. 2005. "A Review of Family and Social Determinants of Children's Eating Patterns and Diet Quality." *Journal of the American College of Nutrition* 24, no. 2: 83–92. https://doi.org/10.1080/07315724.2005.10719448.

Pechey, R., and P. Monsivais. 2016. "Socioeconomic Inequalities in the Healthiness of Food Choices: Exploring the Contributions of Food Expenditures." *Preventive Medicine* 88: 203–209. https://doi.org/10.1016/j.ypmed.2016.04.012.

Peters, L. W. H., C. H. Wiefferink, F. Hoekstra, G. J. Buijs, G. T. M. Ten Dam, and T. G. W. M. Paulussen. 2008. "A Review of Similarities Between Domain-Specific Determinants of Four Health

Behaviors Among Adolescents." *Health Education Research* 24, no. 2: 198–223. https://doi.org/10.1093/her/cyn013.

Pradeilles, R., A. Irache, M. N. Wanjohi, et al. 2021. "Urban Physical Food Environments Drive Dietary Behaviours in Ghana and Kenya: A Photovoice Study." *Health & Place* 71: 102647. https://doi.org/10.1016/j.healthplace.2021.102647.

Qiao, J., X. Lin, Y. Wu, et al. 2022. "Global Burden of Non-Communicable Diseases Attributable to Dietary Risks in 1990–2019." *Journal of Human Nutrition and Dietetics* 35, no. 1: 202–213. https://doi.org/10.1111/jhn.12904.

Sambu, W. C., F. Picchioni, S. Stevano, E. A. Codjoe, P. K. Nkegbe, and C. Turner. 2024. "Food Systems Thinking Unpacked: A Scoping Review on Industrial Diets Among Adolescents in Ghana." *Food Security* 16, no. 1: 79–114.

Sedibe, M., P. Pisa, A. Feeley, T. Pedro, K. Kahn, and S. Norris. 2018. "Dietary Habits and Eating Practices and Their Association With Overweight and Obesity in Rural and Urban Black South African Adolescents." *Nutrients* 10, no. 2: 145. https://doi.org/10.3390/nu10020145.

Shahi, P. V., R. M. Shrestha, P. Schreinemachers, et al. 2023. "Identifying Positive and Negative Deviants and Factors Associated With Healthy Dietary Practices Among Young Schoolchildren in Nepal: A Mixed Methods Study." *BMC Nutrition* 9, no. 1: 42. https://doi.org/10.1186/s40795-023-00700-5.

Sirasa, F., L. J. Mitchell, R. Rigby, and N. Harris. 2019. "Family and Community Factors Shaping the Eating Behaviour of Preschool-Aged Children in Low and Middle-Income Countries: A Systematic Review of Interventions." *Preventive Medicine* 129: 105827. https://doi.org/10.1016/j.ypmed.2019.105827.

Springmann, M., M. Clark, D. Mason-D'Croz, et al. 2018. "Options for Keeping the Food System Within Environmental Limits." *Nature* 562, no. 7728: 519–525. https://doi.org/10.1038/s41586-018-0594-0.

Stok, F. M., E. de Vet, D. T. D. de Ridder, and J. B. F. de Wit. 2016. "The Potential of Peer Social Norms to Shape Food Intake in Adolescents and Young Adults: A Systematic Review of Effects and Moderators." *Health Psychology Review* 10, no. 3: 326–340. https://doi.org/10.1080/17437199.2016.1155161.

Tabbakh, T., and J. H. Freeland-Graves. 2016. "The Home Environment: A Mediator of Nutrition Knowledge and Diet Quality in Adolescents." *Appetite* 105: 46–52. https://doi.org/10.1016/j.appet.2016.05.002.

Uyar, B. T. M., E. F. Talsma, A. W. Herforth, et al. 2023. "The DQQ Is a Valid Tool to Collect Population-Level Food Group Consumption Data: A Study Among Women in Ethiopia, Vietnam, and Solomon Islands." *The Journal of Nutrition* 153: 340–351. https://doi.org/10.1016/j.tjnut.2022.12.014.

Wang, H., A. W. Herforth, B. Xi, and Z. Zou. 2022. "Validation of the Diet Quality Questionnaire in Chinese Children and Adolescents and Relationship With Pediatric Overweight and Obesity." *Nutrients* 14, no. 17: 3551. https://doi.org/10.3390/nu14173551.

Weil, K., I. Coulibaly, H. Fuelbert, A. Herrmann, R. M. Millogo, and I. Danquah. 2023. "Dietary Patterns and Their Socioeconomic Factors of Adherence Among Adults in Urban Burkina Faso: A Cross-Sectional Study." *Journal of Health, Population, and Nutrition* 42, no. 1: 107. https://doi.org/10.1186/s41043-023-00451-w.

Westbury, S., I. Ghosh, H. M. Jones, et al. 2021. "The Influence of the Urban Food Environment on Diet, Nutrition and Health Outcomes in Low-Income and Middle-Income Countries: A Systematic Review." *BMJ Global Health* 6, no. 10: e006358. https://doi.org/10.1136/bmjgh-2021-006358.

Wrottesley, S. V., E. Mates, and E. Brennan, et al. 2023. "Nutritional Status of School-Age Children and Adolescents in Low- and Middle-Income Countries Across Seven Global Regions: A Synthesis of Scoping Reviews." *Public Health Nutrition* 26, no. 1: 63–95. https://doi.org/10.1017/S1368980022000350.

Supporting Information

Additional supporting information can be found online in the Supporting Information section.

Appendix

TABLE A1 | Questions and corresponding groups from the KAP survey (based on Moitra, Verma, and Madan 2021 and Fautsch Macías, Glasauer, and Food and Agriculture Organization of the United Nations 2014).

	Sub-group	Questions
Knowledge (0–12)	Knowledge about NCDs (0–4)	– What are the health problems that can occur when a person is overweight or obese?
		– Can you tell me some reasons why people might be overweight or obese?
		– How can people prevent overweight and obesity?
	Knowledge about food groups (0–4)	– Which food groups should take the most space on your plate?
		– How many servings of fruit and vegetables should children consume per day?
		– Which foods should make up the smallest part of your diet?
	Knowledge about healthy eating (0–4)	– Some children do not have breakfast before going to school and are hungry in class. What is the consequence for children of not having breakfast and being hungry at school?
		– Why should parents discourage sticky and sugar-rich foods, such as sweets and candies? (Why is it so bad to eat too many sweets and candies?)
		– What are healthy alternatives to Sugar-Sweetened Beverages?
Attitude (0-12)	Perceived susceptibility (0–4)	– I will get diseases if I don't eat healthily
		– I am worried about becoming Overweight/Obese
		– I am worried about getting Diabetes
		– I am worried about getting heart diseases
	Perceived benefits (0–4)	– Healthy Eating can reduce the risk of diseases
		– Eating fruits can help you fight infections
		– Eating vegetables can help you lose weight
		– Regular breakfast helps improve being alert
	Perceived barriers (0–4)	– It is difficult to eat two (2) fruits every day
		– I am not sure what and how much I should eat
		– I typically do not have enough money for eating fresh fruits
		– There are no healthy food options offered in and around school
Practices (0–12)	Readiness to change (0–3)	– I try to eat breakfast everyday
		– I try to eat two pieces of fruit everyday
		– I want to improve my eating habits
		– I would like to drink less soft drinks
	Peer habits (0–3)	– In the last 7 days, how often did you and your friends - eat breakfast together away from home
		– In the last 7 days, how often did you and your friends - eat a mid-morning snack together
		– In the last 7 days, how often did you and your friends - eat lunch together away from home/at or around school
		– In the last 7 days, how often did you and your friends - eat dinner together away from home
	Family habits (0–3)	– In the last 7 days, how often did you and your FAMILY - eat out at a restaurant/order take away?
		– In the last 7 days, how often did you and your FAMILY - eat a home-cooked evening meal together at home?
		– In the last 7 days, how often did you and your FAMILY - eat breakfast together at home?
		– In the last 7 days, how often did you and your FAMILY - eat lunch together at home/send you with packed lunch to school?
	Eating patterns (0–3)	– In a normal school week (5 days) how often do you have breakfast before leaving for school?
		– In a normal school week (5 days) how often do you bring your lunch to school?
		– In a normal school week (5 days) how often do you skip a meal?

Abbreviation: NCD, Non-Communicable Diseases.

Study IV: School food environment and adolescents' diets in Ghana

School food environments and adolescents' diets. Evidence from Ghana

Janosch Klemm, Hannah Ameye, Martin Parlasca, Samuel Muli, Amos Laar, Anna Lartey, Christian Borgemeister, Matin Qaim, Ute Nöthlings

Under review at Health and Place - JHAP-D-25-00629

School food environments and adolescents' diets: Evidence from Ghana

Highlights

- Food environments around schools influence adolescents' diets.
- Unfavourable food groups are more likely to be consumed in and around schools, favourable food groups are more frequently consumed at home.
- Vendors nearer to schools sell a larger variety of both favourable and unfavourable food groups than vendors farther away.
- Higher prices of unfavourable food groups around schools are associated with reduced consumption and improved diet quality.
- School health policies should consider regulation of food prices and availability in school food environments.

Abstract

The food environment influences diet quality. Despite emerging evidence, effects on students in low- and middle-income countries are not yet well understood. Here, we evaluate how school food environments are associated with diet quality of junior high school students in Accra, Ghana. Using a cross-sectional design, we collected market information from 1,340 food vendors around 12 schools and dietary and socio-economic details from 409 students. Within a 300-meter radius from schools, nearly 60% of the vendors sell at least one type of food associated with a heightened risk for non-communicable diseases (NCD-Risk). Around 40% of vendors sell at least one item that is considered protective against non-communicable diseases (NCD-Protect). Students tend to consume more unfavourable foods at school than at home. We show that food environment indicators are associated with students' diet intake at school, also after accounting for potential confounders. Higher prices are associated with reduced consumption of both NCD-Risk and NCD-Protect foods. Our findings suggest that regulation of school food environments can improve diet quality among students.

1. Introduction

Food environments are receiving increased attention regarding their impact on individual diet quality and shaping access to healthy, nutritious foods (Global Alliance for Improved Nutrition [GAIN], 2020). Although the precise definition varies across different conceptual frameworks, the food environment typically describes the part of the food system where supply meets demand in the form of individuals acquiring their foods (Downs et al., 2020; Fanzo et al., 2020b; Osei-Kwasi et al., 2020; Turner et al., 2018). Important dimensions of the (market-based) food environment include availability, affordability, convenience and desirability (Herforth & Ahmed, 2015). While it is established that food environments influence the ability of individuals to access a healthy, nutritious diet, the exact pathways are not yet sufficiently clear. Understanding the role that food environments play for diet intake is crucial to inform policies and programmes that shape the interaction between individual and external factors (Fanzo et al., 2020a; Sambu et al., 2024; Turner et al., 2020). This is particularly relevant for well-designed double-duty actions – reducing the risk of undernutrition as well as overweight, obesity and diet-related non-communicable diseases (NCDs).

In high-income countries, food environment research spans over two decades (Barbosa et al., 2023; Black et al., 2014; Cummins, 2003; Laska et al., 2010; McInerney et al., 2016; Mercille et al., 2016; Nollen et al., 2007), whereas evidence from low- and middle-income countries (LMICs) has only started emerging more recently (Carducci et al., 2020; Colozza, 2022; Klemm et al., 2024; O'Meara et al., 2023; Osei-Kwasi et al., 2020; Pradeilles et al., 2021; Turner et al., 2020; Westbury et al., 2021). Nearly all studies report *some* relationship between the food environment and diet quality or nutrition, but most do not capture availability, intake and individual socio-economic characteristics at the same local level and time period. One recent exception is Hülsen et al. (2024), who combined geocoded household and market survey data along a rural-urban continuum in Malawi. More empirical insights from LMICs are needed to improve food environment policies for healthier nutrition. It remains unclear how food environments affect the diets of specific and possibly vulnerable groups in LMICs. In this study, we analyse how school food environments may influence adolescent diets in urban Ghana.

Adolescents are of particular interest in food policy research for numerous reasons. First, in most LMICs, including Ghana, adolescents constitute a significant share of the total population

(Ghana Statistical Service (GSS) and ICF, 2024). Second, adolescence is a critical age for nutrition and one of the last phases where catch-up growth from previously suboptimal phases is possible (ALjaraedah et al., 2019; Norris et al., 2022). Adolescent girls in particular require micronutrient dense diets for optimal cognitive and physiological development (Bose et al., 2021). Third, adolescence is typically the age when the first independent food choices and purchase decisions are made. Fourth, and related to the previous point, it has been documented that dietary habits and eating patterns developed in adolescence often carry on through adulthood (Contento et al., 2006; Norris et al., 2022). Nevertheless, adolescents' dietary habits and how they are influenced are rarely captured in standard household surveys. Here, we address this research gap by concentrating on this particular group.

Focusing on school food environments to reach adolescents has been identified as a promising strategy in Ghana's public health policy (Tandoh et al., 2023). Previous work in urban Ghana, and Accra specifically, has provided evidence that students regularly purchase snack-foods from vendors in and around schools and that most of these snacks are energy-dense ultra-processed foods (Abizari and Ali, 2019; Fernandes et al., 2017; Ogum-Alangea et al., 2020). Vendors in school food environments predominantly stock ultra-processed foods, which are known to be unhealthy, while fresh and more nutritious foods are more challenging to obtain (Holdsworth et al., 2020; Laar et al., 2023; Pradeilles et al., 2021). It has also been documented that nutrient-dense foods are relatively more expensive than energy-dense foods (Mockshell et al., 2022; Sambu et al., 2024), possibly leading to affordability constraints for healthy eating patterns (Holdsworth et al., 2020; Liguori et al., 2022). Adolescents are also being explicitly targeted by advertisements around schools and in radio and television broadcasts (Kalog et al., 2022; Soliman et al., 2022; Tandoh et al., 2023), underlining that the food industry considers them as an important group of consumers.

To inform policy and programme development, the potential of leveraging food environments for improved nutrition needs to be better understood. This paper contributes to this direction with recent primary survey data. Specifically, we evaluate high school food environments in Accra, develop suitable metrics and link these school food environment metrics to the dietary intakes of school-going adolescents while controlling for other socio-economic factors. Our study contributes to the food environment literature by characterizing and evaluating the role of the urban food environment around schools that adolescents encounter.

The remainder of this paper is structured as follows. In section 2, we describe the data and variables used in this study, as well as the estimation strategy. In section 3, we present the results, while in section 4 we discuss the findings and derive some policy implications.

2. Materials and methods

2.1 Sampling design and study population

To better understand the linkages between school food environments and adolescent diets, we performed a cross-sectional survey in Accra, Ghana, using a two-stage proportional stratified random sampling strategy. We selected three areas within Greater Accra as sampling sites based on similar economic, infrastructure and public health indicators: Ayawaso East Municipality, Ablekuma Central Municipality and Accra Metro. Following a public-to-private school ratio representative of official enrolment statistics, we randomly selected 12 out of 115 schools (eight public and four private schools, serving as the primary sampling unit) and determined a minimum sample of 379 students (secondary sampling unit), using 5% margin of error, 95% confidence level and 50% population proportion on an estimated 24,000 students in the identified metropolitan areas.

Unlike basic schools, junior high school (JHS) students (age 12-15 years) do not receive free institutional school meals, nor do they receive financial support, as often provided by senior high schools. Everything that JHS students consume during a school day is therefore purchased, gifted, or brought from home. Thirty-six students from grades JHS1 and JHS2 who attended school on the preceding day (to match the dietary recall timeframe), were randomly selected per school, except for one school, where only 34 students were enrolled in both grades, yielding a total of 428 students. Nineteen students were excluded due to implausible consumption patterns, e.g. alleged consumption of all food groups with low budget and few meals consumed at home, from the final study sample (n = 409).

For each of the 12 schools, we defined a 300m circular perimeter around the school ground and within this area surveyed all vendors (n = 1,340) that sold ready-to-eat foods (foods that can be consumed without preparation). The 300m buffer aligns with similar studies carried out in Peru and Guatemala (Chew et al., 2020; Saavedra-Garcia et al., 2020) and were chosen as a walkable distance during break time. Note that we use 100m buffers for the statistical analysis in this paper, based on results from the vendor analysis (results for 200m and 300m buffers are reported in the Annex).

2.2 Data collection

Participant data were collected in November 2022. We carried out participant surveys Tuesdays to Fridays to ensure the dietary recall period (i.e. the previous day) was always on a school day.

2.2.1. Vendor data

For each vendor, geolocation (<5m accuracy) and store type information were collected. Items sold by each vendor were manually aligned with the diet quality questionnaire (DQQ) food groups (Table 1) (Herforth et al., 2020). We surveyed vendors on the availability (number of different food groups), assortment/variety (number of items per food group) as well as price and weight of foods (price and weight of the cheapest item per food group). Exceptions to this are fruits and vegetables, where we collected prices and weight of all available items. Where weight was not obtainable through scales (e.g., meals served in canteens), we used the Ghana Food Atlas as a reference to estimate weight (Folson et al., 2022). Additionally, background questions on the number of students that purchase from each vendor and the main food items purchased by students were asked (full questionnaire in supplementary materials). We used count data per food group type to determine clusters in and around schools (see section 2.3.1).

2.2.2. School data

Each head of school was given a 12-item questionnaire (full questions reported in supplementary materials), with background questions on management of school canteens or vendors around school (if they are allowed to operate), and other policies, such as the type of gate policy (i.e., whether students are allowed to leave the school during recess or lunch).

2.2.3. Individual data

For each adolescent, we collected data on the daily food budget, household socio-economic characteristics, including knowledge, attitude and practice (Fautsch Macías et al., 2014; Moitra et al., 2021), and diet intake information referring to the previous 24h using the DQQ methodology (Herforth et al., 2020; Uyar et al., 2023). These data were collected through individual interviews. In addition, height and weight measurements were taken.

Detailed descriptions of relevant variables and indicator groups are reported in the supplementary materials, alongside the full questionnaire. The DQQ methodology allows the calculation of several indicators related to dietary intake. For this study, we focus on the global dietary recommendations (GDR) score (0-18) as well as its components, the NCD-Risk score (0-9) and the NCD-Protect score (0-9) (Herforth et al., 2020). Table 1 outlines the food groups used to derive each of these indicators. For context, we also report the food group diversity score (FGDS) and the percentage of students that achieved FGDS above or equal to 5, which is the threshold for minimum dietary diversity (MDD).

Table 1 |Food groups and respective indicators according to Diet Quality Questionnaire methodology.

Food Group	NCD-Risk	NCD-Protect	Snack /meal
Baked sweets	x		Snack
Citrus		x	Snack
Deep fried food	x		Meal
Dark green leafy vegetables		x	Meal
Fast food / instant noodles	x		Meal
Nuts and seeds		x	Snack
Other fruits		x	Snack
Other sweets	x		Snack
Other vegetables		x	Meal
Processed meat	x		Meal
Pulses		x	Meal
Red meat	x		Meal
Soft drinks	x		N/A
Ultra-processed salty snacks	x		Snack
Vitamin A-rich fruits		x	Snack
Vitamin A-rich vegetables		x	Meal
Whole grains		x	Meal

Note: Snack/Meal refers to whether this food group is predominantly consumed as a snack or as a meal by students in and around schools (cf. Figure 2*).*
'Other fruits' includes banana, pineapple, watermelon, apple, guava; 'Other vegetables' includes tomatoes, okra, garden eggs, cabbage, sweet green pepper; 'Other sweets' includes toffees, chocolates, ice cream. For a full list of commodities by food group, see supplementary materials or the DQQ webpage (dietquality.org).

To calculate a food environment-specific estimate relating to our dietary indicators, we asked students whether they consumed each of the relevant food groups at home, on their way to/from school, around school or in school. Due to a coding error in the survey, location for NCD-Risk foods from the baked sweets and unbaked sweets group were collected jointly, which reduces the NCD-Risk score by 1. While this reduces the range of NCD-Risk, it does not affect the validity of the findings.

2.3. Statistical analysis

To determine diet quality at the school level, we use the student GDR score, NCD-Risk score and NCD-Protect score consumed in the school food environment (i.e., to and from school, around school and in school). To characterize the school food environment, we include the mean price of NCD-Protect food groups, mean price of NCD-Risk food groups, number of hotspots of NCD-Protect foods, number of hotspots of NCD-Risk foods and school gate policy (open vs. closed school gates). We focus on results for 100m buffers in the statistical analysis due to the results from the polynomial graphs (Figure 2), but report results for 0m, 200m and 300m buffers in the annex.

2.3.1. Hotspot analysis

In order to identify the prevalence and density of NCD-Risk and NCD-Protect foods in the school vicinity, we first calculate Moran's I to detect if (global) spatial autocorrelation is present in the data (Getis, 2008). Next, to identify spatial clusters in the food environment, we calculate local Getis-Ord G (Getis and Ord, 1992). The Getis-Ord G statistic captures variation in the local mean at location *i* compared to the global mean and indicates whether high or low clusters are present in the data and if these are statistically significant. To avoid the influence of outliers, observation *i* is not included in the local mean, i.e., as a neighbour. This measure expresses whether for a given vendor, the number of commodities is high or low and surrounded by other high/low values, relative to the global mean. In our case, a hotspot of NCD-Risk indicates that high numbers of NCD-Risk food groups are clustered, i.e., not spatially random, among vendors in the study area. A cold-spot of NCD-Risk indicates that low numbers of NCD-Risk food groups are clustered among vendors in the study area. The local Getis-Ord statistics is the ratio of the weighted average of the values in the neighbouring location to the sum of all values and expressed as follows:

$$G_i = \frac{\sum_{\substack{j=1 \\ j \neq i}}^{n} w_{ij} x_j}{\sum_{\substack{j=1 \\ j \neq i}}^{n} x_j} \quad (1)$$

Where G_i is the Getis-Ord statistic for location *i*, with *j* representing the neighbouring location(s), w_{ij} is the spatial weight between locations *i* and *j*, where *i* is not equal to *j* (i.e. *j* is a neighbour of *i*, but *i* is not included in the summation), x_j is the value of the variable (number of food groups) at location *j*. The term $\sum_{\substack{j=1 \\ j \neq i}}^{n} w_{ij} x_j$ represents the weighted sum of the values at neighbouring locations (excluding *i*) and $\sum_{\substack{j=1 \\ j \neq i}}^{n} x_j$ is the sum of *all* values in the dataset, excluding the value at location i. We take a nearest neighbour approach, defining neighbour relationships as the five nearest vendors and use these to calculate hotspots for NCD-Risk and NCD-Protect foods. We perform a simple count of these hotspots within 100m of each school and use these as an indicator of food group density. A detailed overview of the spatial analysis is reported in the supplementary material, including sensitivity analysis for different neighbourhood definitions.

2.3.2. Regression analysis

To empirically test the relationship between individual dietary quality and the school food environment, we use the following linear regression model:

$$\begin{aligned} DQ_{ij} = {} & \beta_1 Price\ NCDr_j + \beta_2 Price\ NCDp_j + \beta_3 Clusters\ NCDr_j + \beta_4 Clusters\ NCDp_j \\ & + \beta_5 School\ Gate\ Policy_j + \beta_6 Budget_i + \beta_7 X_i + \varepsilon_{ij} \end{aligned} \tag{2}$$

where DQ is diet quality of individual *i* at the school *j*, proxied by our GDR score, NCD-Risk score and NCD-Protect score. *Price NCDr* refers to the average price of NCD-Risk foods, and *Price NCDp* refers to the average price of NCD-Protect foods in or around school *j*. *Clusters NCDr (NCDp)* represent the number of NCD-Risk (NCD-Protect) hotspots within a 100m radius of the school. *School Gate Policy* indicates whether the school operates with an open or closed school gate. *Budget* refers to the total food budget of individual *i*. *X* is a vector of socio-economic controls, including age, sex, bringing food to school, individual knowledge, attitude and practice scores, and whether the school is a private or public school. We calculate robust standard errors.

As we use cross-sectional data, it is not possible to control for unobservables that may influence dietary quality or school environments. Therefore, we run additional robustness checks using the Oster coefficient stability tests (reported in Annex Table A3) (Oster, 2019). This test infers how sensitive the results are to the influence of potential unobserved heterogeneity, thus helping to better understand the robustness of results to potential omitted variable bias. For further sensitivity analysis, we also create a hierarchical model, with school random effects and compare the two models using ANOVA likelihood ratio tests and comparing AIC. Results of this comparison suggest that adding a random intercept (i.e., the hierarchical model) does not significantly improve the model compared to the single level regression (full results reported in supplementary materials).

3. Results

3.1. Student descriptive statistics

We first assess the dietary patterns of the students in our sample, paying special attention to differences between sexes. Table 2 presents several descriptive statistics on individual characteristics and dietary quality. Students are on average 14 years old with an appropriate height and weight score for their age-group. Nearly all (99%) students brought some money to school to purchase food. Only 13% of all students brought any food with them from home during the last week, with slightly more girls bringing food (16%) than boys (11%). Consistent with this, boys report having a slightly higher budget to spend on food. The difference in total budget is roughly half a Ghanaian cedi (0.6 GHS, approx. 5 cents USD) and stems largely from having minimally higher breakfast and lunch budgets.

Regarding consumption patterns, girls show a slightly higher score for all food groups, indicating that they eat both more favourable and unfavourable foods, on average, compared to boys. This small disparity between girls and boys is also visible in the proportion of students achieving minimum dietary diversity (MDD, 65% vs 59%) and diet scores such as NCD-Protect (3.4 vs 3.1), NCD-Risk (3.2 vs 2.9) and FGDS (5.2 vs 5.1), as well as the diet scores both at home and at school. At home, girls tend to consume slightly more food groups than boys for both NCD-Protect (2.3 vs 2.1) and NCD-Risk (1.3 vs 1.0) foods. Out of home – in, around or on their way to and from school – average scores for NCD-Protect are identical (1.5 for both), but NCD-Risk scores are minimally higher for girls (1.6 vs 1.5) than for boys. While there are differences between sexes that are important to reflect on (full t-test results in Annex Table A2), the levels at which boys and girls differ are quite low and therefore may be negligible given the overall room for improvement on these scores. Therefore, we proceed by pooling girls and boys in our analysis.

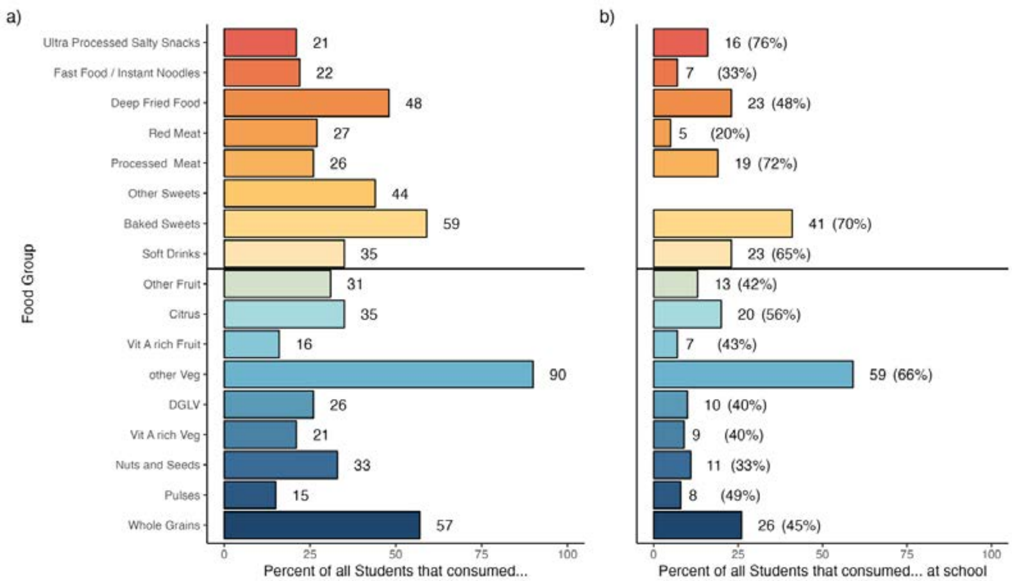
Table 2| Summary characteristics of junior high school students

Variable	All (n = 409)		Female (n = 206)		Male (n = 203)		Female-male difference
	Mean	SD	Mean	SD	Mean	SD	
Age (years)	14.35	1.28	14.27	1.13	14.42	1.41	
Weight (kg)	51.38	10.61	52.56	11.10	50.19	9.96	**
Height (cm)	161.36	8.20	159.13	6.49	163.62	9.11	***
Body mass index (BMI)	19.70	3.70	20.73	4.05	18.65	2.97	***
BMI for age z-scores	-0.18	1.23	0.13	1.20	-0.49	1.19	***
Total budget (GHS per day)	10.20	5.42	9.86	5.05	10.54	5.76	
Breakfast budget (GHS per day)	2.80	2.84	2.68	2.71	2.92	2.97	
Snack budget (GHS per day)	2.24	2.51	2.21	2.50	2.27	2.53	
Lunch budget (GHS per day)	4.24	2.86	4.15	2.79	4.33	2.93	
Students that brought food (%)	13.4	34.9	16.0	38.1	10.8	31.2	
Students that brought money (%)	98.5	12.0	98.5	12.0	98.5	12.1	
FGDS (0-10)	5.12	1.62	5.19	1.62	5.05	1.63	
MDD (%)	61.9	48.6	65.0	47.8	58.6	49.4	
GDR score (0-18)	9.15	2.07	9.15	2.10	9.14	2.04	
NCD-Risk score (0-9)	3.09	2.00	3.23	2.04	2.94	1.96	
NCD-Protect score (0-9)	3.24	1.67	3.39	1.73	3.08	1.61	*
GDR score at home (1-18)	10.04	1.68	10.02	1.94	10.07	1.38	
GDR score at school (1-18)	8.96	1.55	8.91	1.67	9.00	1.43	
NCD-Risk score at home (0-8)	1.15	1.37	1.29	1.55	1.02	1.14	**
NCD-Risk score at school (0-8)	1.53	1.36	1.57	1.34	1.49	1.38	
NCD-Protect score at home (0-9)	2.20	1.44	2.30	1.54	2.09	1.33	
NCD-Protect score at school (0-9)	1.49	1.10	1.48	1.18	1.49	1.03	

Note: GHS – Ghana Cedi, FGDS – food group diversity score, MDD – minimum dietary diversity, GDR – global dietary recommendations, NCD – non-communicable disease, SD – standard deviation.
*Due to a survey error no difference was made between sweets baked and sweets unbaked of the NCD-Risk category for home and school consumption. Therefore, NCD-Risk scores for those locations only range from 0-8, rather than 0-9 and GDR scores are 1-18, rather than 0-18. Overall NCD-Risk scores were not affected and collected and analysed as per protocol. *p<0.1; **p<0.05; ***p<0.01 (based on t-tests)*

Disaggregating the diet scores (NCD-Risk and NCD-Protect categories) into food groups, Figure 1 shows the percentage of all students that consumed (a) one of the relevant food groups throughout the previous day and (b) while they were at school. Parentheses in panel b indicate the share of absolute consumption (panel a) taking place in school (panel b). For example, 21% of all students reported eating ultra processed salty snacks on the previous day (panel a), and 16% reported eating ultra processed salty snacks at school (panel b), suggesting that 76% of the overall consumption of ultra processed snacks took place at school. Strikingly, among those students that consumed NCD-Risk snack foods such as baked and other sweets, salty snacks, sugar sweetened beverages or processed meat, over two-thirds of the consumption took place (also) at school. Deep fried foods, which are consumed by nearly half of our sample, are also consumed by one quarter of students in the school food environment. Other vegetables as well as whole grains are also consumed by many, with two thirds of students consuming other vegetables and nearly half eating whole grains at school. Vitamin A-rich vegetables and fruits, pulses, nuts and seeds, other fruits or dark green leafy vegetables (DGLV) are consumed by only one-third of the students or less, and only around 10% consume these commodities in the school food environment. The fraction of consumption at school also indicates that consumption at school is on average higher for NCD-Risk than NCD-Protect food groups (also cf. Table 1).

Figure 1 | Consumption of (a) all food groups in the previous 24h and (b) in the school food environment



Note: Due to a survey error no distinction was made between baked sweets and other sweets of the NCD-Risk category for school consumption, therefore only baked sweets are reported here. Numbers in parentheses in panel b indicate the share of consumption at school (expressed as proportion of total consumption). DGLV – dark green leafy vegetables.

3.2. Vendor descriptive statistics

In addition to student information, it is crucial to understand vendor characteristics around the school. Table 3 shows key characteristics of vendors within 300m of participating schools. Most merchants are either street vendors (45%) that have a stationary vendor table in a non-enclosed setting (on the sidewalk, outside a building) or corner shops (28%). The vast majority (86%) of vendors surveyed were stationary. Nearly 80% of vendors report that they typically sell foods to students on a school day, with the mean number of reported students per vendor at 21.4. Almost 60% of vendors sell foods that are classified in the NCD-Risk food group, whereas only 40% of vendors sell any foods that are classified in the NCD-Protect food group. Additionally, we can see that the assortment/variety (mean number of items per food group) is higher for NCD-Risk than NCD-Protect foods. Expanded summary characteristics, including by vendor type, are provided in the supplementary materials.

Table 3 | Selected characteristics of Vendors included in this study

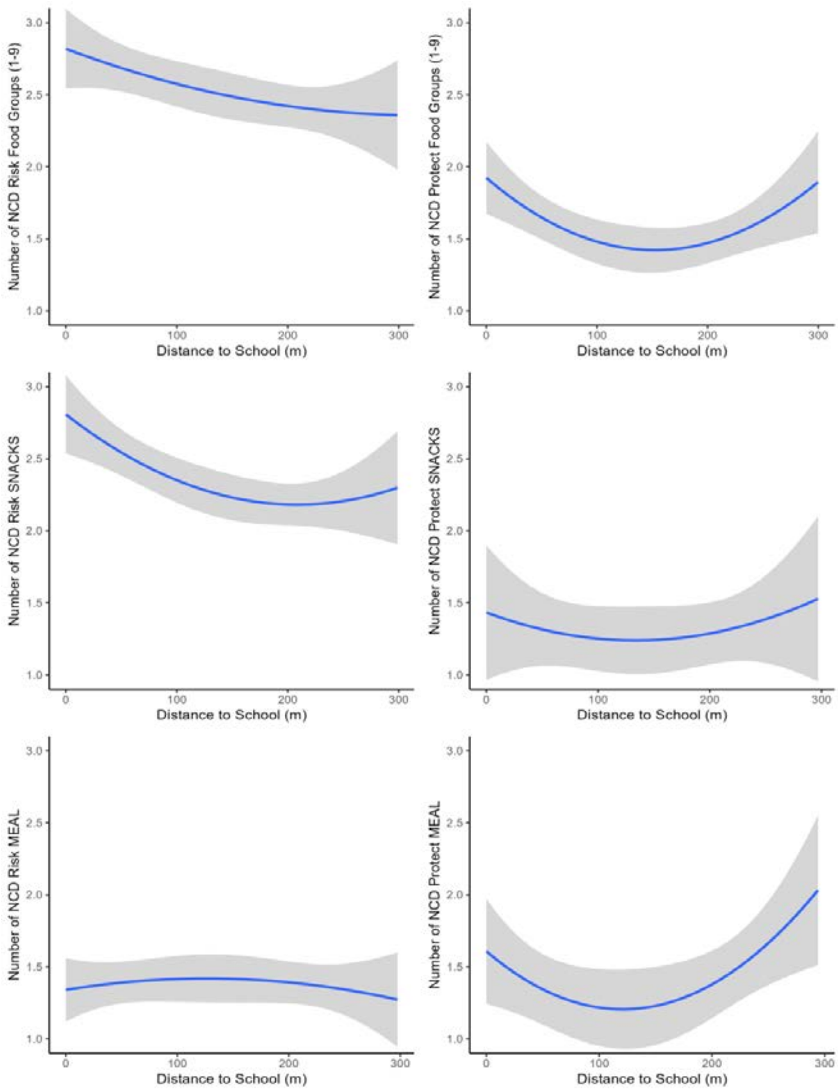
Variable	N	%	Mean count* (at vendor)	SD*
Vendor type				
Street vendor	596	44.5%	-	-
Corner shop	381	28.4%	-	-
Mobile vendor	185	13.8%	-	-
School vendor	81	6.0%	-	-
Other	48	3.6%	-	-
Restaurant/café	39	2.9%	-	-
Supermarket/ minimarket	10	0.7%	-	-
Vendors that sold to students	1042	77.8%	21.4	46.1
Vendors with NCD-Risk foods („Unfavourable" – ready to eat)	764	57.0%	2.5	1.6
Vendors selling softdrinks	445	33.2%	6.5	4.9
Vendors selling sweets	386	28.8%	5.3	4.7
Vendors selling (savoury) snacks	250	18.7%	2.7	1.9
Vendors with NCD-Protect foods („Favourable" – ready to eat)	528	39.4%	1.6	1.3
Vendors selling nuts	249	18.6%	1.2	0.7
Vendors selling fresh fruits	109	8.1%	2.6	2
Vendors selling fresh vegetables	19	1.4%	1.8	1.3

Note: n = 1,340, within 300m radius of participating schools
** among vendors with at least one item. "Other" vendor types include vendors such as wholesale drink shops or mobile money agents that also sell some foods*
NCD – Non-Communicable Disease, SD – Standard Deviation

Using geocoded data from vendors, we also document how food group assortment changes with distance from schools. Figure 2 shows the mean number of NCD-Protect and NCD-Risk food groups sold per vendor. The number of items per food group decreases within the first

100m from school. Beyond 100m, there is a slight increase for NCD-Protect but a continuous decrease for NCD-Risk, although confidence intervals widen. There is also a strong decrease of NCD-Risk snacks (Figure 2) with distance, i.e., higher variety closer to schools. Given the observed trend and significance within the first 100m we use this radius as a cut-off for the regression models (results for different cut-offs are provided in Annex Figure A2 a-c).

Figure 2 | Polynomial graphs of different NCD-Risk and NCD-Protect food groups sold per vendor and distance to school in Accra, Ghana

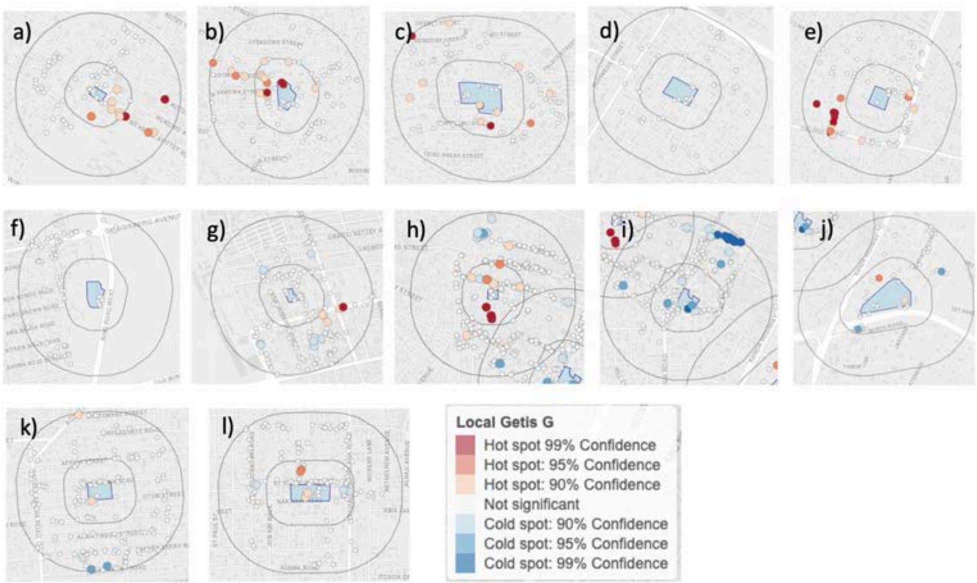


Note: Numbers are counted among vendors who hold at least one of the commodity groups, therefore the sample size varies between these graphs, for polynomial graphs of count per food group of all vendors (including those with no food per food group), see Annex Figure A1. NCD – Non-Communicable Disease

3.3. Hotspots around schools

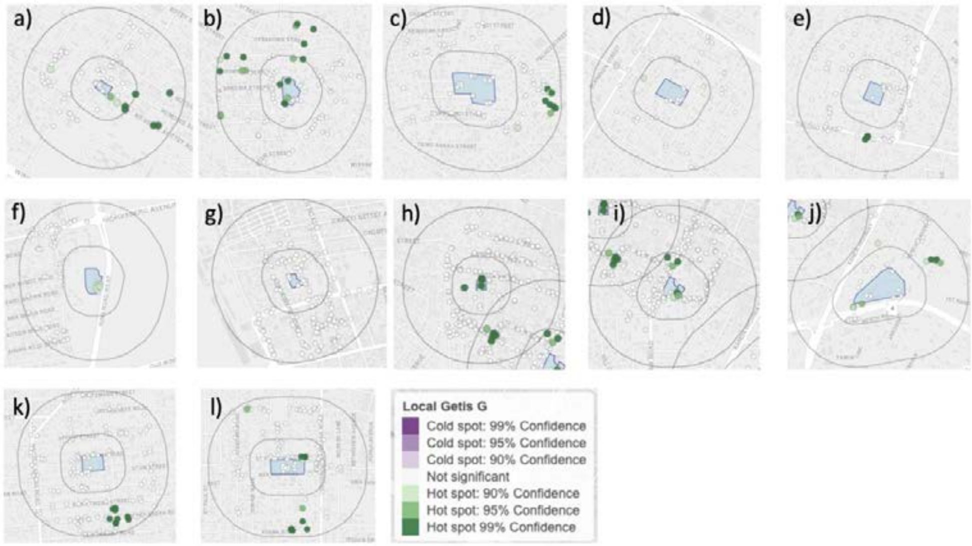
To better understand the distribution of vendors around schools, we calculate Moran's I (reported in supplementary materials) to check whether overall spatial clusters are visible in our data or whether food group assortment is relatively homogenously distributed. We report the results from the analysis of local concentration of values (Getis-Ord G) in Figure 3, showing significant hot- and cold-spots of NCD-Risk food groups around participating schools. Nine out of the twelve study schools are directly adjacent to a hotspot (local mean above the global mean) of NCD-Risk foods. Notably, and as visualized in Figure 4, this is also the case for NCD-Protect foods. The spatial clustering analysis suggests that there is a higher assortment of foods closer to schools, but that this is the case for both favourable and unfavourable food groups. Still, NCD-Risk and NCD-Protect food groups are not always available in the same places. For schools (c), (e), (i), (k) and (l) the respective hotspots of NCD-Risk and NCD-Protect food groups are not overlapping.

Figure 3 | Hot- and cold-spots of NCD-Risk foods within 300m perimeter (outer boundary) of study schools in Accra, Ghana



Note: Blue areas are school campus areas. 100m and 300m perimeters are visualized by black boundaries. Dots represent individual vendors, colours indicate hot- and cold-spots. Hotspots indicate a relatively high number of NCD-Risk food groups per vendor, cold-spots indicate a relatively low number of NCD-Risk food groups per vendor.

Figure 4 | Hot- and cold-spots of NCD-Protect foods within 300m perimeter (outer boundary) of study schools in Accra, Ghana



Note: Blue areas are school campus areas. 100m and 300m perimeters are visualized by black boundaries. Dots represent individual vendors, colours indicate hot and cold-spots. Hotspots indicate relative high number of NCD-Protect food groups per vendor, coldspots indicate relatively low number of NCD-Protect food groups per vendor.

3.4. Regression results

We now analyse whether food environment characteristics observed around the school are associated with the diet quality of students eating in those food environments. Table 3 shows the results from the linear regression models, using school food environment characteristics at 100m buffers as exposure variables and three different diet intake indicators (GDR, NCD-Protect and NCD-Risk) at school as outcomes while controlling for individual-level factors. 100m buffers were chosen because of the trends in the polynomial graphs (see Figure 2).

The results in Table 4 show an inverse association between price and consumption of NCD-Risk and NCD-Protect food groups. An increase in the mean price of NCD-Risk food groups is associated with lower consumption of these foods; the same is true also for NCD-Protect food groups. This leads to an overall positive association between prices of NCD-Risk and the GDR score, and a negative association between prices of NCD-Protect foods and the GDR score. In other words, a school food environment in which unfavourable foods are more expensive and favourable foods are available is associated with higher diet quality, whereas a school food environment where favourable foods are more expensive is associated with lower diet quality. Notably, these associations are observed after controlling for individual budget and other background characteristics. Regressions without controls can be found in the Annex (Table A1), with similar results.

Table 4| Association between school food environment and diet quality

	Dependent variable		
	GDR score (at school)	NCD-Risk (at school)	NCD-Protect (at school)
	(1)	(2)	(3)
Price NCD-Risk	0.550^{**}	-0.402^{**}	0.148
	(0.215)	(0.186)	(0.142)
Price NCD-Protect	-0.197^{***}	0.105	-0.092^{*}
	(0.076)	(0.066)	(0.048)
Number of hotspots NCD-Risk	-0.005	-0.002	-0.007
	(0.030)	(0.024)	(0.020)
Number of hotspots NCD-Protect	-0.056	0.034	-0.022
	(0.063)	(0.050)	(0.041)
Open gate (ref: closed)	0.075	0.034	0.108
	(0.282)	(0.217)	(0.188)
Total budget	-0.029^{*}	0.077^{***}	0.048^{***}
	(0.017)	(0.014)	(0.011)
Controlled for individual factors	YES	YES	YES
Observations	409	409	409
R^2	0.069	0.134	0.101
F statistic (df = 13; 395)	2.260^{***}	4.685^{***}	3.404^{***}

*Note: N = 409. Robust standard errors in parentheses. Individual controls include age, sex, bringing food to school, knowledge, attitude and practice scores and school type. *p<0.1; **p<0.05; ***p<0.01*

Beyond the pricing of food groups, we do not find evidence that a higher number of foods around schools (measured by number of hotspots for these food groups within 100m) is associated with higher consumption of these foods. Results show that, in terms of individual factors and when accounting for the food environment, a one cedi increase in the individual food budget is associated with a 0.077 increase in NCD-Risk and a 0.048 increase in NCD-Protect foods consumed in the school food environment. Overall, a higher budget somewhat reduces dietary quality, proxied by the GDR score. Results from the Oster coefficient-stability test show that bias-adjusted treatment effects (Annex Table A3) are typically very close to the coefficients reported in Table 4, suggesting that the results are robust to potential omitted variable bias. Results for different distance buffers from 0-300m are reported in Annex Figure A2.

4. Discussion and conclusion

4.1. Discussion

Food environments are an important determinant of diet quality. In addition to the home food environment, which has recently received increased attention, the school food environment is a context in which students spend a large portion of their day. Understanding what elements of the school food environment contribute to high or low diet quality can inform research and policies on food and nutrition. Here, we have focused on school food environments and adolescent diets in Accra, Ghana. Earlier studies showed that students in Accra engage with the school food environment (Abizari and Ali, 2019; Finnerty et al., 2010; Ogum-Alangea et al., 2020) and that many purchases by school students fall into the category of unfavourable foods (Abizari and Ali, 2019; Liguori et al., 2022; Ogum-Alangea et al., 2020). However, the exact characteristics of the school food environment and their links to individual diets have not been explored previously.

Much of the existing food environment research focuses on the household as the primary pathway to diet quality. However, students, especially adolescents, spend a large part of their time in and around schools and are likely to engage with the food environment independently from household purchases and eating patterns. This is especially important as food-away-from-home (FAFH) is generally absent from household-level dietary surveys (Ignowski et al., 2023; Sauer et al., 2021). Existing studies suggest that students are consumers in the broader food environment around schools. This raises important questions as to how policies could possibly influence school food environments to promote healthier nutrition for vulnerable population groups. Adolescents are a critical age group for nutrition and public health interventions and are explicitly mentioned as part of the national health policy in Ghana, which articulates access to healthy, nutritious diets as a central element for public health.

We contribute to the research on food environments and diets by measuring food environments around schools and linking metrics of these school food environments to the diet quality of school-attending adolescents. Foods that are considered risk factors for NCDs are more frequently consumed in and around schools than at home. Our spatial analysis shows that there is a higher assortment/variety of food groups of all types offered by vendors closer to schools compared to vendors further away. We show that the prices of NCD-Risk and NCD-Protect food groups in and around schools are significantly associated with diet quality of students at school. Lower prices of NCD-Risk foods are associated with lower overall diet quality.

Our study is innovative as it includes student-level, school-level and food environment- level information, making it one of the first studies to account for both individual and external drivers of diets within the school context. By capturing both favourable (NCD-Protect) and unfavourable (NCD-Risk) food options, we use a methodology that considers all elements relevant for overall diet quality and healthy nutrition, rather than focusing on partial indicators such as diet diversity or ultra-processed foods. This is key in settings where the triple burden of malnutrition is becoming increasingly worrisome, which is true not only in Ghana but in LMICs more generally.

An important result are the opposing patterns for the consumption of favourable and unfavourable foods at home and at school. Favourable foods are more likely to be consumed at home, whereas unfavourable foods are more likely to be consumed in and around schools. Related to this, we find that very few adolescents carry food to school from home. To our knowledge, little previous evidence exists on the location of food group consumption for adolescents in LMICs. One study in Ghana suggests that women tend to consume ultra-processed foods mainly when away from home (Liguori et al., 2022). Similarly, a few studies, mostly from high-income countries, show that food consumption of adults around the workplace tends to be less healthy and more processed than consumption at home (Adams et al., 2015; U.S. Department of Agriculture Agricultural Research Service, 2018), or that out of home consumption more generally is associated with obesity and unhealthy diets (Ignowski et al., 2023; Kim et al., 2019; Liu et al., 2021). The school food environment can and should, therefore, play a central role in reducing the intake of unhealthy foods among children and adolescents and improving the consumption of favourable foods.

A second important finding is that the number of foods offered by vendors increases with proximity to a school. Within a perimeter of 100m around schools this is the case for both favourable and unfavourable foods. Previous studies document that there is ubiquity of ultra-processed foods in urban contexts in sub-Saharan Africa (Global Alliance for Improved Nutrition (GAIN), 2020; Kushitor et al., 2023; Landais et al., 2023; Madzorera et al., 2023; Weil et al., 2023) as well as around schools (Fernandes et al., 2017; Iyassu et al., 2023; Kalog et al., 2022; Ogum-Alangea et al., 2020; Soliman et al., 2022; Tandoh et al., 2023). However, much of this research focusing on unfavourable foods around schools does not capture favourable food options in school food environments. Therefore, our findings add an important dimension. Both favourable and unfavourable foods are available around schools, and while more vendors stock unfavourable than favourable foods, we do not find evidence that vendors highly frequented by students (and closer to school) offer relatively more unfavourable foods than vendors less frequented by students (and farther away from school). Food environments closer to schools are *denser* – meaning that they offer more foods and food groups – but the ratio between favourable and unfavourable foods does not change much with distance to schools. Note however that the locations of favourable and unfavourable food hotspots do not always overlap spatially.

A third important result is that food prices are significantly associated with consumption, even after controlling for individual-level factors such as budget or knowledge, attitude and practices. We find that the pricing of foods is more important than the availability, and that the magnitude of the association between price and consumption is larger for foods of the NCD-Risk category. This means that in the context of Accra, where junior high school students do not receive institutional school meals, the main barrier to a healthy, nutritious diet is of financial nature and directly related to double-duty actions. Some students may not be able to afford favourable foods. But even if they could in principle afford these, lower prices for unfavourable foods make favourable foods less attractive for students in their daily choices. This is in line with our finding that higher individual budget is associated with slightly reduced dietary quality (GDR) and other studies showing that higher incomes do not necessarily improve dietary quality or dietary outcomes in urban settings (Ameye, 2023; Cockx et al., 2018). The lack of association between availability measures and intake could imply that higher exposure and choice of types of food do not influence dietary quality when prices are accounted for.

It is important to note a few limitations of our study. Nearly all data used are self-reported, which could create some bias due to measurement errors. Additionally, the food consumption data were collected over a short recall period, namely the preceding 24 hours. While short recall periods lead to more precise data, they fail to capture certain foods that are only consumed occasionally. Likewise, possible seasonal variations in consumption cannot be captured with one-time 24h recalls. It should also be stressed that we only collected data for consumption on school days. A more comprehensive picture of adolescent diet quality would require repeated 24h recalls on different days of the week and during different seasons of the year.

In terms of the diet quality indicators, our analysis builds on the DQQ food group frequency questionnaires, which remain general and do not allow more disaggregated analysis of specific food items. In terms of the food environment indicators, we only focus on the school food environment, not the home food environment, which is also expected to be relevant for adolescent diet quality. Finally, it should be kept in mind that our study uses data from a relatively small number of schools in Accra, meaning that the external validity of our results may be limited. We expect that school food environments are also associated with adolescent diet quality in similar locations within Ghana and beyond. Given the scarcity of related studies, follow-up research in different geographical settings to support this hypothesis would be useful.

4.2. Policy implications

We showed that offering unfavourable NCD-Risk foods at low prices in and around schools is associated with reduced adolescent diet quality, while offering favourable NCD-Protect foods at low prices is associated with improved diet quality. These associations are particularly pronounced in the immediate vicinity of schools, namely within a radius of 100m from the school compound. These results have clear policy implications concerning double-duty actions around schools. Policy interventions in school food environments could be implemented as part of school health policies in close cooperation with the city administration.

First, the sale of unfavourable NCD-Risk foods in the immediate school food environment could be taxed. This would increase their price and make them relatively less attractive choices, leading to lower consumption. Taxes could be implemented either on all ultra-processed foods or based on specific ingredients such as sugar, salt, or fat. While evidence of food-related taxes only in school food environments is limited and practical implementation is not straightforward, some insights from broader sugar taxes exist. For instance, results from general sugar taxes in Chile (Cuadrado et al., 2020; Nakamura et al., 2018), Mexico (Salgado Hernández et al., 2023) and South Africa (Stacey et al., 2021) suggest that such tools can be an effective step towards more healthy diets for adolescents in urban contexts. Making unfavourable foods more expensive in and around schools can be useful to enhance health policies (Laar et al., 2023). The advantage of such a tax policy is that – apart from administrative costs – it does not require public outlays and instead leads to public tax revenues. Price regulations will only influence consumption decisions to a certain extent. Once student budgets increase, further disincentivizing policies will need to be considered.

Second, the sales of favourable NCD-Protect foods in school food environments could be subsidized to make them more affordable. Lower prices for favourable foods would incentivize higher consumption, as our results demonstrate. Such subsidies could be obtained by linking tax and subsidy policies for unhealthy and healthy foods, respectively. Schools could also license and subsidize specific vendors that commit to offer only favourable foods.

Third, the types of foods that vendors in school food environments offer could be regulated, by either banning unfavourable items or restricting them in terms of maximum numbers or proportions of all food items offered (for example, by offering school-vendor licenses only to vendors that meet certain criteria). Fourth, schools could themselves engage in offering healthy snacks or meals at subsidized rates. While this is the most-costly option, it is likely also the most effective one to promote healthy diets and nutrition.

The optimal types of policy interventions and policy designs may differ depending on various contextual factors. Testing certain policies, evaluating their effectiveness and adjusting approaches, if necessary, should be relatively straightforward, as school food environments are small areas that can be monitored comparatively well. Various approaches could also be compared across schools using tools of randomized experimentation. Given rising rates of childhood and adolescent overweight and obesity around the world, including in LMICs, identifying levers and effective approaches for improving diets during these critical life stages should have high policy priority. Our findings suggest that school food environments may be promising entry points.

Acknowledgements

The authors would like to thank all study participants and staff members of the Ghana Education Service for providing support to the study and granting access to the study sites, in particular: Dorcas Hushie, Ernest Amoah Ampah, Theresa Oppong Mensah, Patrick Banafo, Stephen Abanfo, Kwabena Bempah Tandoh, Cynthia Nyarko, Grace Homiah, and Philipina Tupper, as well as all teachers who supported the data collection at the schools visited. We would like to thank all enumerators active in the data collection and research assistant Kezia Dampare. Thank you to Linus Linnaeus Tannor for his guidance and help during the design phase of the survey.

References

Abizari, A.R., Ali, Z., 2019. Dietary patterns and associated factors of schooling Ghanaian adolescents. J Health Popul Nutr 38, 5. https://doi.org/10.1186/s41043-019-0162-8

Adams, J., Goffe, L., Brown, T., Lake, A.A., Summerbell, C., White, M., Wrieden, W., Adamson, A.J., 2015. Frequency and socio-demographic correlates of eating meals out and take-away meals at home: Cross-sectional analysis of the UK national diet and nutrition survey, waves 1-4 (2008-12). International Journal of Behavioral Nutrition and Physical Activity 12. https://doi.org/10.1186/s12966-015-0210-8

ALjaraedah, T.Y., Takruri, H.R., Tayyem, R.F., 2019. Dietary practices and nutrient intake among adolescents: A general review. Obes Med. https://doi.org/10.1016/j.obmed.2019.100145

Ameye, H., 2023. Dietary quality in rural areas, secondary towns, and cities: Insights from Tanzania. Food Secur 15, 1563–1584. https://doi.org/10.1007/s12571-023-01399-9

Barbosa, B.B., Nielsen, L., de Aguiar, B.S., Failla, M.A., Araújo, L.F., Mendes, L.L., Machado, S.P., Carioca, A.A.F., 2023. Local Food Environment and Consumption of Ultra-Processed Foods: Cross-Sectional Data from the Nutritionists' Health Study—NutriHS. Int J Environ Res Public Health 20, 6749. https://doi.org/10.3390/ijerph20186749

Black, C., Moon, G., Baird, J., 2014. Dietary inequalities: What is the evidence for the effect of the neighbourhood food environment? Health Place. https://doi.org/10.1016/j.healthplace.2013.09.015

Bose, I., Baldi, G., Kiess, L., Klemm, J., Deptford, A., de Pee, S., 2021. The difficulty of meeting recommended nutrient intakes for adolescent girls, in: Global Food Security. Elsevier B.V. https://doi.org/10.1016/j.gfs.2020.100457

Carducci, B., Oh, C., Keats, E.C., Roth, D.E., Bhutta, Z.A., 2020. Effect of food environment interventions on anthropometric outcomes in school-aged children and adolescents in low- And middle-income countries: A systematic review and meta-analysis. Curr Dev Nutr. https://doi.org/10.1093/cdn/nzaa098

Chew, A., Moran, A., Barnoya, J., 2020. Food swamps surrounding schools in three areas of guatemala. Prev Chronic Dis 17. https://doi.org/10.5888/PCD17.200029

Cockx, L., Colen, L., De Weerdt, J., 2018. From corn to popcorn? Urbanization and dietary change: Evidence from rural-urban migrants in Tanzania. World Dev 110, 140–159. https://doi.org/10.1016/j.worlddev.2018.04.018

Colozza, D., 2022. A qualitative exploration of ultra-processed foods consumption and eating out behaviours in an Indonesian urban food environment. Nutr Health. https://doi.org/10.1177/02601060221133897

Contento, I.R., Williams, S.S., Michela, J.L., Franklin, A.B., 2006. Understanding the food choice process of adolescents in the context of family and friends. Journal of Adolescent Health 38, 575–582. https://doi.org/10.1016/j.jadohealth.2005.05.025

Cuadrado, C., Dunstan, J., Silva-Illanes, N., Mirelman, A.J., Nakamura, R., Suhrcke, M., 2020. Effects of a sugar-sweetened beverage tax on prices and affordability of soft drinks in Chile: A time series analysis. Soc Sci Med 245. https://doi.org/10.1016/j.socscimed.2019.112708

Cummins, S.C.J., 2003. The Local Food Environment and Health: Some Reflections from the United Kingdom. Am J Public Health 93, 521. https://doi.org/https://doi.org/10.2105%2Fajph.93.4.521

Downs, S.M., Ahmed, S., Fanzo, J., Herforth, A., 2020. Food environment typology: Advancing an expanded definition, framework, and methodological approach for improved characterization of wild, cultivated, and built food environments toward sustainable diets. Foods 9. https://doi.org/10.3390/foods9040532

Fanzo, J., Covic, N., Dobermann, A., Henson, S., Herrero, M., Pingali, P., Staal, S., 2020a. A research vision for food systems in the 2020s: Defying the status quo. Glob Food Sec 26. https://doi.org/10.1016/j.gfs.2020.100397

Fanzo, J., Haddad, L., McLaren, R., Marshall, Q., Davis, C., Herforth, A., Jones, A., Beal, T., Tschirley, D., Bellows, A., Miachon, L., Gu, Y., Bloem, M., Kapuria, A., 2020b. The Food Systems Dashboard is a new tool to inform better food policy. Nat Food. https://doi.org/10.1038/s43016-020-0077-y

Fautsch Macías, Yvette., Glasauer, Peter., Food and Agriculture Organization of the United Nations., 2014. Guidelines for assessing nutrition-related knowledge, attitudes and practices : KAP manual. Food and Agriculture Organization of the United Nations.

Fernandes, M., Folson, G., Aurino, E., Gelli, A., 2017. A free lunch or a walk back home? The school food environment and dietary behaviours among children and adolescents in Ghana. Food Secur 9, 1073–1090. https://doi.org/10.1007/s12571-017-0712-0

Finnerty, T., Reeves, S., Dabinett, J., Jeanes, Y.M., Vögele, C., 2010. Effects of peer influence on dietary intake and physical activity in schoolchildren. Public Health Nutr 13, 376–383. https://doi.org/10.1017/S1368980009991315

Folson, G., Bannermann, B., Gabriel Ador, Vicentia Atadze, Saudatu Akoto, Stephen Asante, Joseph Abbeyquaye, Audrey Anang-Tetteh, Erica Guri, Gabriel Ibrahim, Jamil Alhassan, Bastien Koch, Peter McCloskey, Rohit Gangupantulu, Bianca C. Braga, David Hughes, Aulo Gelli, 2022. A Photographic Food Atlas with Portion Sizes of Commonly Consumed Foods in Accra, Ghana. Washington, DC.

Getis, A., 2008. A History of the Concept of Spatial Autocorrelation: A Geographer's Perspective. Geogr Anal 40. https://doi.org/https://doi.org/10.1111/j.1538-4632.2008.00727.x

Getis, A., Ord, J.K., 1992. The Analysis of Spatial Association by Use of Distance Statistics. Geogr Anal 24, 189–206. https://doi.org/10.1111/j.1538-4632.1992.tb00261.x

Ghana Statistical Service (GSS) and ICF, 2024. Ghana Demographic and Health Survey 2022. Accra, Ghana, and Rockville, Maryland, USA.

Global Alliance for Improved Nutrition (GAIN), 2020. Urban Food Environments in Low-and Middle-Income Countries.

Herforth, A., Ahmed, S., 2015. The food environment, its effects on dietary consumption, and potential for measurement within agriculture-nutrition interventions. Food Secur 7, 505–520. https://doi.org/10.1007/s12571-015-0455-8

Herforth, A.W., Wiesmann, D., Martínez-Steele, E., Andrade, G., Monteiro, C.A., 2020. Introducing a Suite of Low-Burden Diet Quality Indicators That Reflect Healthy Diet Patterns at Population Level. Curr Dev Nutr 4. https://doi.org/https://doi.org/10.1093/cdn/nzaa168

Holdsworth, M., Pradeilles, R., Tandoh, A., Green, M., Wanjohi, M., Zotor, F., Asiki, G., Klomegah, S., Abdul-Haq, Z., Osei-Kwasi, H., Akparibo, R., Bricas, N., Auma, C., Griffiths, P., Laar, A., 2020. Unhealthy eating practices of city-dwelling Africans in deprived neighbourhoods: Evidence for policy action from Ghana and Kenya. Glob Food Sec 26. https://doi.org/10.1016/j.gfs.2020.100452

Hülsen, V., Khonje, M.G., Qaim, M., 2024. Market food environments and child nutrition. Food Policy 128. https://doi.org/10.1016/j.foodpol.2024.102704

Ignowski, L., Belton, B., Tran, N., Ameye, H., 2023. Dietary inadequacy in Tanzania is linked to the rising cost of nutritious foods and consumption of food-away-from-home. Glob Food Sec 37. https://doi.org/10.1016/j.gfs.2023.100679

Iyassu, A., Laillou, A., Tilahun, K., Workneh, F., Mogues, S., Chitekwe, S., Baye, K., 2023. The influence of adolescents' nutrition knowledge and school food environment on adolescents' dietary behaviors in urban Ethiopia: A qualitative study. Matern Child Nutr. https://doi.org/10.1111/mcn.13527

Kalog, G.L.S., Kasim, F., Anyebuno, B., Tei, S., Kubuga, C.K., Mogre, V., Aryee, P.A., 2022. Food advertisement influences food decision making and not nutritional status: a study among university students in Ghana. BMC Nutr 8. https://doi.org/10.1186/s40795-022-00571-2

Kim, H.J., Oh, S.Y., Choi, D.W., Park, E.C., 2019. The association between eating-out rate and BMI in Korea. Int J Environ Res Public Health 16. https://doi.org/10.3390/ijerph16173186

Klemm, J., Coffey, C., Balagamwala, M., Turowska, Z., Kuri, S., de Pee, S., 2024. Exploring the relationship between food environment indicators and dietary intake of children 6–23 months old; findings from 20 low and lower-middle income countries. Glob Food Sec 42. https://doi.org/10.1016/j.gfs.2024.100795

Kushitor, S.B., Alangea, D.O., Aryeetey, R., de-Graft Aikins, A., 2023. Dietary patterns among adults in three lowincome urban communities in Accra, Ghana. PLoS One 18. https://doi.org/10.1371/journal.pone.0293726

Laar, A., Amoah, J.M., Massawudu, L.M., Pereko, K.K.A., Yeboah-Nkrumah, A., Amevinya, G.S., Nanema, S., Odame, E.A., Agyekum, P.A., Mpereh, M., Sandaare, S., 2023. Making food-related health taxes palatable in sub-Saharan Africa: Lessons from Ghana. BMJ Glob Health 8. https://doi.org/10.1136/bmjgh-2023-012154

Landais, E., Miotto-Plessis, M., Bene, C., Maitre d'Hotel, E., Truong, M.T., Somé, J.W., Verger, E.O., 2023. Consumption of food away from home in low- and middle-income countries: a systematic scoping review. Nutr Rev 81, 727–754. https://doi.org/10.1093/nutrit/nuac085

Laska, M.N., Hearst, M.O., Forsyth, A., Pasch, K.E., Lytle, L., 2010. Neighbourhood food environments: Are they associated with adolescent dietary intake, food purchases and weight status? Public Health Nutr 13, 1757–1763. https://doi.org/10.1017/S1368980010001564

Liguori, J., Pradeilles, R., Laar, A., Zotor, F., Tandoh, A., Klomegah, S., Osei-Kwasi, H.A., Le Port, A., Bricas, N., Aryeetey, R., Akparibo, R., Griffiths, P., Holdsworth, M., 2022. Individual-level drivers of dietary behaviour in adolescents and women through the reproductive life course in urban Ghana: A Photovoice study. Matern Child Nutr 18. https://doi.org/10.1111/mcn.13412

Liu, J., Lee, Y., Micha, R., Li, Y., Mozaffarian, D., 2021. Trends in junk food consumption among US children and adults, 2001-2018. American Journal of Clinical Nutrition 114, 1039–1048. https://doi.org/10.1093/ajcn/nqab129

Madzorera, I., Bromage, S., Mwanyika-Sando, M., Vandormael, A., Sherfi, H., Worku, A., Shinde, S., Noor, R.A., Baernighausen, T., Sharma, D., Fawzi, W.W., 2023. Dietary intake and quality for young adolescents in sub-Saharan Africa: Status and influencing factors. Matern Child Nutr. https://doi.org/10.1111/mcn.13463

McInerney, M., Csizmadi, I., Friedenreich, C.M., Uribe, F.A., Nettel-Aguirre, A., McLaren, L., Potestio, M., Sandalack, B., McCormack, G.R., 2016. Associations between the neighbourhood food environment, neighbourhood socioeconomic status, and diet quality: An observational study. BMC Public Health 16. https://doi.org/10.1186/s12889-016-3631-7

Mercille, G., Richard, L., Gauvin, L., Kestens, Y., Shatenstein, B., Daniel, M., Payette, H., 2016. The food environment and diet quality of urban-dwelling older women and men: Assessing the moderating role of diet knowledge. Canadian Journal of Public Health 107, eS34–eS41. https://doi.org/10.17269/CJPH.107.5309

Mockshell, J., Ogutu, S.O., Álvarez, D., Asante-Addo, C., Asante, F.A., 2022. How healthy and food secure is the urban food environment in Ghana? World Dev Perspect 26. https://doi.org/10.1016/j.wdp.2022.100427

Moitra, P., Verma, P., Madan, J., 2021. Development and validation of a questionnaire measuring knowledge, attitudes, and practices (KAP) to healthy eating and activity patterns in school children (HEAPS). Nutr Health 27, 199–209. https://doi.org/10.1177/0260106020982356

Nakamura, R., Mirelman, A.J., Cuadrado, C., Silva-Illanes, N., Dunstan, J., Suhrcke, M., 2018. Evaluating the 2014 sugar-sweetened beverage tax in Chile: An observational study in urban areas. PLoS Med 15. https://doi.org/10.1371/journal.pmed.1002596

Nollen, N.L., Befort, C.A., Snow, P., Daley, C.M., Ellerbeck, E.F., Ahluwalia, J.S., 2007. The school food environment and adolescent obesity: qualitative insights from high school principals and food service personnel. International Journal of Behavioral Nutrition and Physical Activity 4, 18. https://doi.org/10.1186/1479

Norris, S.A., Frongillo, E.A., Black, M.M., Dong, Y., Fall, C., Lampl, M., Liese, A.D., Naguib, M., Prentice, A., Rochat, T., Stephensen, C.B., Tinago, C.B., Ward, K.A., Wrottesley, S. V, Patton, G.C., 2022. Nutrition in adolescent growth and development. The Lancet 399, 172–184. https://doi.org/10.1016/S0140-6736(21)01590-7

Ogum-Alangea, D., Aryeetey, R.N.O., Gray, H.L., Laar, A.K., Adanu, R.M.K., 2020. Basic school pupils' food purchases during mid-morning break in urban Ghanaian schools. PLoS One 15, e0238308. https://doi.org/10.1371/journal.pone.0238308

O'Meara, L., De Bruyn, J., Dominguez-Salas, P., Hope, T., Turner, C., Stoynova, M., Wellard, K., Ferguson, E., 2023. Characteristics of food environments that influence food acquisition and diets of women in low- and middle-income countries: a scoping review protocol. JBI Evid Synth. https://doi.org/10.11124/JBIES-22-00299

Osei-Kwasi, H., Mohindra, A., Booth, A., Laar, A., Wanjohi, M., Graham, F., Pradeilles, R., Cohen, E., Holdsworth, M., 2020. Factors influencing dietary behaviours in urban food environments in Africa: A systematic mapping review. Public Health Nutr. https://doi.org/10.1017/S1368980019005305

Oster, E., 2019. Unobservable Selection and Coefficient Stability: Theory and Evidence. Journal of Business & Economic Statistics 37, 187–204. https://doi.org/10.1080/07350015.2016.1227711

Pradeilles, R., Irache, A., Wanjohi, M.N., Holdsworth, M., Laar, A., Zotor, F., Tandoh, A., Klomegah, S., Graham, F., Muthuri, S.K., Kimani-Murage, E.W., Coleman, N., Green, M.A., Osei-Kwasi, H.A., Bohr, M., Rousham, E.K., Asiki, G., Akparibo, R., Mensah, K., Aryeetey, R., Bricas, N., Griffiths, P., 2021. Urban physical food environments drive dietary behaviours in Ghana and Kenya: A photovoice study. Health Place 71. https://doi.org/10.1016/j.healthplace.2021.102647

Saavedra-Garcia, L., Meza-Hernández, M., Yabiku-Soto, K., Hernández-Vásquez, A., Kesar, H. V., Mejia-Victorio, C., Diez-Canseco, F., 2020. Food and beverage supply and advertising in schools and their surroundings in metropolitan lima. An exploratory study. Rev Peru Med Exp Salud Publica 37, 726–732. https://doi.org/10.17843/rpmesp.2020.374.5838

Salgado Hernández, Juan Carlos, Basto-Abreu, A., Junquera-Badilla, I., Moreno-Aguilar, L.A., Barrientos-Gutiérrez, T., Colchero, M.A., 2023. Building upon the sugar beverage tax in Mexico: A modelling study of tax alternatives to increase benefits. BMJ Glob Health 8. https://doi.org/10.1136/bmjgh-2023-012227

Salgado Hernández, J. C., Ng, S.W., Colchero, M.A., 2023. Changes in sugar-sweetened beverage purchases across the price distribution after the implementation of a tax in Mexico: a before-and-after analysis. BMC Public Health 23. https://doi.org/10.1186/s12889-023-15041-y

Sambu, W.C., Picchioni, F., Stevano, S., Codjoe, E.A., Nkegbe, P.K., Turner, C., 2024. Food systems thinking unpacked: a scoping review on industrial diets among adolescents in Ghana. Food Secur. https://doi.org/10.1007/s12571-023-01408-x

Sauer, C.M., Reardon, T., Tschirley, D., Liverpool-Tasie, S., Awokuse, T., Alphonce, R., Ndyetabula, D., Waized, B., 2021. Consumption of processed food & food away from home in big cities, small towns, and rural areas of Tanzania. Agricultural Economics (United Kingdom) 52, 749–770. https://doi.org/10.1111/agec.12652

Soliman, G.A., Barnoya, J., Malik, V., Laar, A., 2022. Advertising of unhealthy foods and beverages around primary and junior high schools in Ghana's most urbanized and populous region. Front. Public Health. https://doi.org/10.3389/fpubh.2022.917456

Stacey, N., Edoka, I., Hofman, K., Swart, E.C., Popkin, B., Ng, S.W., 2021. Changes in beverage purchases following the announcement and implementation of South Africa's Health Promotion Levy: an observational study. Lancet Planet Health 5, e200–e208. https://doi.org/10.1016/S2542-5196(20)30304-1

Tandoh, A., Laar, A., Pradeilles, R., Le Port, A., Osei-Kwasi, H., Amevinya, G.S., Aryeetey, R.N.O., Agyemang, C., Holdsworth, M., 2023. Addressing the marketing and availability of unhealthy food and beverages in and around selected schools in Ghana: A community readiness appraisal. BMJ Open 13. https://doi.org/10.1136/bmjopen-2023-075166

Turner, C., Aggarwal, A., Walls, H., Herforth, A., Drewnowski, A., Coates, J., Kalamatianou, S., Kadiyala, S., 2018. Concepts and critical perspectives for food environment research: A global framework with implications for action in low- and middle-income countries. Glob Food Sec 18, 93–101. https://doi.org/10.1016/j.gfs.2018.08.003

Turner, C., Kalamatianou, S., Drewnowski, A., Kulkarni, B., Kinra, S., Kadiyala, S., 2020. Food Environment Research in Low- and Middle-Income Countries: A Systematic Scoping Review. Advances in Nutrition 11, 387–397. https://doi.org/10.1093/advances/nmz031

U.S. Department of Agriculture Agricultural Research Service, 2018. Away from Home: Percentages of Selected Nutrients Contributed by Food and Beverages Consumed Away from Home, by Race/Ethnicity and Age.

Uyar, B.T.M., Talsma, E.F., Herforth, A.W., Trijsburg, L.E., Vogliano, C., Pastori, G., Bekele, T.H., Huong, L.T., Brouwer, I.D., 2023. The DQQ is a Valid Tool to Collect Population-Level Food Group Consumption Data: A Study Among Women in Ethiopia, Vietnam, and Solomon Islands. Journal of Nutrition 340–351. https://doi.org/10.1016/j.tjnut.2022.12.014

Weil, K., Coulibaly, I., Fuelbert, H., Herrmann, A., Millogo, R.M., Danquah, I., 2023. Dietary patterns and their socioeconomic factors of adherence among adults in urban Burkina Faso: a cross-sectional study. J Health Popul Nutr 42. https://doi.org/10.1186/s41043-023-00451-w

Westbury, S., Ghosh, I., Jones, H.M., Mensah, D., Samuel, F., Irache, A., Azhar, N., Al-Khudairy, L., Iqbal, R., Oyebode, O., 2021. The influence of the urban food environment on diet, nutrition and health outcomes in low-income and middle-income countries: A systematic review. BMJ Glob Health 6. https://doi.org/10.1136/bmjgh-2021-006358

Protocol

Ethical approval for this study was obtained from the Ghana Health Service Ethical Review Committee (GHS ERC #021/08/22), the University of Ghana, Legon (ECH 064/ 22-23) and the Center of Development Research Ethics Committee at Bonn University (15c_22). We obtained written informed consent from all study participants: parents or legal guardians of all eligible students before their selection (n = 1510, response rate of parents >80%), and written assent from the students before conducting the survey. All eligible and selected students ("participants" from here on) assented to and completed the survey.

6. Discussion

The main aim of this research was to investigate nuances of the role of the food environment for the diet quality of children and adolescents in different settings. This was done by focussing on three conceptual areas: 1) External factors, especially price, availability and accessibility; 2) Individual factors, especially budget, cognitive and aspirational factors and socio-economic characteristics and 3) Spatial variation, especially the difference of food environment indicators on varying levels of scale.

We find that financial indicators among the external (food prices) and individual (food budget) factors are consistently associated with diet quality throughout the different studies and contexts (where this is part of the dataset). While attitudes and practices are associated with improved dietary balance, knowledge of the individual shows no or negative association with diet quality. Results from all studies show that variation within the food environment is associated with diet quality and that therefore the food environment needs to be considered as an important determinant of diet quality.

A detailed discussion for each specific research aim can be found in each of the respective publications 1-4 in Chapter 5. The following sections connect the results of the individual research aims and discuss them overarchingly with reference to the current literature (section 6.1). Subsequently, section 6.2. provides an overview of the strength and weaknesses of the conducted analyses. This chapter ends on the discussion of the relevance and policy implications of the findings (section 6.3.).

6.1. Conclusions from this research

Price

Key findings:

- *Food prices of NCD-Risk and NCD-Protect food are inversely associated with their consumption even after including individual-level factors.*
- *Relative caloric and minimum price show negative association with diet quality of young children across subnational areas in LMICs.*

Studies I, III and IV provide evidence that the pricing of foods is an important driver of diet quality, complementing established evidence that price and affordability are main barriers to nutrient-adequate or healthy diets [18,67,134–136].

These findings expand beyond the existing literature in two aspects: Firstly, these results suggests that with similar individual factors, variation in food environments are associated with different outcomes from a diet quality perspective. Some determinants of diet quality are outside the control of the individual, which carries important implications for public health policies, especially for minors and institutional mandates.

Secondly, food choices are also influenced by the relative price of foods. That is highly relevant because it emphasizes that individuals do not make their decision for each commodity individually but (have to) consider multiple options. This is consistent with studies showing that consumption adjusts to food price shocks [137,138]. Both findings reflect the alternative choices (poor) individuals have and emphasize the importance of considering food prices in a non-isolated manner and are in line with findings from a cross-country survey [67].

Availability and access

Key findings:

- *Food school environments are denser than other areas: We find more hotspots of food groups around schools than farther away.*
- *In the regression models, availability of foods appear to play a less important role, compared to financial constraints.*

Many studies carried out on the food environment in LMICs report high density of unfavourable foods – (ultra-)processed foods [43,60,74,78,79,139], sugar-sweetened beverages [62,70,96,140] or snacks [54,73,109,141]. Most of these did not include an observational measure of favourable foods, although some report on fruits and vegetables [42,120,142]. It is therefore unclear whether there is a shift in availability of favourable versus unfavourable foods or whether the food environment offers more options overall, while retaining the average density. While **study IV** confirms that there is more relative availability of unfavourable foods (than favourable ones) around schools, we find that this does not change with distance to school (within 300m).

Had this study only focussed on unfavourable food groups, it would have likely led to the conclusion that there are more unfavourable foods present around school than farther away. Additionally, it is important to emphasize that once we account for the price of food groups around the school, the observed number of hotspots of foods does not carry explanatory weight in our models. Hotspots of unfavourable foods around schools are not associated with higher consumption of these foods, once price differences between different schools are considered. While further research on the role of availability vis-à-vis economic drivers is therefore needed, these findings already imply relevant policy considerations (discussed below in section 6.3.).

In addition, study I reports association of food group assortment with consumption in young children. These are the same food groups for which price was associated with dietary intake. This suggests that availability could also serve as a proxy for food environment in contexts where price data is too resource-intensive to collect.

Cognitive, aspirational and economic individual factors

Key findings:

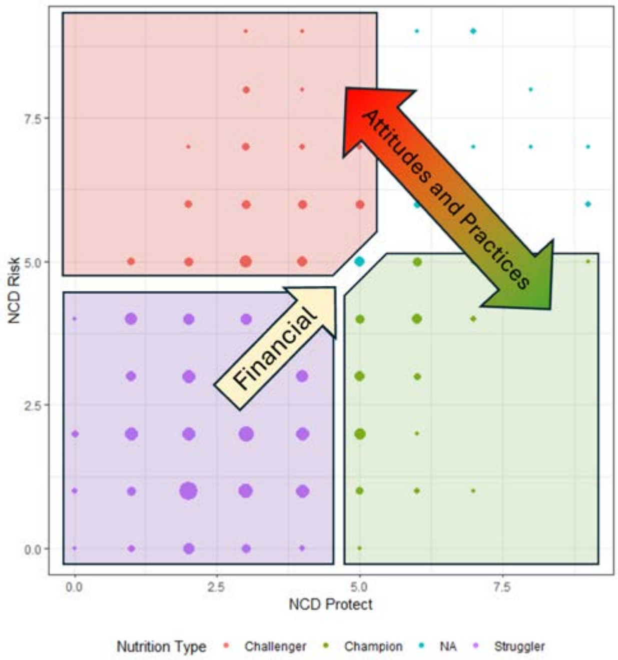
- *Higher budget is associated with slightly lower diet quality.*
- *There is no budget difference between groups that have a high diversity favourable diet and those that have a high diversity unfavourable diet.*

A well-established finding is that income, household food expenditure or share of food expenditure are associated with diet quality [66,143–146]. Individual economic constraints (and changes in these [147]) are consistently reported as barriers to adequate nutrition or healthy diets.

Our results show that in the urban contexts, for school-going adolescents, individuals with higher budget tend to have slightly lower diet quality (**study III**). Recent studies from Malawi and Tanzania have found similar patterns [55–57]: Income is associated with slightly deteriorated diet quality in urban contexts. **Study III** brings additional nuance to this by showing that increased budget of adolescents is associated with slightly lower diet quality due to (on average) higher intake of unfavourable food groups compared to intake of favourable food groups in individuals with higher budget.

An important finding in the context of individual factors is that we found no budget difference between our two groups with diverse diets – the negative (‘Challengers’) and positive deviants (‘Champions’). Being in the group with a low diversity diet (‘Strugglers’) is associated with lower budget. This suggests a hierarchy of drivers: Financial drivers are associated with higher diversity of diets and are a necessary condition for any type of food group diversity. Attitudes and practices, which are found to be the main differences between negative and positive deviants, form a second-order constraint, which can shape the direction in which diet diversity is balanced. Figure 3 outlines this conceptual idea in a simplified graphical manner.

Figure 3: Conceptual graph displaying the main drivers between movements of diversity and balance between favourable or more unfavourable patterns.



Spatial variation

Key findings:

- *Food environments are denser when closer to demand (e.g. schools), but the ratio between unfavourable and favourable foods – although skewed towards unfavourable – does not change.*
- *After accounting for socio-economic factors, we still find intra-city differences in intake among a homogenous HIC target group.*
- *In-country variation can be as high as variation across world bank income groups.*

A key secondary aim of this research was to provide improved understanding of the spatial variation of food environments. Food environments can be and are researched anywhere from the home [111,117,148,149], schools [47,54,59–62,106,107,112,150] to the neighbourhood [25,40,41,151–156]. It is therefore helpful to understand at which level we can find variation within food environments to sharpen the focus of future research and policies.

Results from this research show that there is relevant variation of food availability at the subnational (study I), inner-city (study II) and neighbourhood (study III and IV) level. Many studies report similar findings for specific food groups at different levels, including in

LMICs generally [74], urban settings [7,50,79,81,157] and around schools [54,60,73,158]. Our finding expands beyond the existing evidence in one important regard. Several studies imply that the variation of unfavourable foods is different than the variation of favourable foods [59,93,96,106]. We provide first – explorative – evidence that this is not the case. Instead, our findings offer an alternative hypothesis: that the density of food availability varies generally, but not systematically by type of foods on offer.

Another important insight can be generated from the different scope of the surveys carried out here: after accounting for individual socio-economic status, variation of diet intake remains within a homogenous study group in Dortmund, Germany. Although no food environment variables were included in the study design, evidence from studies in USA and UK would suggest that the food environment may influence these differences [30,36,159,160]. Intra-city variation of dietary intake had not been analysed in the German context prior to this. Our findings indicate that food environment variation could be a major constraint for diet quality even within a city in Germany.

6.2. Weaknesses and strengths of this approach

Weaknesses of some of the approaches listed here are i) the short and self-reported survey methodology, ii) unobserved variables and residual confounding, iii) lack of psychometric calibration of behavioural study tools and iv) lack of comparability due to varying sampling design and target group across studies. Limitations are extensively discussed in the respective manuscripts in Chapter 5. All of these limitations in our study design are among the main shortcomings of food environment research in general as described in systematic reviews on food environment research [122,123]. It should be noted that the concerns raised in those reviews typically come from a distinct disciplinary perspective and that multidisciplinary research – such as the work presented here – is often faced with trade-offs between disciplines and priorities.

A strength of this dissertation is its balance in the measurements of different food types and diet intake to expand beyond an obesogenic focus of food environment research. This is done by including three indicators of the DQQ-methodology (GDR, NCD-Risk and NCD-Protect Score). In addition to established (continuous) measures of diet quality, we also define three categorical groups that help distinguish the trade-offs when increasing diversity overall vs. increasing diversity of specific food groups. Our concept of the

“Strugglers”, “Challengers” and “Champions” evades the shortcoming of a linear diet score, such as the GDR, where a highly diverse diet can be numerically identical to a low-diversity diet, as long as the balance of the components remains comparable. This is beneficial because it combines the aspects of diversity (as each individual score does) with the aspects of balance (as the GDR does). It is informative as it allows us to draw comparisons between high-diversity diets that are on different ends of the spectrum in terms of the WHO recommended guidelines.

A second strength is that we include measures that are under-researched in the LMIC context, such as food price, and are able to report results with availability and price accounted for in the same model. Although mutually adjusted coefficients should be compared and interpreted with care [161], our findings support evidence on the dominance of the financial constraint.

Another strength of this work lies in including both economic and behavioural measurements as covariates, as well as accounting for internal and external factors. Many studies that do not explicitly capture the balance of different components report associations of budget or income with diversity of favourable foods or diversity of unfavourable foods. In our studies III and IV we show that higher budget alone is associated with slightly lower diet quality, but that the mechanism behind this is a slightly lower intake of favourable food groups. So far in research many of these elements have been given isolated attention, i.e. analysed individually. Considering these jointly emphasizes the interconnectedness, but also the relative strength they have in shaping diet quality.

6.3. Relevance and policy recommendations

Of major relevance to policy recommendations are two findings of this research: One, that different drivers are associated with the respective pathways of the WHO recommended healthy diet and two, that food prices are inversely associated with consumption of food groups. Our finding that increase and moderation of food groups follow different drivers aligns well with the concept of double-duty actions. Double-duty actions are actions that have the potential to simultaneously decrease the burden of undernutrition and overweight or diet-related NCDs. Additionally, in the cross-sectional comparison, higher food budget slightly decreases diet quality due to elevated intake of unfavourable foods. This suggests that with a growing middle-class and economy in most LMICs, an unmitigated trajectory will lead to deteriorated healthy diets.

Actions that support the reduction of unhealthy food group consumption are focussed on increasing the barriers for these foods and moderating the intake. Actions typically belong to one of three categories: Reformulation, regulation or taxation. Using the reference to the existing food environment domains, reformulation targets the domain of product characteristics (cf. Chapter 2). Regulation targets availability and promotion; and taxation targets food prices. Great potential exists in making foods more favourable through reformulation, for example by (i) fortification, (ii) providing favourable alternatives to processed foods, or (iii) reducing sugar or trans fats in convenience foods. Due to the focus of this dissertation on the physical food environment, I will mainly focus on the policy relevance of regulation and taxation for moderating the diet intake of unfavourable foods.

Regulation of the school food environment could take place by creating specific sets of rules for vendors at schools, regarding the availability or ratio of foods offered. This could be implemented by banning unfavourable items or setting an upper limit of unfavourable commodities that can be sold in exchange for a license to sell at schools. Additionally, taxes could be implemented to increase the price of unfavourable foods. Our findings suggest that an increase of prices for unfavourable food groups could lead to a decreased consumption. An implementation just at school would likely be met with challenges to enforce, however, studies looking at the impact of similar policies in South Africa [162], Mexico [71,163] and Chile [69,70] are overwhelmingly positive. Such tools are an efficient way to leverage the urban food environment to support the consumption of a healthy diet.

To improve consumption of favourable foods, actions typically belong to some of these categories: Food based dietary guidelines, behavioural prevention, creating incentives for vendors or providing subsidies. As in the moderating actions, these actions can be framed according to the common domains outlined in Chapter 2: Subsidies aim at the price domain, incentives for vendors focus on availability, food based dietary guidelines are a way of promoting healthy diets.

Food based dietary guidelines and other behavioural prevention methods, such as knowledge sessions, are a great tool to create awareness for nutrition. Our findings in study I emphasize that knowledge in itself is insufficient to improve dietary quality. While attitude towards healthy eating is important in striking a favourable balance of food groups, it requires sufficient budget to be realized. Other policy work has also emphasized that knowledge-based interventions alone are inadequate to improve diets [111,149]. Therefore, in addition to providing behavioural nudges, creating incentives for vendors to provide favourable foods and subsidizing favourable foods more generally are necessary to radically improve consumption of children and adolescents.

7. Summary and Outlook

Increased evidence suggests a potential negative influence of the food environment on diet quality. Children and adolescents are particularly vulnerable groups for inadequate diet quality. However, it was unclear which relative role the food environment has vis-à-vis individual level factors for these groups. The presented work provides evidence on this: Using the data from 20 LMICs, Germany and Ghana, we describe the characteristics that the food environment has and which role it plays in the diet quality of children and adolescents. Furthermore, we analyse the role of individual level factors and identify spatial variation of diet quality in different contexts that is likely attributable to the food environment.

Results of this research underscore the necessity of public-health interventions and policies embracing double duty actions for children and adolescents. These show that to increase the consumption of favourable foods financial barriers remain and that due to the socio-economic nature of drivers of diet quality, behavioural prevention alone is insufficient. Findings from this research also emphasize that regulation and taxation are effective tools to moderate intake of unfavourable foods in urban areas around schools. Researchers and other studies have already suggested a wide number of possible steps to regulate the food environment.

Future studies should focus on experimental design to gain more information on cost-optimal interventions and to strike the right balance between regulation and incentives. Additionally, replication studies with longitudinal design and larger study groups in different contexts could be helpful in confirming results presented here.

References

1. Global Panel. Improving nutrition through enhanced food environments. Policy Brief No. 7. London; 2017.
2. HLPE. Nutrition and food systems. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security [Internet]. Rome; 2017. Available from: www.fao.org/cfs/cfs-hlpe
3. Swinburn B, Sacks G, Vandevijvere S, Kumanyika S, Lobstein T, Neal B, et al. INFORMAS (International Network for Food and Obesity/non-communicable diseases Research, Monitoring and Action Support): Overview and key principles. Obesity Reviews. 2013. p. 1–12.
4. Atanasova P, Kusuma D, Pineda E, Frost G, Sassi F, Miraldo M. The impact of the consumer and neighbourhood food environment on dietary intake and obesity-related outcomes: A systematic review of causal impact studies. Soc Sci Med. 2022;299.
5. Shaw S, Barrett M, Shand C, Cooper C, Crozier S, Smith D, et al. Influences of the community and consumer nutrition environment on the food purchases and dietary behaviors of adolescents: A systematic review. Obesity Reviews. John Wiley and Sons Inc; 2023.
6. Pineda E, Stockton J, Scholes S, Lassale C, Mindell JS. Food environment and obesity: A systematic review and meta-analysis. BMJ Nutr Prev Health. 2024;7:204–11.
7. Westbury S, Ghosh I, Jones HM, Mensah D, Samuel F, Irache A, et al. The influence of the urban food environment on diet, nutrition and health outcomes in low-income and middle-income countries: A systematic review. BMJ Glob Health. 2021;6.
8. Turner C, Kalamatianou S, Drewnowski A, Kulkarni B, Kinra S, Kadiyala S. Food Environment Research in Low- and Middle-Income Countries: A Systematic Scoping Review. Advances in Nutrition. 2020;11:387–97.
9. Passarelli S, Free CM, Shepon A, Beal T, Batis C, Golden CD. Global estimation of dietary micronutrient inadequacies: a modelling analysis. Lancet Glob Health. 2024;12:e1590–9.
10. The triple burden of malnutrition. Nat Food. Springer Nature; 2023. p. 925.
11. Downs SM, Ahmed S, Fanzo J, Herforth A. Food environment typology: Advancing an expanded definition, framework, and methodological approach for improved characterization of wild, cultivated, and built food environments toward sustainable diets. Foods. 2020;9.
12. Turner C, Aggarwal A, Walls H, Herforth A, Drewnowski A, Coates J, et al. Concepts and critical perspectives for food environment research: A global framework with implications for action in low- and middle-income countries. Glob Food Sec. 2018;18:93–101.
13. World Health Organisation. Healthy diet factsheet no. 394 [Internet]. Geneva; 2018. Available from: http://www.who.int/mediacentre/factsheets/fs394/en/
14. Neufeld L, Hendriks S, Hugas M. Healthy Diet. A definition for the United Nations Food Systems Summit 2021. 2021 [cited 2024 Nov 14]; Available from: https://sc-fss2021.org/wp- content/uploads/2021/04/Healthy_Diet.pdf
15. Deptford A, Allieri T, Childs R, Damu C, Ferguson E, Hilton J, et al. Cost of the Diet: A method and software to calculate the lowest cost of meeting recommended intakes of energy and nutrients from local foods. BMC Nutr. 2017;3.

16. Turowska Z, Klemm J, de Pee S. Analyzing diet cost and affordability: A dataset from Fill the Nutrient Gap analyses (2015–2021). Glob Food Sec. 2024;42.
17. Herforth A, Bai Y, Venkat A, Mahrt K, Ebel A, Masters WA. Cost and affordability of healthy diets across and within countries. Background paper for The State of Food Security and Nutrition in the World 2020. Cost and affordability of healthy diets across and within countries. Rome: FAO; 2020 Dec.
18. Bai Y, Alemu R, Block SA, Headey D, Masters WA. Cost and affordability of nutritious diets at retail prices: Evidence from 177 countries. Food Policy. 2021;99.
19. Trijsburg L, Talsma EF, De Vries JHM, Kennedy G, Kuijsten A, Brouwer ID. Diet quality indices for research in low- and middle-income countries: A systematic review. Nutr Rev. Oxford University Press; 2019. p. 515–40.
20. Alkerwi A. Diet quality concept. Nutrition. Elsevier Inc.; 2014. p. 613–8.
21. Miller V, Webb P, Micha R, Mozaffarian D. Defining diet quality: a synthesis of dietary quality metrics and their validity for the double burden of malnutrition. Lancet Planet Health. Elsevier B.V.; 2020. p. e352–70.
22. Ruel MT. Operationalizing Dietary Diversity: A Review of Measurement Issues and Research Priorities. J. Nutr. 2003.
23. Fanzo J, Haddad L, McLaren R, Marshall Q, Davis C, Herforth A, et al. The Food Systems Dashboard is a new tool to inform better food policy. Nat Food. Springer Nature; 2020. p. 243–6.
24. Toure D, Herforth A, Pelto GH, Neufeld LM, Mbuya MN. An Emergent Framework of the Market Food Environment in Low-and Middle-Income Countries. Curr Dev Nutr [Internet]. 2021; Available from: https://academic.oup.com/cdn/.
25. Morland K, Wing S, Roux AD, Poole C. Neighborhood Characteristics Associated with the Location of Food Stores and Food Service Places. Am J Prev Med. 2002;22:23–9.
26. Cummins S, Macintyre S. "Food deserts"-evidence and assumption in health policy making. British Journal of Medicine [Internet]. 2002;325:436–8. Available from: http://dictionary.oed.com/cgi/
27. Cummins SCJ. The Local Food Environment and Health: Some Reflections from the United Kingdom. Am J Public Health. 2003;93:521.
28. Shaw HJ. Food deserts: Towards the development of a classification. Geogr Ann Ser B. 2006;88:231–47.
29. Beaulac J, Kristjansson E, Cummins S. A Systematic Review of Food Deserts, 1966-2007. Prev Chronic Dis [Internet]. 2009;6:1–10. Available from: http://www.cdc.gov/pcd/issues/2009/jul/08_0163.htm.Accessed[date].
30. Hager ER, Cockerham A, O'Reilly N, Harrington D, Harding J, Hurley KM, et al. Food swamps and food deserts in Baltimore City, MD, USA: Associations with dietary behaviours among urban adolescent girls. Public Health Nutr. 2017;20:2598–607.
31. Augustin H. Stadt, Ernährung und soziale Ungleichheit [Internet]. artec-paper. Bremen: artec Forschungszentrum Nachhaltigkeit; 2014 Apr. Report No.: 197. Available from: www.uni-bremen.de/artec
32. Blanchard TC, Lyson TA, Blanchard T. Retail Concentration, Food Deserts, and Food Disadvantaged Communities in Rural America.
33. Smith C, Morton LW. Rural Food Deserts: Low-income Perspectives on Food Access in Minnesota and Iowa. J Nutr Educ Behav. 2009;41:176–87.
34. Schafft KA, Jensen EB, Hinrichs CC. Food Deserts and Overweight Schoolchildren: Evidence from Pennsylvania. Rural Sociol. 2009;74:153–77.

35. Cooksey-Stowers K, Schwartz MB, Brownell KD. Food swamps predict obesity rates better than food deserts in the United States. Int J Environ Res Public Health. 2017;14:1366.
36. Rose D, Bodor JN, Swalm CM, Rice JC, Farley TA, Hutchinson PL. Deserts in New Orleans? Illustrations of urban food access and implications for policy. Michigan: University of Michigan; 2009 Feb.
37. Hendrickson D, Smith C, Eikenberry N. Fruit and vegetable access in four low-income food deserts communities in Minnesota. Agric Human Values. 2006;23:371–83.
38. Walker RE, Keane CR, Burke JG. Disparities and access to healthy food in the United States: A review of food deserts literature. Health Place. 2010;16:876–84.
39. Barbosa BB, Nielsen L, de Aguiar BS, Failla MA, Araújo LF, Mendes LL, et al. Local Food Environment and Consumption of Ultra-Processed Foods: Cross-Sectional Data from the Nutritionists' Health Study—NutriHS. Int J Environ Res Public Health. 2023;20:6749.
40. Laska MN, Hearst MO, Forsyth A, Pasch KE, Lytle L. Neighbourhood food environments: Are they associated with adolescent dietary intake, food purchases and weight status? Public Health Nutr. 2010;13:1757–63.
41. Black C, Moon G, Baird J. Dietary inequalities: What is the evidence for the effect of the neighbourhood food environment? Health Place. Elsevier Ltd; 2014. p. 229–42.
42. Bruna Vieira de Lima Costa, Cláudia Di Lorenzo Oliveira, Aline Cristine Souza Lopes. Food environment of fruits and vegetables in the territory of the Health Academy Program. Cad Saúde Pública [Internet]. 2015; Available from: http://www.pbh.gov.br
43. Vedovato GM, Trude ACB, Kharmats AY, Martins PA. Degree of food processing of household acquisition patterns in a Brazilian urban area is related to food buying preferences and perceived food environment. Appetite. 2015;87:296–302.
44. Herforth A, Ahmed S. The food environment, its effects on dietary consumption, and potential for measurement within agriculture-nutrition interventions. Food Secur. 2015;7:505–20.
45. FAO. Influencing Food Environments for Healthy Diets [Internet]. 2016. Available from: www.fao.org/publications
46. Hansen KL, Golubovic S, Eriksen CU, Jørgensen T, Toft U. Effectiveness of food environment policies in improving population diets: a review of systematic reviews. Eur J Clin Nutr. Springer Nature; 2022. p. 637–46.
47. Williams J, Scarborough P, Matthews A, Cowburn G, Foster C, Roberts N, et al. A systematic review of the influence of the retail food environment around schools on obesity-related outcomes. Obesity Reviews. 2014;15:359–74.
48. Engler-Stringer R, Le H, Gerrard A, Muhajarine N. The community and consumer food environment and children's diet: A systematic review. BMC Public Health. BioMed Central Ltd.; 2014.
49. Micha R, Karageorgou D, Bakogianni I, Trichia E, Whitsel LP, Story M, et al. Effectiveness of school food environment policies on children's dietary behaviors: A systematic review and meta-analysis. PLoS One. Public Library of Science; 2018.
50. Osei-Kwasi H, Mohindra A, Booth A, Laar A, Wanjohi M, Graham F, et al. Factors influencing dietary behaviours in urban food environments in Africa: A systematic mapping review. Public Health Nutr. Cambridge University Press; 2020. p. 2584–601.
51. Carducci B, Oh C, Keats EC, Roth DE, Bhutta ZA. Effect of food environment interventions on anthropometric outcomes in school-aged children and adolescents in

low- And middle-income countries: A systematic review and meta-analysis. Curr Dev Nutr. 2020;4.
52. Downs S, Demmler KM. Food environment interventions targeting children and adolescents: A scoping review. Glob Food Sec. 2020;27.
53. FAO, IFAD, UNICEF, WFP, WHO. The State of Food Security and Nutrition in the World 2024. The State of Food Security and Nutrition in the World 2024. FAO; IFAD; UNICEF; WFP; WHO; 2024.
54. Ogum-Alangea D, Aryeetey RNO, Gray HL, Laar AK, Adanu RMK. Basic school pupils' food purchases during mid-morning break in urban Ghanaian schools. PLoS One [Internet]. 2020;15:e0238308. Available from: http://dx.doi.org/10.1371/journal.pone.0238308
55. Ignowski L, Belton B, Tran N, Ameye H. Dietary inadequacy in Tanzania is linked to the rising cost of nutritious foods and consumption of food-away-from-home. Glob Food Sec. 2023;37.
56. Ameye H. Dietary quality in rural areas, secondary towns, and cities: Insights from Tanzania. Food Secur. 2023;15:1563–84.
57. Hülsen V, Khonje MG, Qaim M. Market food environments and child nutrition. Food Policy. 2024;128.
58. Iyassu A, Laillou A, Tilahun K, Workneh F, Mogues S, Chitekwe S, et al. The influence of adolescents' nutrition knowledge and school food environment on adolescents' dietary behaviors in urban Ethiopia: A qualitative study. Matern Child Nutr. 2023;
59. Chew A, Moran A, Barnoya J. Food swamps surrounding schools in three areas of guatemala. Prev Chronic Dis. 2020;17.
60. Leite FHM, De Oliveira MA, Cremm EDC, De Abreu DSC, Maron LR, Martins PA. Availability of processed foods in the perimeter of public schools in urban areas. J Pediatr (Rio J). 2012;88:328–34.
61. Pinheiro AC, Quintiliano-Scarpelli D, Flores JA, Álvarez C, Suárez-Reyes M, Palacios JL, et al. Food Availability in Different Food Environments Surrounding Schools in a Vulnerable Urban Area of Santiago, Chile: Exploring Socioeconomic Determinants. Foods. 2022;11.
62. Tandoh A, Laar A, Pradeilles R, Le Port A, Osei-Kwasi H, Amevinya GS, et al. Addressing the marketing and availability of unhealthy food and beverages in and around selected schools in Ghana: A community readiness appraisal. BMJ Open. 2023;13.
63. Ganle JK, Boakye PP, Baatiema L. Childhood obesity in urban Ghana: Evidence from a cross-sectional survey of in-school children aged 5-16 years. BMC Public Health. 2019;19.
64. Liguori J, Pradeilles R, Laar A, Zotor F, Tandoh A, Klomegah S, et al. Individual-level drivers of dietary behaviour in adolescents and women through the reproductive life course in urban Ghana: A Photovoice study. Matern Child Nutr. 2022;18.
65. Fernandes M, Folson G, Aurino E, Gelli A. A free lunch or a walk back home? The school food environment and dietary behaviours among children and adolescents in Ghana. Food Secur. 2017;9:1073–90.
66. Muhammad A, D'Souza A, Meade B, Micha R, Mozaffarian D. How income and food prices influence global dietary intakes by age and sex: Evidence from 164 countries. BMJ Glob Health. 2017;2.

67. Headey DD, Alderman HH. The Relative Caloric Prices of Healthy and Unhealthy Foods Differ Systematically across Income Levels and Continents. Journal of Nutrition. 2019;149:2020–33.
68. Pineda E, Bascunan J, Sassi F. Improving the school food environment for the prevention of childhood obesity: What works and what doesn't. Obesity Reviews. Blackwell Publishing Ltd; 2021.
69. Nakamura R, Mirelman AJ, Cuadrado C, Silva-Illanes N, Dunstan J, Suhrcke M. Evaluating the 2014 sugar-sweetened beverage tax in Chile: An observational study in urban areas. PLoS Med. 2018;15.
70. Cuadrado C, Dunstan J, Silva-Illanes N, Mirelman AJ, Nakamura R, Suhrcke M. Effects of a sugar-sweetened beverage tax on prices and affordability of soft drinks in Chile: A time series analysis. Soc Sci Med. 2020;245.
71. Salgado Hernández JC, Ng SW, Colchero MA. Changes in sugar-sweetened beverage purchases across the price distribution after the implementation of a tax in Mexico: a before-and-after analysis. BMC Public Health. 2023;23.
72. Sambu WC, Picchioni F, Stevano S, Codjoe EA, Nkegbe PK, Turner C. Food systems thinking unpacked: a scoping review on industrial diets among adolescents in Ghana. Food Secur. Springer Science and Business Media B.V.; 2024. p. 79–114.
73. Abizari AR, Ali Z. Dietary patterns and associated factors of schooling Ghanaian adolescents. J Health Popul Nutr. 2019;38:5.
74. Monteiro CA, Moubarac JC, Cannon G, Ng SW, Popkin B. Ultra-processed products are becoming dominant in the global food system. Obesity Reviews. 2013. p. 21–8.
75. Monteiro CA, Cannon G, Moubarac JC, Levy RB, Louzada MLC, Jaime PC. The UN Decade of Nutrition, the NOVA food classification and the trouble with ultra-processing. Public Health Nutr. Cambridge University Press; 2017. p. 5–17.
76. MacHado PP, Steele EM, Levy RB, Sui Z, Rangan A, Woods J, et al. Ultra-processed foods and recommended intake levels of nutrients linked to non-communicable diseases in Australia: Evidence from a nationally representative cross-sectional study. BMJ Open. 2019;9.
77. Matos RA, Adams M, Sabaté J. Review: The Consumption of Ultra-Processed Foods and Non-communicable Diseases in Latin America. Front Nutr. Frontiers Media S.A.; 2021.
78. Sauer CM, Reardon T, Tschirley D, Liverpool-Tasie S, Awokuse T, Alphonce R, et al. Consumption of processed food & food away from home in big cities, small towns, and rural areas of Tanzania. Agricultural Economics (United Kingdom). 2021;52:749–70.
79. Colozza D. A qualitative exploration of ultra-processed foods consumption and eating out behaviours in an Indonesian urban food environment. Nutr Health. 2022;
80. Mensah P, Yeboah-Manu D, Owusu-Darko K, Ablordey A. Street foods in Accra, Ghana: How safe are they? Bull World Health Organ. 2002;80:546–54.
81. Mockshell J, Ogutu SO, Álvarez D, Asante-Addo C, Asante FA. How healthy and food secure is the urban food environment in Ghana? World Dev Perspect. 2022;26.
82. Hawkes C. MARKETING FOOD TO CHILDREN: Changes in the Global Regulatory Environment. 2004.
83. Reisch LA, Gwozdz W, Barba G, De Henauw S, Lascorz N, Pigeot I. Experimental evidence on the impact of food advertising on children's knowledge about and preferences for healthful food. J Obes. 2013;2013.

84. Story M, French S. International Journal of Behavioral Nutrition and Physical Activity Food Advertising and Marketing Directed at Children and Adolescents in the US [Internet]. 2004. Available from: http://www.ijbnpa.org/content/1/1/3
85. Signal LN, Stanley J, Smith M, Barr MB, Chambers TJ, Zhou J, et al. Children's everyday exposure to food marketing: An objective analysis using wearable cameras. International Journal of Behavioral Nutrition and Physical Activity. 2017;14.
86. Prinz P. The role of dietary sugars in health: molecular composition or just calories? Eur J Clin Nutr. NLM (Medline); 2019. p. 1216–23.
87. Wem A, Den V, Msc W. Nutrition labelling: purpose, scientific issues and challenges. S68 Asia Pacific J Clin Nutr. 2002.
88. Fichera E, von Hinke S. The response to nutritional labels: Evidence from a quasi-experiment. J Health Econ. 2020;72.
89. Courbet D, Jacquemier L, Hercberg S, Touvier M, Sarda B, Kesse-Guyot E, et al. A randomized controlled trial to test the effects of displaying the Nutri-Score in food advertising on consumer perceptions and intentions to purchase and consume. International Journal of Behavioral Nutrition and Physical Activity. 2024;21.
90. Jurkenbeck K, Mehlhose C, Zuhlsdorf A. The influence of the Nutri-Score on the perceived healthiness of foods labelled with a nutrition claim of sugar. PLoS One. 2022;17.
91. McGeown L. The calorie counter-intuitive effect of restaurant menu calorie labelling. Canadian Journal of Public Health. Springer; 2019. p. 816–20.
92. Besancon S, Beran D, Batal M. A study is 21 times more likely to find unfavourable results about the nutrition label Nutri-Score if the authors declare a conflict of interest or the study is funded by the food industry. BMJ Glob Health. BMJ Publishing Group; 2023.
93. Saavedra-Garcia L, Meza-Hernández M, Yabiku-Soto K, Hernández-Vásquez A, Kesar H V., Mejia-Victorio C, et al. Food and beverage supply and advertising in schools and their surroundings in metropolitan lima. An exploratory study. Rev Peru Med Exp Salud Publica. 2020;37:726–32.
94. Alcaraz A, Pichon-Riviere A, Palacios A, Bardach A, Balan DJ, Perelli L, et al. Sugar sweetened beverages attributable disease burden and the potential impact of policy interventions: a systematic review of epidemiological and decision models. BMC Public Health. 2021;21:1460.
95. Kalog GLS, Kasim F, Anyebuno B, Tei S, Kubuga CK, Mogre V, et al. Food advertisement influences food decision making and not nutritional status: a study among university students in Ghana. BMC Nutr. 2022;8.
96. Soliman GA, Barnoya J, Malik V, Laar A. Advertising of unhealthy foods and beverages around primary and junior high schools in Ghana's most urbanized and populous region. Front Public Health. 2022;
97. Sight and Life. Nutrient Profiling: Designing a Healthier Future for Global Benefit. Basel; 2021.
98. Laar A, Amoah JM, Massawudu LM, Pereko KKA, Yeboah-Nkrumah A, Amevinya GS, et al. Making food-related health taxes palatable in sub-Saharan Africa: Lessons from Ghana. BMJ Glob Health. 2023;8.
99. Holdsworth M, Pradeilles R, Tandoh A, Green M, Wanjohi M, Zotor F, et al. Unhealthy eating practices of city-dwelling Africans in deprived neighbourhoods: Evidence for policy action from Ghana and Kenya. Glob Food Sec. 2020;26.

100. Trumbo PR, Bleiweiss-Sande R, Campbell JK, Decker E, Drewnowski A, Erdman JW, et al. Toward a science-based classification of processed foods to support meaningful research and effective health policies. Front Nutr. 2024;11.
101. Hall KD, Ayuketah A, Brychta R, Cai H, Cassimatis T, Chen KY, et al. Ultra-Processed Diets Cause Excess Calorie Intake and Weight Gain: An Inpatient Randomized Controlled Trial of Ad Libitum Food Intake. Cell Metab. 2019;30:67-77.e3.
102. Rose D, Wadhwa A, Bottone R, Miller D, Hjelm L, Mathiassen A, et al. Food Security Assessment at WFP: Report on Continued Development and Testing of a Standardized Approach. 2013.
103. Lele U, Masters WA, Kinabo J, Meenakshi J V, Ramaswami B, Tagwireyi J, et al. Technical Working Group on Measuring Food and Nutrition Security Measuring Food and Nutrition Security: An Independent Technical Assessment and User's Guide for Existing Indicators [Internet]. 2016. Available from: http://www.fsincop.net/topics/fns-
104. Carducci B, Oh C, Keats EC, Roth DE, Bhutta ZA. Effect of food environment interventions on anthropometric outcomes in school-aged children and adolescents in low- And middle-income countries: A systematic review and meta-analysis. Curr Dev Nutr. Oxford University Press; 2020.
105. Shahi PV, Shrestha RM, Schreinemachers P, Shibanuma A, Kiriya J, Ong KIC, et al. Identifying positive and negative deviants and factors associated with healthy dietary practices among young schoolchildren in Nepal: a mixed methods study. BMC Nutr. 2023;9.
106. Barrera LH, Rothenberg SJ, Barquera S, Cifuentes E. The Toxic Food Environment Around Elementary Schools and Childhood Obesity in Mexican Cities. Am J Prev Med. 2016;51:264–70.
107. Omidvar N, Babashahi M, Abdollahi Z, Al-Jawaldeh A. Enabling food environment in kindergartens and schools in iran for promoting healthy diet: Is it on the right track? Int J Environ Res Public Health. 2021;18.
108. de Bont J, Márquez S, Fernández-Barrés S, Warembourg C, Koch S, Persavento C, et al. Urban environment and obesity and weight-related behaviours in primary school children. Environ Int. 2021;155.
109. Govender K, Naicker A, Napier C, Singh D. School snacking preferences of children from a low socio-economic status community in South Africa. Journal of Consumer Sciences. 2018;3:1–10.
110. Prados MJ, Nicosia N, Datar A. Impact of built, social, and economic environments on adolescent obesity and related health behaviors. Obesity. 2023;31:1085–94.
111. Tabbakh T, Freeland-Graves JH. The home environment: A mediator of nutrition knowledge and diet quality in adolescents. Appetite. 2016;105:46–52.
112. Azeredo CM, de Rezende LFM, Canella DS, Claro RM, Peres MFT, Luiz O do C, et al. Food environments in schools and in the immediate vicinity are associated with unhealthy food consumption among Brazilian adolescents. Prev Med (Baltim). 2016;88:73–9.
113. Zuccolotto DC, Barbieri P, Saes Sartorelli D. Food environment and family support in relation to fruit and vegetable intake in pregnant women [Internet]. 2015. Available from: http://msm.dife.de.
114. Anggraini R, Februhartanty J, Bardosono S, Khusun H, Worsley A. Food Store Choice among Urban Slum Women Is Associated with Consumption of Energy-Dense Food. Asia Pac J Public Health. 2016;28:458–68.

115. Kupka R, Siekmans K, Beal T. The diets of children: Overview of available data for children and adolescents. Glob Food Sec. 2020;26.
116. Norris SA, Frongillo EA, Black MM, Dong Y, Fall C, Lampl M, et al. Nutrition in adolescent growth and development. The Lancet [Internet]. 2022;399:172–84. Available from: https://doi.org/10.1016/S0140-6736(21)01590-7
117. Landais E, Miotto-Plessis M, Bene C, Maitre d'Hotel E, Truong MT, Somé JW, et al. Consumption of food away from home in low- and middle-income countries: a systematic scoping review. Nutr Rev. 2023;81:727–54.
118. Getis A. A History of the Concept of Spatial Autocorrelation: A Geographer's Perspective. Geogr Anal. 2008;40.
119. Getis A, Ord JK. The Analysis of Spatial Association by Use of Distance Statistics. Geogr Anal. 1992;24:189–206.
120. Duran AC, De Almeida SL, Latorre MDR Do, Jaime PC. The role of the local retail food environment in fruit, vegetable and sugar-sweetened beverage consumption in Brazil. Public Health Nutr. 2016;19:1093–102.
121. Davies G, Frausin G, Parry L. Are There Food Deserts in Rainforest Cities? Ann Am Assoc Geogr. 2017;107:794–811.
122. Kirkpatrick SI, Reedy J, Butler EN, Dodd KW, Subar AF, Thompson FE, et al. Dietary assessment in food environment research: A systematic review. Am J Prev Med. 2014;46:94–102.
123. Lytle LA, Sokol RL. Measures of the food environment: A systematic review of the field, 2007–2015. Health Place. Elsevier Ltd; 2017. p. 18–34.
124. Lane HG, Calvert HG, Deitch R, Harris R, Babatunde OT, Turner L, et al. A systematic review of existing observational tools to measure the food and physical activity environment in schools. Health Place. Elsevier Ltd; 2020.
125. Kroke A, Manz F, Kersting M, Remer T, Sichert-Hellert W, Alexy U, et al. The DONALD Study: History, current status and future perspectives. Eur J Nutr. 2004;43:45–54.
126. Lampert T, Müters S, Stolzenberg H, Kroll LE. Messung des sozioökonomischen Status in der KiGGS-Studie: Erste Folgebefragung (KiGGS Welle 1). Bundesgesundheitsblatt Gesundheitsforschung Gesundheitsschutz. 2014;57:762–70.
127. Moitra P, Verma P, Madan J. Development and validation of a questionnaire measuring knowledge, attitudes, and practices (KAP) to healthy eating and activity patterns in school children (HEAPS). Nutr Health. 2021;27:199–209.
128. Fautsch Macías Yvette, Glasauer Peter, Food and Agriculture Organization of the United Nations. Guidelines for assessing nutrition-related knowledge, attitudes and practices : KAP manual [Internet]. Food and Agriculture Organization of the United Nations; 2014 [cited 2024 Feb 7]. Available from: https://www.fao.org/3/i3545e/i3545e00.htm
129. UNICEF, WHO, World Bank. Joint Malnutrition Estimates Database. https://data.unicef.org/resources/unicef-who-world-bank-joint-child-malnutrition-estimates-2023-edition-interactive-dashboard-2/. 2021.
130. Demographic and Health Surveys (DHS) Program. The DHS Program indicator data API. https://api.dhsprogram.com/#/index.html. 2022.
131. Perrar I, Alexy U, Nöthlings U. Cohort profile update–overview of over 35 years of research in the Dortmund Nutritional and Anthropometric Longitudinally Designed (DONALD) study. Eur J Nutr. 2024;63:727–40.
132. Herforth AW, Wiesmann D, Martínez-Steele E, Andrade G, Monteiro CA. Introducing a Suite of Low-Burden Diet Quality Indicators That Reflect Healthy Diet Patterns at

Population Level. Curr Dev Nutr [Internet]. 2020;4. Available from: https://academic.oup.com/cdn/.
133. Benjamini Y, Hochberg Y. Controlling the False Discovery Rate: A practical and powerful approach to multiple testing. Journal of the Royal Statistical Society [Internet]. 1995 [cited 2023 Dec 8];57:289–300. Available from: https://www.jstor.org/stable/2346101
134. Kuri S, Turowska Z, Damu C, Klemm J, de Pee S. Affordability of nutrient-adequate diets as an indicator for food and nutrition security. Evidence from fill the nutrient gap analyses. Glob Food Sec. 2024;42.
135. Headey D, Ruel M. Food inflation and child undernutrition in low and middle income countries. Nat Commun. 2023;14.
136. Darmon N, Drewnowski A. Contribution of food prices and diet cost to socioeconomic disparities in diet quality and health: A systematic review and analysis. Nutr Rev. 2015;73:643–60.
137. Cornelsen L, Green R, Turner R, Dangour AD, Shankar B, Mazzocchi M, et al. What happens to patterns of food consumption when food prices change? Evidence from a systematic review and meta-analysis of food price elasticities globally. Health Economics (United Kingdom). 2015;24:1548–59.
138. Green R, Cornelsen L, Dangour AD, Honorary RT, Shankar B, Mazzocchi M, et al. The effect of rising food prices on food consumption:systematic review with meta-regression. BMJ (Online). 2013;347.
139. Chen X, Zhang Z, Yang H, Qiu P, Wang H, Wang F, et al. Consumption of ultra-processed foods and health outcomes: A systematic review of epidemiological studies. Nutr J. BioMed Central Ltd; 2020.
140. Malik VS, Hu FB. The role of sugar-sweetened beverages in the global epidemics of obesity and chronic diseases. Nat Rev Endocrinol. 2022;18:205–18.
141. Kushitor SB, Alangea DO, Aryeetey R, de-Graft Aikins A. Dietary patterns among adults in three lowincome urban communities in Accra, Ghana. PLoS One. 2023;18.
142. Nyanchoka MA, van Stuijvenberg ME, Tambe AB, Zuma MK, Mbhenyane XG. Fruit and Vegetable Consumption Patterns and Risk of Chronic Diseases of Lifestyle among University Students in Kenya. Int J Environ Res Public Health. 2022;19:6965.
143. Bouis HE, Eozenou P, Rahman A. Food prices, household income, and resource allocation: Socioeconomic perspectives on their effects on dietary quality and nutritional status. Food Nutr Bull. 2011;32:S14–23.
144. Chilot D, Belay DG, Merid MW, Kibret AA, Alem AZ, Asratie MH, et al. Triple burden of malnutrition among mother-child pairs in low-income and middle-income countries: A cross-sectional study. BMJ Open. 2023;13.
145. French SA, Wall M, Mitchell NR. Household income differences in food sources and food items purchased. International Journal of Behavioral Nutrition and Physical Activity. 2010;7.
146. Colen L, Melo PC, Abdul-Salam Y, Roberts D, Mary S, Gomez Y Paloma S. Income elasticities for food, calories and nutrients across Africa: A meta-analysis. Food Policy. 2018;77:116–32.
147. Headey DD, Ruel MT. Economic shocks predict increases in child wasting prevalence. Nat Commun. 2022;13.
148. Glanz K, Metcalfe JJ, Folta SC, Brown A, Fiese B. Diet and health benefits associated with in-home eating and sharing meals at home: A systematic review. Int J Environ Res Public Health. MDPI AG; 2021. p. 1–20.

149. Campbell KJ, Abbott G, Spence AC, Crawford DA, McNaughton SA, Ball K. Home food availability mediates associations between mothers' nutrition knowledge and child diet. Appetite. 2013;71:1–6.
150. Gonçalves VSS, Figueiredo ACMG, Silva SA, Silva SU, Ronca DB, Dutra ES, et al. The food environment in schools and their immediate vicinities associated with excess weight in adolescence: A systematic review and meta-analysis. Health Place. Elsevier Ltd; 2021.
151. Ziso D, Chun OK, Puglisi MJ. Increasing Access to Healthy Foods through Improving Food Environment: A Review of Mixed Methods Intervention Studies with Residents of Low-Income Communities. Nutrients. MDPI; 2022.
152. Zhou P, Li R, Liu K. The Neighborhood Food Environment and the Onset of Child-Hood Obesity: A Retrospective Time-Trend Study in a Mid-sized City in China. Front Public Health. 2021;9.
153. Wasserman JA, Suminski R, Xi J, Mayfield C, Glaros A, Magie R. A multi-level analysis showing associations between school neighborhood and child body mass index. Int J Obes. 2014;38:912–8.
154. Powell LM, Slater S, Mirtcheva D, Bao Y, Chaloupka FJ. Food store availability and neighborhood characteristics in the United States. Prev Med (Baltim). 2007;44:189–95.
155. Franco M, Diez Roux A V., Glass TA, Caballero B, Brancati FL. Neighborhood Characteristics and Availability of Healthy Foods in Baltimore. Am J Prev Med. 2008;35:561–7.
156. Inagami S, Cohen DA, Finch BK, Asch SM. You Are Where You Shop. Grocery Store Locations, Weight, and Neighborhoods. Am J Prev Med. 2006;31:10–7.
157. Pradeilles R, Irache A, Wanjohi MN, Holdsworth M, Laar A, Zotor F, et al. Urban physical food environments drive dietary behaviours in Ghana and Kenya: A photovoice study. Health Place. 2021;71.
158. Faber M, Laurie S, Maduna M, Magudulela T, Muehlhoff E. Is the school food environment conducive to healthy eating in poorly resourced South African schools? Public Health Nutr. Cambridge University Press; 2014. p. 1214–23.
159. Morland K, Filomena S. Disparities in the availability of fruits and vegetables between racially segregated urban neighbourhoods. Public Health Nutr. 2007;10:1481–9.
160. Block D, Kouba J. A comparison of the availability and affordability of a market basket in two communities in the Chicago area. Public Health Nutr. 2006;9:837–45.
161. Green MJ, Popham F. Interpreting mutual adjustment for multiple indicators of socioeconomic position without committing mutual adjustment fallacies. BMC Public Health. 2019;19.
162. Stacey N, Edoka I, Hofman K, Swart EC, Popkin B, Ng SW. Changes in beverage purchases following the announcement and implementation of South Africa's Health Promotion Levy: an observational study. Lancet Planet Health. 2021;5:e200–8.
163. Salgado Hernández JC, Basto-Abreu A, Junquera-Badilla I, Moreno-Aguilar LA, Barrientos-Gutiérrez T, Colchero MA. Building upon the sugar beverage tax in Mexico: A modelling study of tax alternatives to increase benefits. BMJ Glob Health. 2023;8.
164. Forde CG. "Beyond Ultra-processed"; Considering the Future Role of Food Processing in Human Health. Proceedings of the Nutrition Society. Cambridge University Press; 2023.

Annex and materials

A. Supplementary Materials for Study I

Supplementary Materials for "Exploring the relationship between food environment indicators and dietary intake of children 6-23 months; findings from 20 low and lower middle income countries"

***Supplementary Table 1**: RCP for all food groups by country*

		Eggs		Fish		Meat		Dairy		Pulses		Orange flesh fruit		Other fruit		Orange flesh vegetables		Green leafy vegetables		Other vegetables	
		Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)
Low Income	Afghanistan	11.44	3.06	30.78	11.16	21.36	3.77	5.41	1.68	2.68	0.74	8.98	2.40	5.73	1.15	14.10	5.75	21.08	10.14	8.22	1.73
	BurkinaFaso	24.37	5.77	12.22	4.01	11.53	3.20	8.00	2.51	1.54	0.44	13.20	4.78	4.76	2.15	30.13	24.85	5.25	1.63	9.39	2.02
	Burundi	16.94	3.36	26.21	18.33	7.92	2.37	14.07	3.71	1.11	0.22	4.40	1.25	9.37	2.57	12.29	3.90	6.21	1.71	4.30	1.30
	Ethiopia	19.65	7.51	35.24	10.37	31.43	9.43	11.10	4.37	1.47	0.39	16.37	4.31	14.24	6.60	16.39	7.78	26.04	10.28	6.25	3.15
	Mali	18.11	5.69	10.62	5.66	12.24	3.86	9.06	4.25	1.13	0.35	15.19	4.12	2.71	0.99	24.70	10.57	23.47	29.92	7.51	2.44
	Mozambique	23.95	10.19	19.49	15.63	28.73	14.12	27.68	15.92	4.18	2.06	16.21	6.46	27.23	11.59	52.52	17.36	17.76	6.90	31.11	17.27
	Nepal	11.48	2.07	35.25	7.75	11.45	0.88	9.85	0.89	2.18	0.36	8.90	1.73	7.66	1.10	28.80	3.55	22.88	7.16	9.09	1.74
	Uganda	12.93	4.90	12.38	8.41	9.46	3.12	3.80	1.17	1.66	0.56	4.62	2.26	4.96	1.94	9.23	8.73	15.18	6.29	5.11	2.41
Low Middle Income	Bangladesh	16.70	2.02	12.46	2.35	19.14	4.66	11.44	1.50	2.31	0.38	9.46	2.40	14.26	4.34	17.68	4.43	10.42	3.38	8.91	2.13
	Cambodia	13.88	4.90	9.21	2.56	4.59	1.35	14.11	5.73	2.24	0.47	8.00	3.67	7.07	3.25	21.84	5.86	13.60	5.45	8.34	2.53
	ElSalvador	5.77	0.61	19.74	6.15	3.71	0.68	4.70	0.43	3.90	4.42	6.57	1.76	6.50	0.65	10.34	3.21	28.61	6.19	9.21	2.29
	Ghana	13.12	10.71	4.94	5.55	9.62	6.59	NA		0.99	0.70	4.90	5.05	17.34	11.31	NA		NA		11.42	9.47
	Kyrgyz Republic	4.56	0.40	16.95	4.15	6.25	2.47	2.36	0.21	0.94	0.20	9.72	0.90	9.23	1.63	4.14	0.65	32.71	6.31	6.30	0.42
	Laos	12.92	7.49	11.05	3.29	3.67	1.03	11.58	2.91	2.64	0.67	8.00	2.98	5.60	0.24	19.86	5.25	7.65	2.33	6.83	2.44
	Lesotho	6.13	0.71	27.43	15.39	6.39	1.16	8.46	1.48	4.77	0.58	11.91	2.20	14.69	3.79	14.36	5.37	156.67	21.95	18.64	3.22
	Mauritania	12.50	3.65	10.00	7.18	10.23	2.23	5.37	2.39	1.61	0.76	17.67	3.76	11.38	11.44	20.51	4.64	63.03	27.00	13.44	4.57
	Myanmar	6.40	1.18	9.08	2.35	13.79	2.43	1.88	1.61	2.79	0.51	8.94	4.76	18.72	6.72	NA		6.88	2.36	4.61	1.75
	Philippines	6.63	2.07	3.13	1.08	3.94	1.06	1.21	0.91	4.27	3.90	6.40	6.36	16.48	13.07	28.19	8.25	11.59	4.13	7.12	2.64
	Sri Lanka	5.77	0.49	10.17	1.88	15.80	1.81	9.15	0.88	2.53	0.27	8.81	1.55	4.28	0.75	29.87	3.79	9.58	2.19	9.49	1.30
	Zambia	15.89	4.13	25.72	8.33	13.69	4.15	19.11	5.80	12.82	4.38	24.40	15.72	18.84	8.26	36.54	21.19	15.70	7.49	21.71	7.29

Supplementary Table 2*: Price per 100kcal for all food groups by country*

		Eggs		Fish		Meat		Dairy		Pulses		Orange flesh fruit		Other fruit		Orange flesh vegetables		Green leafy vegetables		Other vegetables	
		Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)
Low Income	Afghanistan	0.55	0.12	1.48	0.53	1.34	0.10	0.31	0.07	0.38	0.04	0.64	0.15	0.59	0.14	0.68	0.27	1.02	0.46	1.06	0.22
	Burkina Faso	0.84	0.07	0.81	0.15	0.76	0.19	0.48	0.13	0.09	0.02	0.56	0.19	0.33	0.10	1.14	0.82	0.36	0.11	0.60	0.10
	Burundi	0.81	0.05	1.94	1.78	0.58	0.04	0.91	0.14	0.07	0.00	0.45	0.02	0.44	0.04	0.58	0.10	0.57	0.21	0.62	0.06
	Ethiopia	0.76	0.09	1.41	0.30	1.37	0.20	0.54	0.08	0.11	0.01	0.95	0.24	0.99	0.22	0.63	0.12	0.62	0.24	0.52	0.05
	Mali	0.57	0.07	0.87	0.27	0.78	0.23	0.33	0.11	0.07	0.02	0.75	0.18	0.25	0.06	0.80	0.22	1.12	1.15	0.78	0.22
	Mozambique	0.42	0.01	0.43	0.12	0.52	0.06	0.56	0.23	0.09	0.04	0.35	0.14	0.52	0.13	1.00	0.23	0.43	0.13	0.63	0.16
	Nepal	0.49	0.04	1.54	0.53	1.05	0.08	0.54	0.07	0.21	0.03	0.80	0.19	0.87	0.14	1.15	0.10	1.33	0.52	1.63	0.25
	Uganda	0.53	0.09	0.33	0.13	0.47	0.06	0.16	0.03	0.08	0.03	0.25	0.10	0.22	0.09	0.38	0.33	0.66	0.31	0.40	0.13
Low Middle Income	Bangladesh	0.60	0.05	0.83	0.09	1.09	0.06	0.34	0.05	0.10	0.02	0.56	0.12	0.93	0.20	0.62	0.15	0.36	0.11	0.43	0.08
	Cambodia	0.75	0.27	0.97	0.18	0.82	0.14	0.72	0.25	0.21	0.07	1.18	0.88	1.08	0.41	0.88	0.19	1.72	0.36	0.91	0.20
	ElSalvador	0.40	0.04	1.53	0.50	0.60	0.08	0.41	0.06	0.27	0.32	0.63	0.23	0.99	0.08	0.72	0.23	1.92	0.63	1.90	0.58
	Ghana	1.20	0.16	0.35	0.25	0.95	0.23	NA		0.09	0.02	0.43	0.14	1.17	0.89	NA		NA		1.31	0.30
	Kyrgyz Republic	0.56	0.03	2.09	0.51	1.12	0.15	0.47	0.04	0.11	0.02	1.23	0.12	1.16	0.27	0.51	0.05	4.16	0.87	1.15	0.08
	Laos	0.75	0.28	1.37	0.14	1.36	0.13	0.84	0.15	0.29	0.06	1.26	0.31	0.86	0.14	1.32	0.36	1.79	0.36	1.16	0.23
	Lesotho	0.32	0.03	1.43	0.88	0.64	0.09	0.52	0.06	0.32	0.02	0.56	0.07	0.74	0.15	0.49	0.07	7.10	1.23	1.14	0.12
	Mauritania	0.86	0.24	1.05	0.57	1.09	0.19	0.69	0.20	0.16	0.05	1.22	0.32	1.41	0.58	1.41	0.32	4.28	1.79	1.84	0.65
	Myanmar	0.44	0.04	1.60	0.39	1.09	0.14	0.12	0.11	0.19	0.03	0.82	0.36	1.40	0.25	NA		0.45	0.22	0.59	0.15
	Philippines	0.46	0.03	0.53	0.13	0.63	0.10	0.09	0.08	0.26	0.13	0.42	0.23	0.98	0.39	1.94	0.35	1.14	0.27	1.28	0.20
	Sri Lanka	0.28	0.02	1.74	0.30	1.17	0.13	0.50	0.04	0.18	0.02	0.80	0.10	0.58	0.03	1.36	0.13	0.49	0.11	1.03	0.17
	Zambia	0.36	0.02	1.10	0.19	0.60	0.03	0.54	0.05	0.37	0.11	0.62	0.39	0.58	0.24	0.79	0.39	0.53	0.16	0.73	0.17

Supplementary Table 3: Number of observations per food group by country

		Eggs		Fish		Meat		Dairy		Pulses		Orange flesh fruit		Other fruit		Orange flesh vegetables		Green leafy vegetables		Other vegetables	
		Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)
Low Income	Afghanistan	1.0	0.0	2.3	0.7	7.8	0.6	5.4	1.4	11.5	1.3	6.0	0.9	10.3	1.5	2.0	0.2	1.0	0.0	10.3	1.2
	BurkinaFaso	2.4	0.6	7.3	1.2	10.9	3.5	6.1	0.8	10.3	1.5	4.9	1.5	9.0	2.1	1.4	0.4	8.4	2.2	12.5	1.4
	Burundi	1.0	0.0	5.7	1.5	8.1	0.9	4.1	1.2	8.6	0.5	9.6	0.5	2.0	0.0	1.6	0.5	4.7	0.5	8.7	0.7
	Ethiopia	1.0	0.0	1.6	0.5	4.2	1.2	5.5	1.0	17.3	1.5	5.9	0.9	5.5	0.9	1.0	0.0	3.2	0.4	9.0	1.1
	Mali	2.6	0.4	12.0	3.5	15.6	1.3	3.9	1.1	11.8	2.2	5.6	1.5	13.3	3.5	1.9	0.2	6.6	3.6	14.4	2.0
	Mozambique	1.0	0.0	6.0	1.9	3.9	1.7	2.3	1.3	3.9	0.6	2.7	1.0	2.0	0.5	1.2	0.2	6.0	1.6	3.2	1.0
	Nepal	1.0	0.0	2.0	0.0	6.9	0.4	5.0	0.0	17.4	0.3	8.3	1.1	8.5	0.5	3.0	0.0	5.0	0.0	1.0	0.0
	Uganda	1.0	0.0	2.9	0.3	3.9	0.4	1.0	0.0	5.5	0.8	4.2	1.3	2.3	0.6	1.3	0.5	1.0	0.0	5.1	1.0
Low Middle Income	Bangladesh	2.0	0.0	14.9	0.2	5.8	0.5	3.0	0.0	5.0	0.0	8.6	0.5	6.4	0.7	1.0	0.0	1.0	0.0	10.0	0.0
	Cambodia	5.2	1.2	23.8	3.1	40.7	3.7	4.2	0.8	13.4	2.2	12.4	1.5	16.6	3.2	2.0	0.0	12.2	1.1	23.9	0.8
	ElSalvador	1.0	0.0	4.0	1.3	14.3	1.8	5.4	0.5	2.0	0.5	4.5	0.8	5.0	0.5	2.0	0.0	2.6	0.9	2.3	0.5
	Ghana	1.0	0.0	3.0	0.0	2.6	0.5	NA		3.0	0.0	3.4	0.5	2.6	0.9	NA		NA		3.8	0.4
	Kyrgyz Republic	1.0	0.0	1.4	0.3	4.9	1.3	9.1	1.3	1.0	0.0	3.1	0.3	4.7	0.4	1.4	0.2	1.0	0.0	6.0	0.3
	Laos	2.6	0.9	17.4	8.4	35.6	6.8	5.2	1.5	10.2	2.2	8.8	1.5	12.6	2.1	3.0	1.4	21.8	5.9	12.2	5.6
	Lesotho	1.0	0.0	1.8	0.7	11.0	2.4	3.7	0.7	4.0	0.0	2.8	0.4	3.8	0.9	2.6	0.5	1.9	0.4	4.5	0.9
	Mauritania	1.5	0.5	5.0	3.8	9.0	3.0	6.9	2.7	7.5	2.7	3.7	1.5	8.3	4.6	1.9	0.3	1.6	0.5	10.7	4.3
	Myanmar	1.9	0.3	8.7	2.8	4.1	0.6	1.6	0.7	1.3	0.5	3.9	0.8	2.5	0.5	NA		2.8	0.4	6.3	0.6
	Philippines	1.1	0.3	10.0	2.5	9.6	2.6	1.3	0.5	1.5	0.4	1.4	0.6	2.3	0.5	1.0	0.0	6.2	1.0	13.0	1.6
	SriLanka	1.0	0.0	12.7	0.4	7.0	0.0	4.0	0.2	7.0	0.0	6.0	0.0	7.0	0.0	3.0	0.0	3.0	0.0	16.0	0.0
	Zambia	1.0	0.0	7.1	1.2	16.2	0.9	6.9	0.9	3.9	0.3	3.9	0.6	4.1	0.9	1.7	0.4	6.1	0.9	8.6	0.8

Supplementary Table 4. Detailed description of indicators used in this analysis

Indicator	Units	Source	Description
Food group price per 100 kcal	PPP USD	FNGSTAT	Median and minimum price in PPP USD (2020) per 100kcal for each food group. A price of 1 PPP USD for eggs means that it costs 1 PPP USD to buy the equivalent of 100kcal in eggs.
Relative Caloric Price	PPP USD	FNGSTAT	Ratio of the price of 1 calorie of a given food to the price of 1 calorie of a representative basket of starchy staple food in each country. An RCP of 5 for eggs implies that it is 5 times as expensive to obtain a calorie from eggs as it is to obtain a calorie from starchy staples.
Assortment	# of foods	FNGSTAT	Count of food items per food group.
Children 6-23 months old with minimum dietary diversity (MDD)	%	DHS API / UNICEF JEM	Percentage of children 6-23 months of age who received foods from 5 or more food groups in the 24 hour preceding the survey. MDD is one of the eight indicators used to asses Infant and Young Child Feeding practices, developed by the WHO. Data is collected through a questionnaire, where the child's caregiver is asked to indicate whether the child has consumed any food item belonging to 8 food groups in the preceding 24-hours. The total number of food groups consumed is summed, and the indicator is calculated by dividing the number of children 6-23 months who received foods from 5 or more food groups (including breastmilk) by the total number of children 6-23 months in that area. (INDDEX Project, 2018; WHO, 2008)
Children 6-23 months old consuming iron-rich foods	%	DHS API	Percentage of children age 6-23 months who received foods rich in iron in the 24 hours preceding the survey. This indicator is one of the eight indicators used to assess IYCF practices, developed by the WHO. Data is collected through a questionnaire, where the child's caregiver is asked to indicate whether the child has consumed any iron-rish or iron fortified food in the preceding 24-hours. Iron-rich or iron fortified foods include flesh foods, commercially fortified foods designed for infants and young children, or foods fortified at home with a supplement containing iron. The number of children who received foods that are iron-rich or iron fortified is divided by the total number of children 6-23 months in that area. (INDDEX Project, 2018; WHO, 2008)
Children 6-23 months old consuming vitamin A-rich foods	%	DHS API	Percentage of children age 6-23 months who consumed foods rich in vitamin A in the 24 hours preceding the survey. This indicator is calculated through a similar methodology as MDD, and often the same questionnaire is used to calculate both indicators. The number of children who received foods from the "vitamin-A rich fruits and vegetables" food group is divided by the total number of children 6-23 months in that area. (INDDEX Project, 2018; WHO, 2008)

Supplementary Table 5. Data sources by indicators used for the analysis, per country. N = number of subnational assessments, MDD, VITA, IRON indicate whether intake indicator was available in reference document.

Country	N	Prices Year	Prices Type	Intake Year	Intake Reference	MDD	VITA	IRON
Afghanistan	34	2019	Primary – WFP and Partners	2018	Afghanistan Health Survey 2018	x	x	x
Bangladesh	8	2016	Household Survey - Household Income and Expenditure Survey (HIES) 2016	2019	Bangladesh Multiple Indicator Cluster Survey 2019, Survey Findings Report. Dhaka, Bangladesh: Bangladesh Bureau of Statistics (BBS)	x	x	x
Burkina Faso	12	2019	Primary – WFP and Partners	2019	Enquete Nutritionnelle Nationale, Burkina Faso 2019	x	N/A	N/A
Burundi	7	2018	Primary – WFP and Partners	2018	Enquete Nationale sur la Situation Nutritionnelle et la Securite Alimentaire au Burundi (ENSNSAB), Decembre 2018	x	x	x
Cambodia	19	2017	Primary – WFP and Partners	2014	Cambodia Demographic and Health Survey 2014. Phnom Penh, Cambodia, and Rockville, Maryland, USA: National Institute of Statistics, Directorate General for Health, and ICF International.	x	x	x
El Salvador	8	2014	Primary – WFP and Partners	2014	Encuesta nacional de salud 2014 - Encuesta de indicadores multiples por conglomerados 2014, Resultados principales. San Salvador, El Salvador: Ministerio de Salud e Instituto Nacional de Salud.	x	N/A	N/A
Ethiopia	11	2019	CPI/Market Monitoring – Central Statistical Agency of Ethiopia	2019	Ethiopia Mini Demographic and Health Survey 2019: Key Indicators. Rockville, Maryland, USA: EPHI and ICF.	x	x	x
Ghana	5	2015	CPI/Market Monitoring – Ministry of Food and Agriculture	2017	Multiple Indicator Cluster Survey (MICS2017/18), Survey Findings Report. Accra, Ghana: GSS	N/A	N/A	N/A
Kyrgyz Republic	9	2017	Household Survey - Kyrgyzstan Integrated Household Survey 2017	2018	Kyrgyzstan Multiple Indicator Cluster Survey 2018, Survey Findings Report. Bishkek, Kyrgyzstan: National Statistical Committee of the Kyrgyz Republic and UNICEF.	x	x	x
Laos	5	2017	Primary – WFP and Partners	2017	Lao Social Indicator Survey II 2017, Survey Findings Report. Vientiane, Lao PDR: Lao Statistics Bureau and UNICEF	x	N/A	N/A
Lesotho	10	2019	CPI/Market Monitoring – Ministry of Development Planning Lesotho, Bureau of Statistics	2017	Lesotho Multiple Indicator Cluster Survey 2018, Survey Findings Report. Maseru, Lesotho: Bureau of Statistics.	x	x	x
Mali	8	2019	Primary – WFP and Partners	2019	Enquête Nationale Nutritionnelle Anthropométrique et de Mortalité rétrospective suivant la méthodologie SMART, Mali 2019	x	x	x

Mauritania	12	2019	Primary – WFP and Partners	2018	Rapport de l'enquête nutritionnelle nationale SMART Aout 2018	x	N/A	N/A
Mozambique	11	2015	Household Survey - Inquérito do Orçamento Familiar (IOF) Household Budget Survey	2015	Relatório final do Inquérito ao Orçamento Familiar - IOF, 2014/15	x	N/A	N/A
Myanmar	15	2017	CPI/Market Monitoring – Central Statistics Organisation	2018	Myanmar Micronutrient and Food Consumption Survey (MMFCS) 2017-2018	x	x	x
Nepal	7	2019	CPI/Market Monitoring – Central Bureau of Statistics	2019	Nepal Multiple Indicator Cluster Survey 2019, Survey Findings Report. Kathmandu, Nepal: Central Bureau of Statistics and UNICEF Nepal.	x	x	x
Philippines	17	2015	CPI/Market Monitoring – Philippine Statistics Authority	2015	Philippine Nutrition Facts and Figures 2015: Anthropometric Survey. Food and Nutrition Research Institute.	x	N/A	N/A
Sri Lanka	25	2016	CPI/Market Monitoring – HARTI (Hector Kobbekaduwa Agrarian Research and Training Institute)	2016	Sri Lanka Demographic and Health Survey 2016	x	N/A	N/A
Uganda	15	2015	Household Survey - Uganda National Panel Survey Wave 5	2016	Uganda Demographic and Health Survey 2016. Kampala, Uganda and Rockville, Maryland, USA: UBOS and ICF. 2018	x	x	x
Zambia	9	2017	CPI/Market Monitoring – Zambia Statistics Agency	2018	Zambia Demographic and Health Survey 2018. Lusaka, Zambia, and Rockville, Maryland, USA: Zambia Statistics Agency, Ministry of Health, and ICF	x	x	x

Regression Equation and Independent Variables used:

Supplementary Table 6: Independent Variable Definition:

	Base Model
Relative Caloric Price	Numerator: Mean price of cheapest three items per food group. Denominator: Mean price of commonly consumed starchy staples
Price per 100kcal	Median price of all foods per food group

	Minimum price per food group (i.e. cheapest food per food group)
Assortment	Count of items available per food group

To assess associations between dependent dietary intake indicators and our independent food environment indicators, we performed individual mixed effects linear regressions for each combination of independent and dependent variables, accounting for country level effects and datatype, with random effects allowing the intercept to vary by country and allowing for fixed effects by datatype. The model can be expressed as follows:

$$\Upsilon_{ij} = \beta_0 + \beta_1 X_{1ij} + \gamma_1 D_{1ij} + \ldots + \gamma_q D_{qij} + \mu_j + \epsilon_{ij}$$

Where:

Υ_{ij} = The dietary intake indicator for the *i-th* observation in the *j-th* country.

β_0 = The overall intercept (the expected value of *Y* when all predictors are *0*, and with a random effect of *0)*.

β_1 = The fixed-effect coefficient for the p continuous/independent variables.

X_1 = The independent food environment indicator for the *i-th* observation in the *j-th* country.

γ_1,..., γ_q= The fixed-effect coefficients for each level of the categorical variable datatype (excluding the reference category). Here, D_{1ij} ,,..., D_{qij} are indicator (dummy) variables created for the *q* levels of datatype.

μ_j= The random effect for the *j-th* country. This captures the country-specific random variation around the overall intercept (β_0). It's assumed that $u_j \sim N(0, \sigma_U^2)$normally distributed with mean 0 and variance σ_U^2

ϵ_{ij}= The residual error for the *i-th* observation in the *j-th* country. Typically, *∼ (0 , 2) ϵ ij ∼ N(0, σ²)* – normally distributed with mean *0* and variance σ^2 . The model assumes that the random effects μ_j and the residual errors ϵ_{ij} are independent of each other.

Interpretation of Coefficients: The coefficients β_1 and γ_1,..., γ_q are interpreted as the average effect of the predictor variables and the categorical levels on the dependent variable, respectively, across all countries (taking into account the random variation among countries).

While the formula represents the structure of the model, the vce(robust) command in Stata[17] was applied to provide robust standard errors to try and account for potential violations of the model assumptions such as heteroskedasticity or clustering of residuals.

Supplementary Table 7: Regression results including p-values and adjusted q-values from Benjamini-Hochberg Procedure. Values significant at FDR <0.10 are in bold.

Dependent Variable:	Independent variables	Co-eff.	SE	p-val	R2o	N	q-value (FDR)
Percentage of children who consumed foods rich in iron							
	Assortment_iron	0.855***	-0.124	0.000	0.583	150	**0.000**
	RCP_meat_	-0.756***	-0.266	0.004474	0.21	150	**0.03187725**
	RCP_fish_	-0.279***	-0.103	0.006432	0.189	150	**0.0366624**
	RCP_eggs_	-0.901***	-0.323	0.005303	0.052	150	**0.03358567**
	Median Price_meat	-0.153	-0.1	0.124752	0.07	150	0.26336533
	Median Price_fish	-0.009	-0.025	0.724992	0.03	150	0.83709418
	Median Price_eggs	-0.147	-0.159	0.353272	0.02	150	0.54422984
	Minimum Price_meat	-0.199***	0.064	0.001965	0.163	150	**0.0186675**
	Minimum Price_fish	-0.014	0.042	0.743753	0.043	150	0.83709418
	Minimum Price_eggs	-0.487***	0.042	0.000	0.307	150	**0.000**
Percentage of children who consumed foods rich in vitamin A							
	assortment_vita	0.390**	-0.191	0.041539	0.36	150	0.135755
	RCP_meat_	-0.667**	-0.329	0.04287	0.299	150	0.135755
	RCP_fish_	-0.112	-0.102	0.269459	0.062	150	0.46542918
	RCP_eggs_	-0.475	-0.318	0.135775	0.007	150	0.27639911
	RCP_glv_	-0.110***	-0.033	0.000697	0.035	147	**0.0097242**
	RCP_ofv_	-0.018	-0.134	0.896116	0.016	134	0.91211807
	RCP_off_	-0.486*	-0.273	0.075268	0.023	150	0.18653374
	Median Price_meat	-0.220**	-0.099	0.025567	0.284	150	**0.09108244**
	Median Price_fish	-0.011	-0.015	0.483443	0.015	150	0.66503393
	Median Price_eggs	-0.138	-0.173	0.424019	0.003	150	0.62529146
	Median Price_glv	-0.016	-0.011	0.164065	0.008	147	0.3117235
	Median Price_ofv	-0.051	-0.035	0.142484	0.008	134	0.28005476
	Median Price_off	-0.023	-0.036	0.52916	0.006	150	0.70144465
	Minimum Price_meat	-0.262***	0.078	0.000853	0.388	150	**0.0097242**
	Minimum Price_fish	-0.072	0.053	0.177738	0.19	150	0.32680858
	Minimum Price_eggs	-0.410**	0.177	0.020869	0.134	150	**0.0793022**
	Minimum Price_glv	-0.012*	0.007	0.082687	0.026	147	0.19440648
	Minimum Price_ofv	-0.007	0.035	0.843437	0.014	134	0.89029461
	Minimum Price_off	-0.243*	0.13	0.06278	0.049	150	0.18653374
Percentage of children with a minimum dietary diversity							
	assortment_mdd	0.180*	-0.096	0.060767	0.073	214	0.16265727
	RCP_meat_	-0.544**	-0.227	0.016724	0.05	214	0.64372238
	RCP_fish_	-0.081	-0.079	0.301746	0.008	214	0.49141491
	RCP_eggs_	-0.598**	-0.256	0.019337	0.073	214	**0.07872921**
	RCP_milk_	-0.128	-0.244	0.600364	0.013	213	0.77774427
	RCP_glv_	-0.112**	-0.057	0.049923	0.022	211	0.149769
	RCP_ofv_	-0.023	-0.111	0.837544	0.028	196	0.89029461
	RCP_off_	-0.175	-0.145	0.225644	0.001	214	0.40192838
	RCP_other_veg_	0.13	-0.366	0.721402	0.009	214	0.83709418
	RCP_other_fruit_	-0.076	-0.156	0.627367	0	214	0.77955059

Median Price_meat	-0.053	-0.071	0.451735	0.003	214	0.64372238
Median Price_fish	0.006	-0.018	0.748979	0.003	214	0.83709418
Median Price_eggs	-0.133	-0.128	0.296172	0.042	214	0.49141491
Median Price_milk	0.112	-0.072	0.119674	0.021	213	0.26236223
Median Price_glv	-0.020*	-0.012	0.085266	0	211	0.19440648
Median Price_ofv	-0.014	-0.029	0.629111	0.06	196	0.77955059
Median Price_off	0.005	-0.016	0.731608	0.007	214	0.83709418
Median Price_other_veg	0.085*	-0.045	0.059843	0.106	214	0.16265727
Median Price_other_fruit	0.065***	-0.025	0.008226	0	214	**0.0468882**
Minimum Price_meat	-0.156**	0.063	0.013483	0.062	214	**0.068951**
Minimum Price_fish	0.005	0.049	0.924336	0.014	214	0.924336
Minimum Price_eggs	-0.360***	0.075	0.000002	0.166	214	**0.000038**
Minimum Price_dairy	0.173	0.219	0.427831	0.027	213	0.62529146
Minimum Price_glv	-0.017**	0.007	0.014516	0	211	**0.068951**
Minimum Price_ofv	-0.006	0.024	0.789606	0.035	196	0.86552965
Minimum Price_off	-0.078	0.08	0.329809	0.003	214	0.52219758
Minimum Price_otherveg	0.018	0.111	0.871892	0.005	214	0.90359716
Minimum Price_otherfruit	0.017	0.024	0.490025	0.023	214	0.66503393

B. Supplementary Materials for Study II

Figure 4: Chloropleth maps of mean dietary intake and nutrient status indicators of Donald study participants (age 6-18) between 2014 and 2019 by city districts (Stadtbezirk) of Dortmund

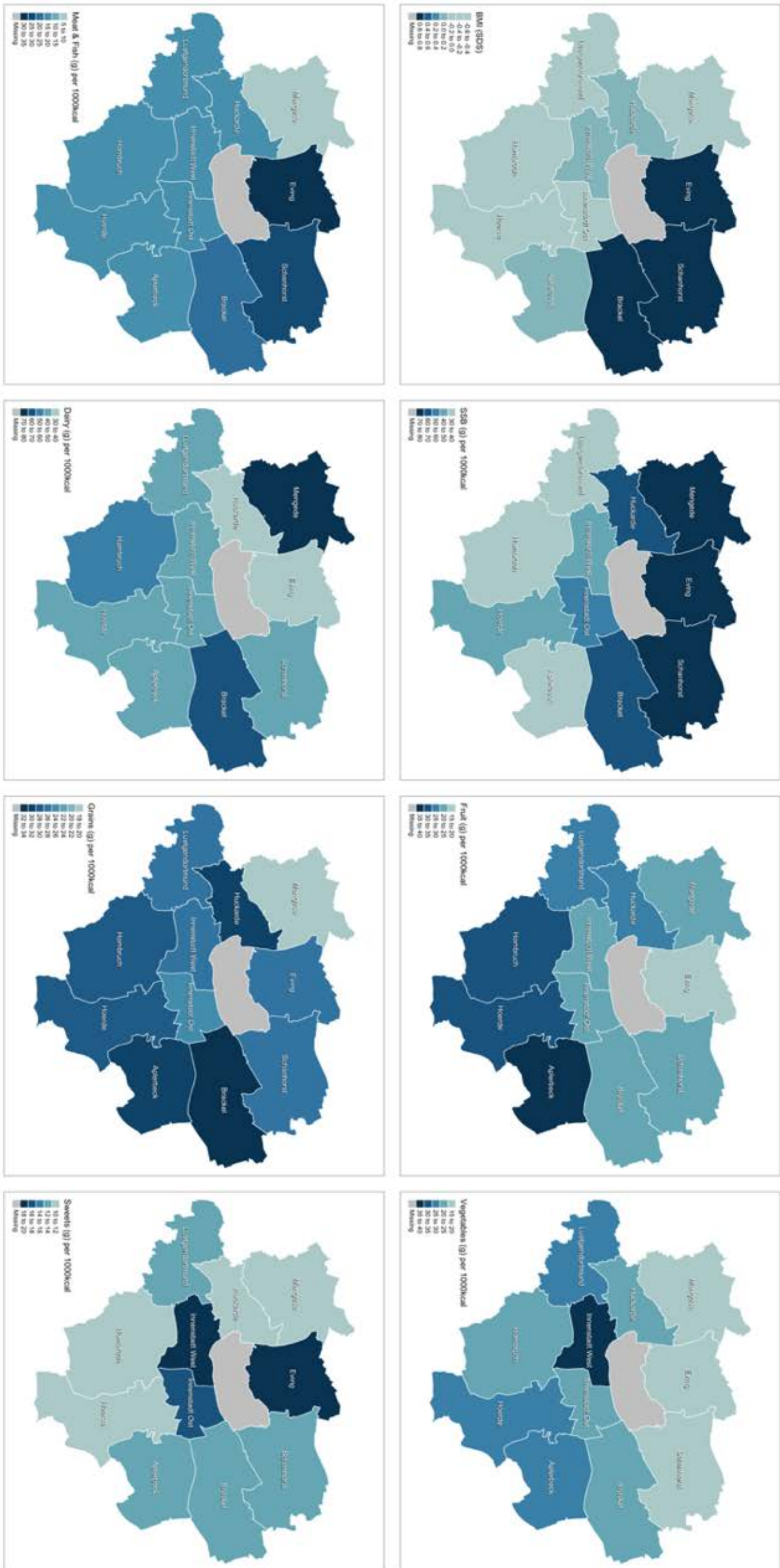


Figure 5: Predicted values for North and South Dortmund, respectively, by model specification

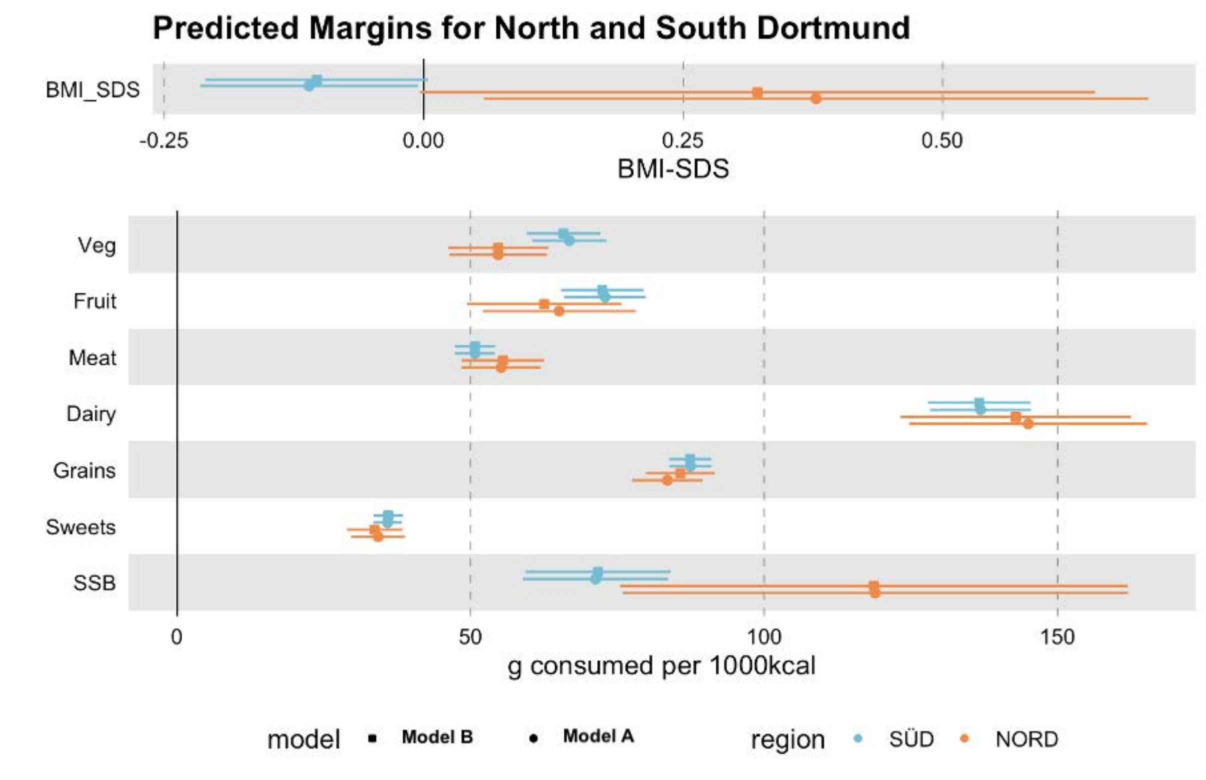


Table 5: Regression results for macronutrients by model specification

			β	p-value	Benjamini-Hochberg p-value	Lower CI	Upper CI
BMI	SDS	Model A	-0.489	**0.005**	**0.005**	-0.827	-0.151
		Model B	-0.425	**0.016**	**0.016**	-0.769	-0.081
		Model B*	-0.417	**0.017**	**0.017**	-0.759	-0.075
Food Groups	SSB	Model A	-47.661	**0.039**	**0.138**	-92.821	-2.501
		Model B	-47	**0.044**	**0.138**	-92.642	-1.359
	Vegetables	Model A	12.133	**0.027**	**0.135**	1.377	22.889
		Model B	11.129	**0.043**	**0.138**	0.351	21.906
	Fruit	Model A	7.829	0.302	0.539	-7.03	22.688
		Model B	9.876	0.196	0.490	-5.094	24.847
	Meat	Model A	-4.468	0.252	0.525	-12.122	3.185
		Model B	-4.746	0.239	0.525	-12.64	3.148
	Sweets	Model A	1.602	0.545	0.706	-3.592	6.796

		Model B	2.327	0.397	0.662	-3.057	7.712
	Grain	Model A	3.905	0.277	0.533	-3.141	10.952
		Model B	1.646	0.637	0.758	-5.2	8.492
	Dairy	Model A	-8.138	0.465	0.706	-29.946	13.671
		Model B	-6.237	0.565	0.706	-27.492	15.017
	Protein	Model A	-0.001	0.668	0.759	-0.008	0.005
		Model B	-0.002	0.524	0.706	-0.009	0.005
Macronutrients	Carbohydrates						
		Model A	-0.001	0.861	0.861	-0.014	0.012
		Model B	-0.002	0.754	0.785	-0.016	0.011
	Fat						
		Model A	0.002	0.723	0.785	-0.011	0.016
		Model B	0.004	0.558	0.706	-0.01	0.018
	Sugar						
		Model A	-0.02	**0.021**	**0.131**	-0.036	-0.003
		Model B	-0.016	0.055	0.153	-0.032	0

Model A is adjusted for age and sex.
Model B is adjusted for age, sex and socio-economic status.
Model B* (BMI-SDS only) is adjusted for age, sex, socio-economic status and physical activity.
FDR (False Discovery Rate) was calculated following Benjamini-Hochberg procedure for each model family and outcome group and set at 0.20.

BMI Body Mass Index, *SDS* Standard Deviation Score, *SSB* Sugar-Sweetened Beverages, *CI* Confidence Intervall, *FDR* False Discovery Rate

C. Supplementary Materials for Study III

Table SI

Categorization of independent variables used according to different food environment frameworks: 1) Fanzo et al. (2020) adapted from HLPE 2) Turner et al. 2018 3) Osei-Kwasi et al. (2020)

Although not formatively used for the design of this study, these dimensions align with the factors outlined for the African urban food environment regarding individual (demographic, cognitions, practices) and social-environment (family, friends, societal) [50]. They are also aligned with the personal domain aspects of the 2018 food environment framework [12].

1 - FSD	Economic	Cognitive	Aspirational	Situational	Consumer Behaviour
2 – Turner	Affordability	Desirability		Convenience	
3 – AU FE	Demographic	Cognitions	Cognitions	Social-Environment	Practices
Predictors	*Food Budget*	*Knowledge about eating practices*	*Perceived Susceptibility*	*Family eating habits*	*Readiness to Change*
	Household Assets	*Knowledge about NCDs*	*Perceived Benefits*	*Peer eating habits*	*Eating Patterns*
		Knowledge about Food Groups	*Perceived Risks*		

D. Supplementary Materials for Study IV

ANNEX

Figure A1: Polynomial graphs of food group diversity at vendor, including all vendors per category, i.e. also including vendors with 0 food group items.

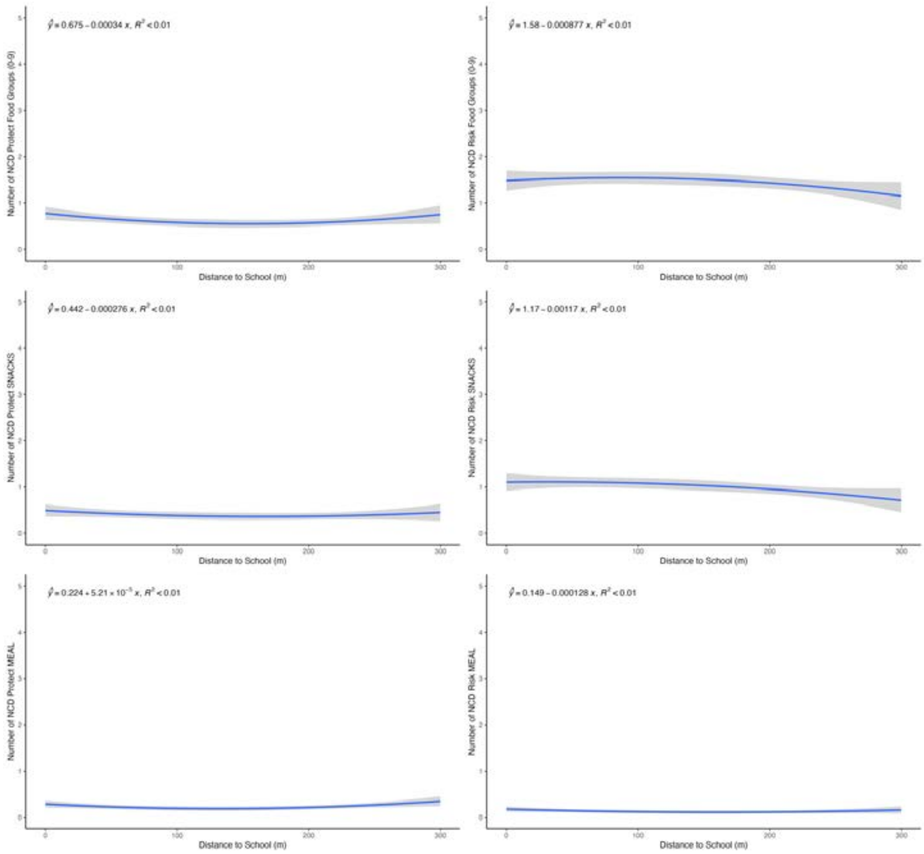


Table A1: Uncontrolled (1, 3, 5) and Controlled Models (2, 4, 6) with full coefficient lists.

	Dependent variable:					
	GDR Score at school		NCD Risk at school		NCD Protect at school	
	(1)	(2)	(3)	(4)	(5)	(6)
Price NCD-Risk	0.321*	0.550**	-0.281*	-0.402**	0.040	0.148
	(0.175)	(0.215)	(0.162)	(0.186)	(0.119)	(0.142)
Price NCD-Protect	-0.146**	-0.197***	0.058	0.105	-0.087*	-0.092*
	(0.071)	(0.076)	(0.065)	(0.066)	(0.049)	(0.048)
Number Hotspots NCD-Risk	-0.040	-0.005	0.026	-0.002	-0.015	-0.007
	(0.025)	(0.030)	(0.022)	(0.024)	(0.017)	(0.020)
Number Hotspots NCD-Protect	0.020	-0.056	-0.012	0.034	0.008	-0.022
	(0.045)	(0.063)	(0.039)	(0.050)	(0.029)	(0.041)
Open Gate (Ref: Closed)	0.369*	0.075	-0.151	0.034	0.218*	0.108
	(0.189)	(0.282)	(0.161)	(0.217)	(0.130)	(0.188)
Sex		0.115		-0.135		-0.020
		(0.152)		(0.127)		(0.105)
Age		-0.001		-0.019		-0.020
		(0.057)		(0.050)		(0.046)
Brought Food		-0.133		0.164		0.030
		(0.206)		(0.194)		(0.165)
Public School (Ref: Private)		0.378		-0.030		0.348*
		(0.273)		(0.219)		(0.186)
Total Budget		-0.029*		0.077***		0.048***
		(0.017)		(0.014)		(0.011)
Knowledge Score		-0.040		-0.030		-0.070**
		(0.038)		(0.032)		(0.028)
Attitude Score		0.107*		-0.097*		0.010
		(0.061)		(0.054)		(0.041)
Practice Score		0.037		0.047		0.084**
		(0.048)		(0.039)		(0.033)
Observations	409	409	409	409	409	409
R^2	0.037	0.069	0.016	0.134	0.017	0.101
F Statistic	3.106*** (df = 5; 403)	2.260*** (df = 13; 395)	1.321 (df = 5; 403)	4.685*** (df = 13; 395)	1.426 (df = 5; 403)	3.404*** (df = 13; 395)
Note:						*p<0.1; **p<0.05; ***p<0.01

Table A2: Results of t-tests for differences between female and male JHS students.

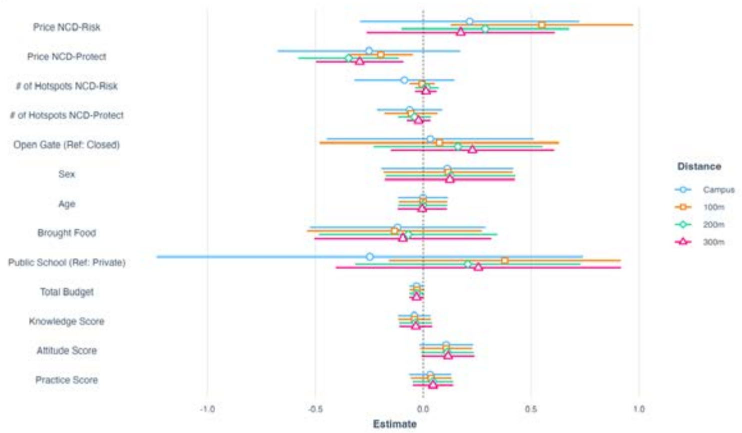
Variable	Group1	Group2	N1	N2	Statistic	DF	P
Age (years)	Female	Male	206	203	-1.16245	385.9138	0.2460
Weight (kg)	Female	Male	206	203	2.273657	403.5111	0.0235
Height (cm)	Female	Male	206	203	-5.73001	364.8564	0.0001
Total budget (GHS per day)	Female	Male	206	203	-1.2532	398.6311	0.2110
Breakfast budget (GHS per day)	Female	Male	206	203	-0.85485	402.3527	0.3930
Snack budget (GHS per day)	Female	Male	206	203	-0.2401	406.7643	0.8100
Lunch budget (GHS per day)	Female	Male	206	203	-0.62293	405.2827	0.5340
FGDS (0-10)	Female	Male	206	203	0.90129	406.8728	0.3680
MDD (%)	Female	Male	206	203	1.337431	406.0987	0.1820
NCD-Protect score (0-9)	Female	Male	206	203	1.847409	405.6865	0.0654
NCD-Risk score (0-9)	Female	Male	206	203	1.475492	406.7366	0.1410
GDR score (0-18)	Female	Male	206	203	0.060992	406.8656	0.9510
NCD-Protect score at home (0-9)	Female	Male	206	203	1.455524	399.7874	0.1460
NCD-Protect score at school (0-9)	Female	Male	206	203	-0.11027	401.16	0.9120
NCD-Risk score at home (0-8)	Female	Male	206	203	1.985668	376.5217	0.0478
NCD-Risk score at school (0-8)	Female	Male	206	203	0.559947	406.4053	0.5760
Body mass index (BMI)	Female	Male	206	203	5.928381	376.4515	0.0001
BMI for age z-scores	Female	Male	206	202	5.265238	405.9757	0.0001
Students that brought food (%)	Female	Male	206	203	1.507271	393.7831	0.1330
Students that brought money (%)	Female	Male	206	203	0.018055	406.8037	0.9860
GDR Score at school (1-18)	Female	Male	206	203	-0.56874	399.4838	0.5700
GDR Score at home (1-18)	Female	Male	206	203	-0.3567	369.3365	0.7220

Table A3: Oster Coefficient Stability Test

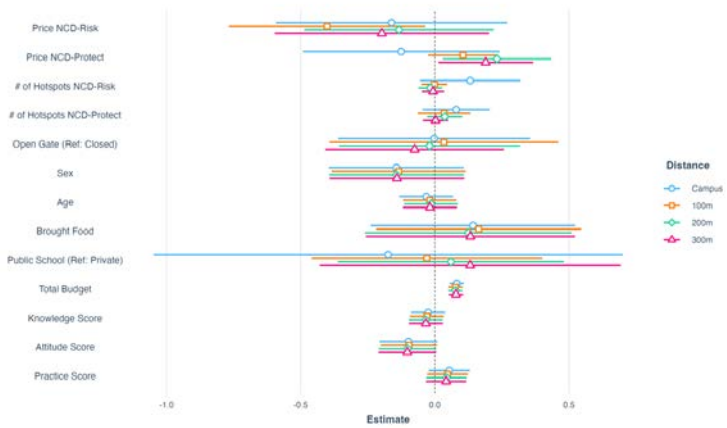
GDR score							
Name	Beta*	Uncontrolled coefficient	Controlled coefficient	Uncontrolled R-square	Controlled R-square	Max R-square	Delta
Price NCD-Protect	-0.244	-0.150	-0.197	0.014	0.069	0.1	1
Price NCD-Risk	0.787	0.296	0.550	0.007	0.069	0.1	1
Hotspot NCD-Protect	-0.367	-0.009	-0.056	0.000	0.069	0.1	1
Hotspot NCD-Risk	0.043	-0.033	-0.005	0.007	0.069	0.1	1
School gate policy	-0.672	0.223	0.075	0.005	0.069	0.1	1
Total budget	-0.023	-0.037	-0.029	0.016	0.069	0.1	1
NCD-Protect score							
Name	Beta*	Uncontrolled coefficient	Controlled coefficient	Uncontrolled R-square	Controlled R-square	Max R-square	Delta
Price NCD-Protect	-0.105	-0.078	-0.092	0.008	0.101	0.15	1
Price NCD-Risk	0.266	0.038	0.148	0.000	0.101	0.15	1
Hotspot NCD-Protect	-0.799	-0.009	-0.022	0.000	0.101	0.15	1
Hotspot NCD-Risk	0.015	-0.015	-0.007	0.003	0.101	0.15	1
School gate policy	-0.665	0.144	0.108	0.004	0.101	0.15	1
Total budget	0.056	0.040	0.048	0.038	0.101	0.15	1
NCD-Risk Score							
Name	Beta*	Uncontrolled coefficient	Controlled coefficient	Uncontrolled R-square	Controlled R-square	Max R-square	Delta
Price NCD-Protect	0.111	0.071	0.105	0.004	0.134	0.15	1
Price NCD-Risk	-0.433	-0.258	-0.402	0.007	0.134	0.15	1
Hotspot NCD-Protect	0.060	0.000	0.034	0.001	0.134	0.15	1
Hotspot NCD-Risk	-0.008	0.018	-0.002	0.002	0.134	0.15	1
School gate policy	0.087	-0.079	0.034	0.001	0.134	0.15	1
Total budget	0.077	0.076	0.077	0.092	0.134	0.15	1

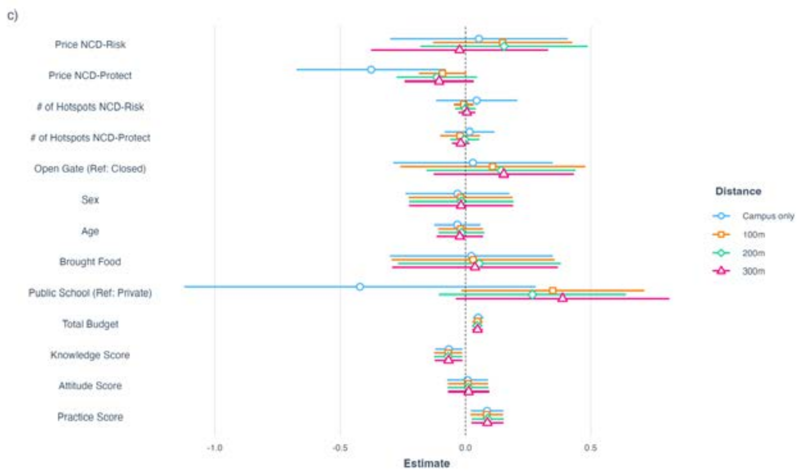
Figure A2 a-c: Regression coefficients using different Distance cut-offs for Global Dietary Recommendation Score (a), NCD-Risk (b), NCD-Protect (c). 100m model reported in main results. Model specifications as per main text.

a)



b)




c)
Price NCD-Risk
Price NCD-Protect
# of Hotspots NCD-Risk
# of Hotspots NCD-Protect
Open Gate (Ref: Closed)
Sex
Age
Brought Food
Public School (Ref: Private)
Total Budget
Knowledge Score
Attitude Score
Practice Score
-1.0
-0.5
0.0
0.5
Estimate
Distance
Campus only
100m
200m
300m

Supplementary Materials for "School food environment and adolescents' diets in Ghana."

S1: Description and references for key indicators used in this study:

Knowledge, Attitude and Practices Scores

A formative set of 28 Knowledge (8), Attitude (8) and Practice (12) (KAP) questions was collected from students to capture individuals' behavioural characteristics following (Fautsch Macías et al., 2014; Moitra et al., 2021). Each of the three components was scored from 0 to 12. For knowledge and attitude, the individual subcategories were scored from 0-4, for Practices, the individual subcategories were scored from 0-3. Knowledge questions were divided into three subcategories: a) Knowledge about NCDs, b) Knowledge about food groups and c) Knowledge about healthy eating. Attitude questions were divided into three subcategories: a) Perceived susceptibility, b) perceived benefits, c) perceived risks. Lastly, practices were divided into four subcategories: a) readiness to change, b) peer habits, c) family habits and d) eating patterns.

Sociodemographic and Food Budget Information

Participants were asked to estimate their food budget for the previous 24h. Specifically, they were asked to report how much money they had at their disposal for breakfast, lunch, snacks and total budget, in case food purchases occur outside of breakfast, lunch or snacks. Participants reported if they brought food from home for any of these eating occasions. They were additionally asked about other household socio-economic characteristics, including maternal education, religion, ethnicity, maternal marital status and whether they live with their parents or a caretaker.

S2: Frequencies and mean values for all food groups by Vendor Type

Variable	Vendor Type [c]	Frequency [a]		Average [b]	
		n	Frequency	mean	SD
	Corner Shop	272	0.71	6.68	4.08
	Mobile Vendor	22	0.12	1.54	3.08
	Other	18	0.38	4.28	4.82
softdrinks_count	Restaurant/ Cafe	16	0.41	4.12	4.82
	School Vendor	23	0.28	2.83	2.57
	Street Vendor	171	0.29	4.58	6.31
	Supermarket	7	0.70	9.71	6.68
	Corner Shop	217	0.57	2.94	1.81
	Mobile Vendor	33	0.18	0.94	1.48
	Other	14	0.29	1.43	1.09
juices_count	Restaurant/ Cafe	9	0.23	3.33	3.67
	School Vendor	24	0.30	1.67	1.74
	Street Vendor	148	0.25	1.57	1.88
	Supermarket	6	0.60	5.67	3.14
	Corner Shop	224	0.59	5.07	4.42
	Mobile Vendor	39	0.21	1.61	2.48
	Other	12	0.25	4.42	3.00
unbaked_sweets	Restaurant/ Cafe	4	0.10	1.50	1.00
	School Vendor	29	0.36	5.24	8.52
	Street Vendor	158	0.27	3.87	4.43
	Supermarket	6	0.60	6.83	6.82
	Corner Shop	234	0.61	5.99	4.71
	Mobile Vendor	50	0.27	1.40	1.74
	Other	14	0.29	5.64	4.76
baked_sweets	Restaurant/ Cafe	5	0.13	1.60	1.14
	School Vendor	35	0.43	4.54	4.42
	Street Vendor	197	0.33	3.34	4.28
	Supermarket	5	0.50	12.20	14.32
	Corner Shop	161	0.42	2.53	2.13
	Mobile Vendor	25	0.14	0.48	0.87
	Other	7	0.15	2.29	1.11
savoury_snack	Restaurant/ Cafe	2	0.05	0.50	0.71
	School Vendor	25	0.31	2.36	2.23
	Street Vendor	135	0.23	1.22	1.43
	Supermarket	6	0.60	4.50	3.39
	Corner Shop	137	0.36	0.95	0.66
	Mobile Vendor	37	0.20	0.70	0.52
	Other	8	0.17	1.12	0.35
nuts	Restaurant/ Cafe	1	0.03	0.00	NA
	School Vendor	23	0.28	0.70	0.76
	Street Vendor	144	0.24	0.76	0.69
	Supermarket	4	0.40	2.75	4.27
	Corner Shop	50	0.13	0.32	1.19
	Mobile Vendor	56	0.30	1.27	1.24
fresh_fruits	Restaurant/ Cafe	1	0.03	0.00	NA
	School Vendor	20	0.25	1.20	1.91
	Street Vendor	106	0.18	1.65	2.25
	Supermarket	2	0.20	0.00	0.00
	Corner Shop	47	0.12	0.04	0.20
	Mobile Vendor	22	0.12	0.41	1.10
fresh_vegetables	Restaurant/ Cafe	1	0.03	0.00	NA
	School Vendor	17	0.21	0.41	0.80
	Street Vendor	67	0.11	0.24	0.80
	Supermarket	2	0.20	0.00	0.00
	Corner Shop	94	0.25	1.11	1.34
	Mobile Vendor	47	0.25	1.00	0.91
	Other	19	0.40	2.10	1.24
prepared_meal	Restaurant/ Cafe	27	0.69	3.82	3.97
	School Vendor	51	0.63	2.20	1.94
	Street Vendor	336	0.56	1.92	1.49
	Supermarket	2	0.20	0.00	0.00
	Corner Shop	296	0.78	16.08	19.70
	Mobile Vendor	150	0.81	13.49	16.54
	Other	32	0.67	15.56	21.12
count_schoolchildren	Restaurant/ Cafe	25	0.64	12.76	11.46
	School Vendor	79	0.98	85.75	141.90
	Street Vendor	487	0.82	16.11	16.04
	Supermarket	7	0.70	8.00	6.06
	Corner Shop	99	0.26	1.15	0.69
	Mobile Vendor	67	0.36	1.52	1.06
	Other	8	0.17	1.00	0.00
count_ncd_protect_rte_snack	School Vendor	16	0.20	2.19	1.97
	Street Vendor	134	0.22	2.08	1.93
	Supermarket	2	0.20	1.50	0.71
	Corner Shop	241	0.63	1.08	0.28
	Mobile Vendor	5	0.03	1.00	0.00
	Other	17	0.35	1.00	0.00
count_ncd_risk_drink	Restaurant/ Cafe	6	0.15	1.17	0.41
	School Vendor	15	0.19	1.13	0.35
	Street Vendor	111	0.19	1.09	0.32
	Supermarket	6	0.60	1.00	0.00
	Corner Shop	256	0.67	2.61	1.34
	Mobile Vendor	45	0.24	1.67	1.30
	Other	18	0.38	2.00	1.08
count_ncd_risk_rte_snack	Restaurant/ Cafe	8	0.21	1.50	0.54
	School Vendor	31	0.38	3.29	1.99
	Street Vendor	202	0.34	2.09	1.19
	Supermarket	6	0.60	3.17	1.17
	Corner Shop	26	0.07	1.61	0.94
	Mobile Vendor	16	0.09	1.12	0.34
	Other	10	0.21	1.30	0.48
count_ncd_protect_meal	Restaurant/ Cafe	13	0.33	1.77	1.24
	School Vendor	18	0.22	1.67	0.69
	Street Vendor	140	0.23	1.32	0.59
	Corner Shop	13	0.03	1.46	0.66
	Mobile Vendor	4	0.02	1.25	0.50
	Other	5	0.10	1.20	0.45
count_ncd_risk_meal	Restaurant/ Cafe	6	0.15	1.17	0.41
	School Vendor	16	0.20	1.31	0.48
	Street Vendor	81	0.14	1.41	0.63

[a] Indicates amount of vendors with characteristic
[b] Averages are among vendors that held item
[c] 'Other' includes shops or retailers that predominantly offer non-food (mobile money, hair dresser) but also sell foods

S3: Summary Characteristics by school gate policy

		Frequency [a]		Average [b]	
Variable	School Gate Policy [c]	n	Frequency	mean	SD
softdrinks_count	closed	244	0.41	5.57	5.00
	open	285	0.39	5.45	5.23
juices_count	closed	212	0.35	2.11	1.83
	open	239	0.32	2.42	2.19
unbaked_sweets	closed	222	0.37	4.03	4.24
	open	250	0.34	4.67	5.13
baked_sweets	closed	260	0.43	4.54	5.10
	open	280	0.38	4.49	4.47
savoury_snack	closed	164	0.27	1.75	1.97
	open	197	0.27	2.03	2.02
nuts	closed	175	0.29	0.75	0.67
	open	179	0.24	0.94	0.90
fresh_fruits	closed	125	0.21	1.11	1.81
	open	110	0.15	1.34	1.94
fresh_vegetables	closed	86	0.14	0.26	0.84
	open	70	0.09	0.17	0.56
prepared_meal	closed	246	0.41	1.65	1.48
	open	330	0.45	1.96	1.94
count_schoolchildren	closed	459	0.76	21.75	57.49
	open	617	0.83	19.92	34.08
count_ncd_protect_rte_snack	closed	153	0.25	1.60	1.39
	open	173	0.23	1.71	1.60
count_ncd_risk_drink	closed	177	0.29	1.10	0.31
	open	224	0.30	1.07	0.27
count_ncd_risk_rte_snack	closed	256	0.43	2.32	1.26
	open	310	0.42	2.39	1.44
count_ncd_protect_meal	closed	94	0.16	1.34	0.61
	open	129	0.17	1.43	0.75
count_ncd_risk_meal	closed	43	0.07	1.42	0.63
	open	82	0.11	1.35	0.58

[a] Indicates amount of vendors with that characteristic

[b] Averages are among vendors that held item

[c] 'Open' indicats that students and vendors can enter and leave the premises during school hours

S4: Frequencies and mean values for food groups by perimeter (0-300m)

		Frequency [a]		Average [b]	
Variable	Distance [c]	n	Frequency	mean	SD
softdrinks_count	300	529	0.39	5.50	5.12
	200	351	0.39	5.46	5.26
	100	147	0.34	4.95	4.35
	0	24	0.25	2.42	2.68
juices_count	300	451	0.34	2.28	2.04
	200	310	0.35	2.23	1.95
	100	140	0.32	2.02	1.76
	0	26	0.27	1.58	1.68
unbaked_sweets	300	472	0.35	4.37	4.74
	200	326	0.36	4.52	4.87
	100	160	0.37	5.03	5.61
	0	37	0.38	4.35	7.72
baked_sweets	300	540	0.40	4.51	4.78
	200	373	0.42	4.74	5.11
	100	184	0.42	4.79	4.81
	0	35	0.36	4.83	4.90
savoury_snack	300	361	0.27	1.90	2.00
	200	253	0.28	1.98	1.97
	100	112	0.26	1.92	1.95
	0	28	0.29	2.00	2.21
nuts	300	354	0.26	0.85	0.80
	200	240	0.27	0.88	0.88
	100	117	0.27	0.92	0.82
	0	28	0.29	0.75	0.75
fresh_fruits	300	235	0.18	1.22	1.87
	200	160	0.18	1.19	1.84
	100	87	0.20	1.28	1.92
	0	28	0.29	1.75	2.27
fresh_vegetables	300	156	0.12	0.22	0.73
	200	109	0.12	0.28	0.85
	100	56	0.13	0.25	0.72
	0	18	0.19	0.39	0.78
prepared_meal	300	576	0.43	1.82	1.76
	200	387	0.43	1.82	1.83
	100	193	0.44	1.89	1.75
	0	52	0.54	2.25	2.10
count_schoolchildren	300	1076	0.80	20.70	45.55
	200	726	0.81	24.33	54.35
	100	362	0.83	35.10	74.17
	0	90	0.93	76.31	134.04
count_ncd_protect_rte_snack	300	326	0.24	1.66	1.50
	200	220	0.25	1.66	1.46
	100	106	0.24	1.81	1.62
	0	25	0.26	2.64	2.02
count_ncd_risk_drink	300	401	0.30	1.08	0.29
	200	261	0.29	1.09	0.32
	100	108	0.25	1.11	0.37
	0	14	0.14	1.14	0.36
count_ncd_risk_rte_snack	300	566	0.42	2.36	1.36
	200	396	0.44	2.43	1.41
	100	186	0.43	2.66	1.61
	0	39	0.40	2.92	1.93
count_ncd_protect_meal	300	223	0.17	1.40	0.70
	200	145	0.16	1.34	0.66
	100	71	0.16	1.41	0.73
	0	22	0.23	1.59	0.67
count_ncd_risk_meal	300	125	0.09	1.38	0.59
	200	88	0.10	1.39	0.58
	100	47	0.11	1.36	0.57
	0	16	0.16	1.31	0.48

[a] Indicates amount of vendors with that characteristic
[b] Averages are among vendors that held item
[c] Buffer distance used for summary statistics

S5: Results from hierarchical model (with random effects at school level)

	Dependent variable:		
	GDR Score at school	NCD-Risk at school	NCD-Protect at school
	(1)	(2)	(3)
Price NCD-Risk	0.550**	-0.402**	0.138
	(0.218)	(0.184)	(0.277)
Price NCD-Protect	-0.197***	0.105*	-0.096
	(0.074)	(0.062)	(0.093)
# of Hotspots NCD-Risk	-0.005	-0.002	-0.008
	(0.029)	(0.025)	(0.038)
# of Hotspots NCD-Protect	-0.056	0.034	-0.022
	(0.059)	(0.050)	(0.075)
Open Gate (Ref: Closed)	0.075	0.034	0.126
	(0.259)	(0.218)	(0.321)
Total Budget	-0.029*	0.077***	0.051***
	(0.015)	(0.013)	(0.011)
Controlled for individual factors	YES	YES	YES
Observations	409	409	409
Log Likelihood	-769.573	-702.560	-624.558
Akaike Inf. Crit.	1,571.145	1,437.120	1,281.116
Bayesian Inf. Crit.	1,635.365	1,501.340	1,345.335
Note:			*p<0.1; **p<0.05; ***p<0.01