# Resilient and healthy food systems in low-income settings

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# STATEMENT OF OWN WORK

I, Zakari Ali, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

[redacted]

20th April 2023.

*‘Without good data, we’re flying blind. If you can’t see it, you can’t solve it.’*

Kofi Annan (2018)[1]

[1] Annan, K. 2018. Data can help to end malnutrition across Africa. Nature, 555(7697), 7-8.

# ABSTRACT

Undernutrition and food security have improved in low-and middle-income countries (LMICs) over the last decades. However, food systems in LMICs are now more vulnerable to shocks such as climate change and disease outbreaks which threaten existing gains in nutrition. Diets are key drivers of food systems and nutrition and could be an essential entry point for ensuring food systems' sustainability and resilience.

In a series of six interlinked research papers, this thesis assesses the individual and structural determinants of the effects of food system failures (undernutrition and poor diets) and examines the role that diets could play in ensuring food systems sustainability and resilience in three LMICs: The Gambia, Ghana, and Bangladesh.

The first two papers use sub-national data and focus on the determinants of undernutrition and diets of children and adolescents. The studies show that, poor diet diversity, being a male child and maternal short stature (<150cm) strongly predict undernutrition in children. Among adolescents, diets were driven by socio-economic factors (access to pocket money and living in high wealth households) and parental care.

Building on the determinants of nutrition and diets of children and adolescents, Papers 3 and 4 focus on national diets and potential vulnerabilities to shocks (climate change, crop and trade failure). The results show that, daily per capita caloric supply is adequate but a high reliance on single crop staples increases vulnerability of food supply and diets to potential shocks compared to more diversified diets. The supply of nutritionally important food groups (fruits, vegetables, nuts, and animal-sources) was suboptimal, showing a “double vulnerability” where the nutrient inadequate diets were also those most vulnerable to shocks.

Findings from Papers 3 and 4 informed further investigations into the adherence of national diets to health and environmental sustainability targets (EAT-Lancet dietary guidelines) in low-income settings (Paper 5). While diets were sub-optimal in nutritionally important food groups and high in less healthful food groups (refined grains and sugar), diets were low in food groups known to impact negatively on the environment (beef and lamb, dairy and pork).

Finally, Paper 6 identifies key policy reform strategies for food systems to deliver healthy and sustainable diets while being resilient to external shocks (using COVID-19 as a case).

Collectively, the research presented in this thesis shows that current food systems do not deliver optimal diets and nutrition and despite increasing food availability, overall diet quality is poor and shows a high vulnerability to external food system shocks. There are opportunities to transform food systems in LMICs to be more resilient to shocks and deliver healthy and sustainable diets.

# ACKNOWLEDGEMENTS

Many people have helped me and contributed towards my PhD. It is impossible for me to mention all of you by name – I can only hope that you are aware of my appreciation.

First and foremost, I would like to thank my supervisor, Prof. Andrew Prentice for your encouragement, support, and friendship. Thank you for giving me the opportunity and believing in my ability to complete this PhD while working with the Nutrition and Planetary Health Theme at MRCG. You have been kind to me and kept me sane during the COVID-19 lockdowns. I have learnt so much from you during this period.

To my associate supervisor, Dr. Pauline Scheelbeek, I have always been keen to receive your feedback, you tightened the strings when required and pushed me to go beyond the obvious. Thank you so much for all the sacrifices you made to support my timely completion and bringing out the best of me.

I am also grateful to Prof. Rosie Green who supervised my MSc project work at LSHTM and went on to supervise most of my work on the FACE-Africa project. Thank you, Rosie, for your kindness, support and understanding.

I would like to thank other colleagues on the FACE-Africa project. The late Dr. Momodou K. Darboe introduced me to relevant stakeholders in The Gambia and helped me integrate into the MRCG. Mr. Sulayman M'boob of Kombo Dairy Farms also supported my engagements with policymakers. I am also grateful to our FACE-Africa partners based in IIASA (Amanda and Felicity), Alliance of Bioversity-CIAT (Alcade and Robert) and LSHTM (Alan, Tony, and Genevieve H) for helping me understand some broader aspects of food systems, stakeholder engagements and links to climate change.

I am grateful to my thesis examiners (Dr. Christian Reynolds and Prof. Will Masters) for their time, support and interest in my research.

To my late mentor, Dr. Abdul-Razak Abizari of the University for Development Studies in Ghana, it saddens my heart that you are not around to see the end of this PhD. I was always proud to be your "TA." Thank you for igniting in me, a desire for research right after the completion of my undergraduate studies. I pray you continue to rest in peace with your maker.

Finally, I would like to thank my family and close friends for their support throughout my studies. To my wife (Sirina Mahmoud), thank you very much for your understanding and encouragement. My son's (Mbawin Ahmed) birth has been a joy and a source of strength for this PhD. To my mom (a.k.a. "Mma") and dad (a.k.a. "Baaba"), and my siblings (Adamu, Memuna, Inusa, Rabiyatu and Ahmadu), I am grateful for your support, patience, and prayers.

# PREFACE

This thesis is a culmination of six interlinked studies. The thesis has two main parts: an analytic commentary and a portfolio of publications. The **analytic commentary** is organised into five sections detailed below:

**Section 1** presents an overview of undernutrition, food systems and climate change in low-income settings. The section ends with an introduction to the study contexts: The Gambia, Ghana, and Bangladesh.

**Section 2** describes the rationale for this PhD and presents the aims and objectives of the PhD.

**Section 3** is a narrative linking the publications presented in the thesis.

**Section 4** makes a comprehensive evaluation of the publications presented in the thesis. The section puts each paper into the context for which it was developed, highlights the original contribution to knowledge and discusses advancements in the field as well as limitations in the literature.

**Section 5** is a general discussion where the key findings of the PhD are summarised and discussed. The section presents a reflection on the potential implications of the findings for policy or practice and identifies areas for future research.

The final part of the thesis is the **portfolio of publications** in which the papers in the thesis are presented. The papers are included in the published/accepted format. Supplementary materials for each paper are provided immediately at the end of the papers for easy reference. Each publication is preceded by a description of the candidate's contributions to the development, execution, and publication of the work.

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## ABBREVIATIONS

| | |
|---|---|
| BMI | Body Mass Index |
| DBM | Double Burden of Malnutrition |
| DHS | Demographic and Health Survey |
| FACE-Africa | Food System Adaptations in Changing Environments in Africa |
| FAO | Food and Agriculture Organization |
| FBDG | Food Based Dietary Guideline |
| FSD | Food Systems Dashboard |
| GBD | Global Burden of Disease |
| GDD | Global Dietary Database |
| GDP | Gross Domestic Product |
| GHDx | Global Health Data Exchange |
| GIFTS | Girls' Iron–Folic Acid Tablet Supplementation |
| GNR | Global Nutrition Report |
| HICs | High Income Countries |
| HLPE | High Level Panel of Experts on Food Security and Nutrition |
| IHME | Institute for Health Metrics and Evaluation |
| IPCC | Intergovernmental Panel on Climate Change |
| IYCF | Infant and Young Child Feeding |
| LCA | Latent Class Analysis |
| LMICs | Low-and Middle-income Countries |
| MDD | Minimum Diet Diversity |
| MDGs | Millenium Development Goals |
| MICS | Multiple Indicator Cluster Survey |
| NaNA | National Nutrition Agency of The Gambia |

| | |
|---|---|
| NCD | Non-Communicable Disease |
| PCA | Principal Component Analysis |
| SDGs | Sustainable Development Goals |
| SHDI | Sustainable and Healthy Diet Index |
| STP | Sweet Tooth Diet Pattern |
| TP | Traditional Diet Pattern |
| UN | United Nations |
| UNICEF | United Nations Children's Fund |
| WASH | Water, Sanitation and Hygiene |
| WFP | World Food Program |
| WHO | World Health Organization |
| WRA | Women of Reproductive Age |

## GLOSSARY OF KEY TERMS

**Climate change:** a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer.

**Diet:** the kinds of food that follow a particular pattern that a person or community eats.

**Food system:** all the elements (environment, people, inputs, processes, infrastructures, institutions, etc.) and activities that relate to the production, processing, distribution, preparation and consumption of food, and the output of these activities, including socio-economic and environmental outcomes.

**Planetary health:** a concept based on the understanding that human health and human civilisation depend on ecosystem health and the wise stewardship of ecosystems.

**Resilience:** the capacity of interconnected social, economic, and ecological systems to cope with a hazardous event, trend, or disturbance, responding or reorganising in ways that maintain their essential function, identity, and structure.

**Sustainability:** involves ensuring the persistence of natural and human systems, implying the continuous functioning of ecosystems, the conservation of high biodiversity, the recycling of natural resources and, in the human sector, successful application of justice and equity.

**Vulnerability:** the susceptibility of natural or human systems to a specified hazard normally of unpredicted nature.

# ADMINISTRATIVE INVOLVEMENT

## Candidate's research journey

I have been fortunate to have the opportunity to work across different institutions, research groups and supervisors spanning the last six years which has culminated into outputs presented in this thesis. By reflecting on my involvement in the development and execution of the studies presented in the thesis, I highlight the associated skills learned throughout my research journey.

I am a public health nutritionist with initial training and focus on undernutrition and infant feeding practices. After completing a BSc in Community Nutrition in 2016, I worked as a Research Assistant at the Department of Nutritional Sciences, University for Development Studies (UDS) in Ghana. My role was to assist in the conduct of research in the department. I had little teaching responsibility which released more time to focus on research activities. I also assisted with supervising final year undergraduate nutrition students' dissertation projects. At the initial stages, I was engaged in more field activities including the conduct of interviews with study participants, dietary assessment, and anthropometric measurements. With time, I moved on to take roles in supervision of fieldwork and teams which involved leading and coordinating data collection, data entry and processing using appropriate data management and statistical software (MS Excel and SPSS). The research I engaged in focused on child and adolescent nutrition with opportunities to co-author papers. My supervisors at UDS were Dr. Abdul-Razak Abizari and Dr. Mahama Saaka, who were the Head of Department and Senior Lecturer, respectively. I was the primary lead on two studies including a cohort of adolescents to assess how adolescent diets changed during religious fasting and a cross-sectional study. The two studies culminated into three published papers, two of which are presented as part of this portfolio (Paper 1 and 2). I participated in the development and execution of these studies from conception to field data collection and manuscript drafting (further details of my contributions to each paper are presented in the research cover sheets that precede the papers in the portfolio). As my involvement in research studies increased, I developed special interest in statistics and data analysis. This interest arose partly due to managing large departmental nutrition research data and my observation of research output of faculty members who could analyse their own data as compared to those who relied on other team members for data analysis. The latter had relatively low research outputs. I sought additional guidance from experienced staff members on appropriate data analysis approaches in nutritional epidemiology including generation of z-scores for nutritional status classification and introduction to regression modelling led by my two supervisors at UDS.

After two years of work as a Research Assistant, I gained admission with scholarship to study the MSc in Nutrition for Global Health at the London School of Hygiene and Tropical Medicine (LSHTM), UK in 2018. The programme broadened the scope of my knowledge of nutritional challenges globally and offered me the opportunity to take more advanced statistics and epidemiology courses. I also learned to use a new statistical tool, Stata. A strong component of my masters training was on sustainable diets and food systems which further shaped my perspective and research interests. Therefore, for my final masters' dissertation, I analysed a large national agriculture and food consumption survey from Bangladesh.

Upon completion of my masters' studies at LSHTM, I returned to Ghana in October 2019. Subsequently, I gained employment as Higher Scientific Officer at the MRC Unit The Gambia at LSHTM (MRCG@LSHTM) to work on the Food System Adaptations in Changing Environments in Africa (FACE-Africa) project staring in January 2020. The FACE-Africa project was funded by Wellcome Trust under the Wellcome Climate Change and Health Award Scheme. The Principal Investigators were Prof. Rosie Green (who also supervised my MSc thesis) and Dr. Pauline Scheelbeek (who is my associate PhD supervisor), both of whom were based in London at LSHTM while I worked from the project main site in The Gambia (MRCG@LSHTM). Prof. Andrew Prentice (my primary PhD supervisor) was my line manager and the theme leader for the Nutrition and Planetary Health Theme at the MRCG@LSHTM in

The Gambia. During the initial stages of the FACE-Africa project, I re-visited the dataset which I worked on for my masters' project to perform further analyses to investigate additional questions which arose from the project. This was on dietary vulnerability to shocks (climate change or crop failures) which were not covered in the MSc project (Paper 4).

My role on the FACE-Africa project involved working with a diverse group of partners including local food system stakeholders, policymakers, and a multi-disciplinary team of scientists from LSHTM, the International Institute for Applied Systems Analysis (IIASA)-Austria, CGIAR partners in Mali and the Alliance of Bioversity-CIAT in Senegal. The food system end users and actors such as local farmers, consumers, development agencies and environmental protection groups were key partners of the project which I worked closely with in efforts to co-create locally relevant and acceptable food system recommendations to inform food system policy and practice. I also served as the key representative for our Nutrition and Planetary Health Theme (MRCG@LSHTM) at government policy development and planning meetings where I contributed a scientific perspective to national nutrition and agriculture planning in The Gambia. This regular contact with policymakers was an opportunity to share early findings of my work directly for policy consideration and development. For example, I was heavily involved in the development of the first Gambian Food Based Dietary Guidelines (FBDG), working together with the Gambian Ministry of Health, the National Nutrition Agency (NaNA) and other stakeholders. Outputs from my work on the FACE-Africa project (Paper 3 and 5) partly informed the diet modelling for the determination of recommended intakes in The Gambia.

While continuing to work on the FACE-Africa project, I registered as a staff PhD student at the London School of Hygiene & Tropical Medicine, UK. Funding for my PhD was provided by Wellcome Trust under the FACE-Africa project. At the time of registration, four of my portfolio papers were already published except for Papers 3 and 5 which were still in development and completed during my PhD candidature. I led the development and publication of Papers 3 to 6 while working at the MRCG@LSHTM.

It has been a humbling experience of learning from scientists and researchers who are experts in evidence generation as well as collaborating closely with policymakers on the ground who are experts in translating evidence into practice.

## Additional publications and other outputs

Apart from the studies presented in the portfolio of this thesis, I have also co-authored other publications and contributed outputs in nutrition, food systems and climate change during the period that I was working on the papers presented in the thesis.

**Publications**


Hadida G, **Ali Z**, Kastner T, Carr TW, Prentice AM, Green R, Scheelbeek P. Changes in Climate Vulnerability and Projected Water Stress of The Gambia's Food Supply Between 1988 and 2018: Trading With Trade-Offs. Frontiers in Public Health. 2022;10:786071.

Carr TW, Mkuhlani S, Segnon AC, **Ali Z**, Zougmoré R, Dangour AD, Green R, Scheelbeek P. Climate change impacts and adaptation strategies for crops in West Africa: a systematic review. Environmental Research Letters. 2022;17(5):053001.

Segnon AC, Zougmoré RB, Green R, **Ali Z**, Carr TW, Houessionon P, M'Boob S, Scheelbeek PFD. Climate change adaptation options to inform planning of agriculture and food systems in The Gambia: A systematic approach for stocktaking. Frontiers in Sustainable Food Systems 2022;6.

**Ali Z**, Scheelbeek P, Felix J, Jallow B, Prentice A, Green R. Adherence of Gambian Diets to EAT-Lancet Diet Recommendations for Health and Sustainability. Current Developments in Nutrition. 2022;6(Supplement_1):71. **(Conference abstract, developed into Paper 5)**.

Bonell A, Badjie J, Jammeh S, **Ali Z**, Hydara M, Davies A, Faal M, Ahmed AN, Hand W, Prentice AM, Murray KA, Scheelbeek P. Grassroots and Youth-Led Climate Solutions From The Gambia. Frontiers in Public Health. 2022;10.

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James PT, **Ali Z**, Armitage AE, Bonell A, Cerami C, Drakesmith H, Jobe M, Jones KS, Liew Z, Moore SE, Morales-Berstein F, Nabwera HM, Nadjm B, Pasricha S-R, Scheelbeek P, Silver MJ, Teh MR, Prentice AM. The Role of Nutrition in COVID-19 Susceptibility and Severity of Disease: A Systematic Review. The Journal of Nutrition. 2021;151(7):1854-78.

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Ziba FA, Yakong VN, **Ali Z**. Clinical learning environment of nursing and midwifery students in Ghana. BMC Nursing. 2021;20(1):14.

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Sulley I, Abizari A-R, **Ali Z**, Peprah W, Yakubu HG, Forfoe WW, Saaka M. Growth monitoring and promotion practices among health workers may be suboptimal despite high knowledge scores. BMC Health Services Research. 2019;19(1):267.

Abubakari A, Taabia FZ, **Ali Z**. Maternal determinants of low birth weight and neonatal asphyxia in the Upper West region of Ghana. Midwifery. 2019;73:1-7.

**Ali Z**, Abu N, Ankamah IA, Gyinde EA, Seidu AS, Abizari A-R. Nutritional status and dietary diversity of orphan and non – orphan children under five years: a comparative study in the Brong Ahafo region of Ghana. BMC Nutrition. 2018;4(1):32.

**Ali Z**, Abizari A-R. Ramadan fasting alters food patterns, dietary diversity and body weight among Ghanaian adolescents. Nutrition Journal. 2018;17(1):75.

Garti H, **Ali Z**, Garti HA. Maternal daily work hours affect nutritional status of children in Northern Ghana. Nutrire. 2018;43(1):16.

Abizari A-R, **Ali Z**, Essah CN, Agyeiwaa P, Amaniampong M. Use of commercial infant cereals as complementary food in infants and young children in Ghana. BMC Nutrition. 2017;3(1):72.

**Conference presentations**

Healthy and sustainable diets in The Gambia: an assessment of deviations from EAT-Lancet recommendations (**Poster presentation:** December 6-11, 2022, 22$^{nd}$ IUNS-ICN, Tokyo, Japan).

The utility of global open-source databases for food system decision-making in low-income settings ( **Poster presentation:** December 6-11, 2022, 22$^{nd}$ IUNS-ICN, Tokyo, Japan).

Adherence of Gambian Diets to EAT-Lancet Diet Recommendations for Health and Sustainability (**Poster presentation**: June 14-16, 2022 at Nutrition 2022 Live Online, ASN).

Food systems policy in The Gambia can ensure food and nutrition security and guard against climate change (**Invited oral presentation**: July 8, 2021 at Gambian Government Policy Forum 2021).

## Masters' students' supervision

While working at the MRC Unit The Gambia at LSHTM on the FACE-Africa project and for my PhD, I had the opportunity to supervise MSc summer projects at LSHTM. Completed projects are listed below:

**Eret Ayamba** (2022): Projected dietary and environmental implications of reductions in postharvest loss of fruits and vegetables in Cameroon: a modelling study (**Supervisor**).

**Rebecca Camenzuli** (2022): Associations between women's dietary diversity and non-communicable disease risk and undernutrition in children in The Gambia – a secondary data analysis (**Supervisor**).

**Brighid Morgan** (2022): Crop diversification as a climate risk management strategy to reduce malnutrition in The Gambia: obstacles, opportunities, and policy windows (**Second supervisor**).

**Titus Ng'ang'a** (2022): Evaluating Kenya's preparedness for a changing climate: a policy analysis focused on food security and nutrition (**Second supervisor**).

**Jyoti Felix** (2021). Projected affordability and environmental impacts of a shift to healthy and sustainable diets in The Gambia: A modelling study (**Supervisor**). Abstract was selected for oral presentation by Jyoti at ANH conference in June 2022. Manuscript under preparation.

**Genevieve Hadida** (2020). Exploring the role of trade in food system climate resilience in The Gambia: a secondary data analysis. (**Second supervisor**). This project has now been published: https://doi.org/10.3389/fpubh.2022.786071

# ANALYTIC COMMENTARY

## Section 1: Overview of undernutrition, food systems and climate change

In this first section, I provide an overview of the topics around which my PhD revolve: undernutrition, diets, food systems and climate change in low-income settings. Given the large and varied body of literature on these topics, this section is only meant to provide a summary of the most important highlights of the current state of knowledge and set the scene for the succeeding sections. I end the section by briefly introducing the study contexts: The Gambia, Ghana, and Bangladesh. I have described how these contexts experience common nutrition and food system challenges thus justifying the need to find solutions.

### *1.1 Undernutrition*

Undernutrition is one form of malnutrition consisting of stunting (*too short-for-age*), wasting (*too thin-for-height*), and deficiencies of vital vitamins and minerals (micronutrients), while obesity or overconsumption of certain nutrients is another form of malnutrition called overnutrition (1). Hunger which literally refers to the discomfort that results from not eating, has sometimes also been used to refer to undernutrition – particularly in the context of food insecurity (2).

The different forms of malnutrition exist (often concurrently) globally in varying degrees – a situation known as the dual burden of malnutrition (3). Currently, over 40% of people worldwide are overweight or obese, 195 million children under five years are stunted or wasted (4), and over 1.5 billion children and women of reproductive age have at least one of three micronutrient deficiencies (5).

Low-and middle-income countries (LMICs) are disproportionately affected by undernutrition and at the same time, there is an emerging overweight and obesity in the same populations (4, 6). Despite gains over recent decades in reducing undernutrition, 149.2 million children under-five years were stunted globally in 2020 – representing a 24.5 million reduction since 2012 (7). South Asia and sub-Saharan Africa have the most burden of undernutrition as compared to other parts of the world (8, 9). Undernutrition is a significant contributor to morbidity and mortality in children in LMICs (10). For example, in 2013, Black *et al* estimated that undernutrition "including fetal growth restriction, stunting, wasting, and deficiencies of vitamin A and zinc along with suboptimum breastfeeding" caused 45% of all child deaths (11). Among the children who survive, exposure to undernutrition in early life has been linked to permanent impairment with intergenerational effects (12). The causes of undernutrition are complex and multi-dimensional – operating at various levels, from a proximate level where dietary intake, ill-health, and care play a critical role, to the most distant socioeconomic, political and environmental causes that act together to shape individual level outcomes (13)

(**Figure 1.1**). This complex causation of undernutrition has made it difficult to eliminate despite ongoing efforts.

For decades, undernutrition and food insecurity have been the focus of global attention. Since the 1970s food crisis, there have been targets aimed at eradicating undernutrition and hunger (14). Notable subsequent global milestones include the 2000s' Millennium Development Goals (MDGs) (2000-2015) which aimed to cut undernutrition and hunger by half in 15 years. Through the MDGs' commitments, many LMICs reduced undernutrition and hunger and achieved the target for MDG 1 (15, 16). Building on the MDGs, the current Sustainable Development Goals (SDGs) (2015-2030) have set even more ambitious targets aiming to eradicate undernutrition and hunger including goals for child development, and education that go beyond merely ensuring children's survival (17-19). But progress has been slow, stagnant, or even risk being reversed (20, 21).

Emerging threats of climate change and other shocks (pandemics and conflicts) with cross-cutting influence on the different causes of undernutrition pose the most setbacks to progress on eliminating undernutrition. The so-called triple catastrophes of climate extremes, conflict, and COVID-19 pandemic threaten gains made over the past decades (22, 23). FAO estimates that if the world continues on a business as usual model, 8% of the world's population, or 670 million people, will be food insecure in 2030 (7). This will be the same as when the 2030 Agenda for the SDGs was launched in 2015. Addressing these multitude of challenges concurrently requires a food systems approach that recognises existing resource constraints and trade offs for actions that ensure sustainability of progress while building resilience to external shocks (24-26).

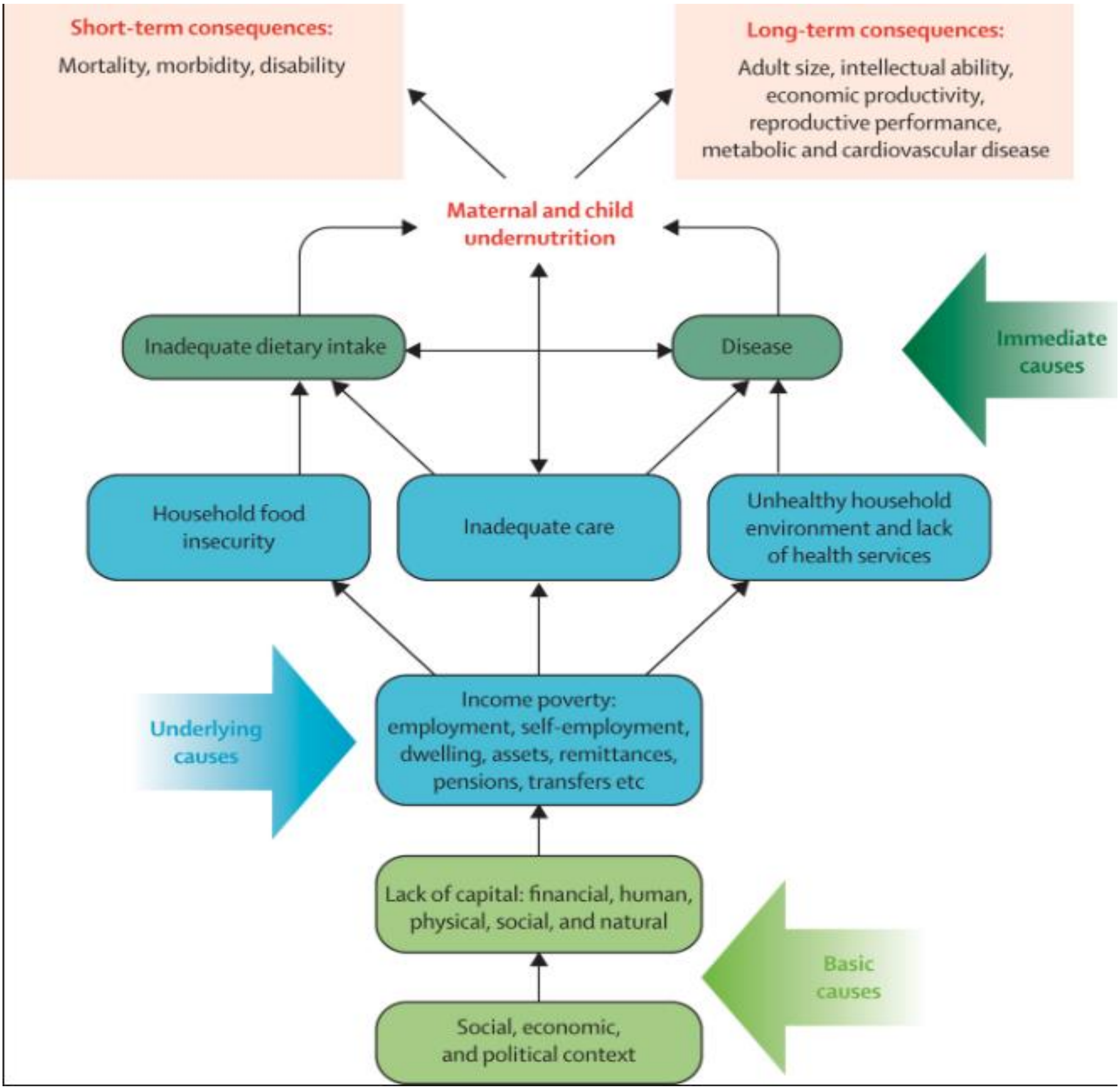


**Figure 1. 1**: Framework of multi-level causes of child undernutrition. Source: Black et al (2008)[1]

[1] Black RE, Allen LH, Bhutta ZA, Caulfield LE, de Onis M, Ezzati M, et al. Maternal and child undernutrition: global and regional exposures and health consequences. The Lancet. 2008;371(9608):243-60. https://doi.org/10.1016/S0140-6736(07)61690-0.

## *1.2 Food systems and climate change*

The food system is often defined as consisting of all the relevant actors (environment, inputs, people, infrastructures, institutions and etc.) along with the activities that relate to the production, processing, distribution, preparation and consumption of food, and the associated outputs of these activities, including socio-economic and environmental outcomes (27).

The global food system has been successful in certain aspects. It has largely matched rapid population growth over the last six decades with a profound increase in food production and reduced undernutrition and hunger substantially. This is attributable to innovations in agronomic practices including mechanisation of farm labour, development of improved crop varieties and inorganic fertilizers (28).

However, a major, often overlooked challenge in agriculture and food systems is providing an adequate diversity of nutrients required for a healthy life, in addition to producing enough calories (29, 30). Growth in agricultural productivity over years has mainly focused on a small number of crop and animal species: mainly cereals, root tubers, ruminants, and poultry. Thus, perpetuating a largely monotonous diet lacking diversity. The Asian Green Revolution is a typical example which advanced the production of cereals to the detriment of a diverse supply of food crops. It has since been criticised for contributing to poor diet diversity, micronutrient deficiency, undernutrition and local biodiversity loss despite overall increase in coarse cereal production (31, 32).

Consequently, despite the increase in food production globally, food insecurity, undernutrition and overnutrition still persist and poor diets remain a top risk factor for non-communicable diseases and mortality globally (33). Moreover, the increase in agricultural productivity has come with appropriation of large natural resources. The agriculture sector alone is estimated to be responsible for nearly 70% of global fresh water use, 23-42% of greenhouse gas emissions, along with significant soil degradation and biodiversity loss (34, 35). Additionally, food systems are also affected by climate and environmental changes that threaten their sustainability (36). The relationship between climate change and food systems is complex and geographically and temporally variable. Climate change factors (e.g. increased temperatures, droughts, erratic rainfall patterns, disease outbreaks) affect the food system in many ways such as through reductions in labour productivity, low crop yields (37), reduced nutrient quality of foods, poor food safety, increased food prices and a decrease in dietary diversity (38, 39).

Clearly, current food systems are not delivering as expected on both human health and environmental sustainability and require urgent transformation (40). The food systems transformation agenda is gaining global traction. Several global efforts to accelerate the transformation of food systems, such as the United Nation's Food Systems Summit that was convened in September 2021. The aim of the summit was to boost efforts to transform food systems globally and to get the SDGs back on track (41). The Summit had five main action tracks for achieving its goal: ensuring access to safe and nutritious food; shifting to sustainable consumption patterns; boosting nature positive production; advancing equitable livelihoods; and building resilience (42). **Figure 1.2** summarises the interrelationships between food systems and climate change. The figure highlights the role of diets and food production systems in adapting to, and mitigating against, climate change (43). Food systems transformation can offer 20-30% of the global mitigation needed for a 1.5°C or 2°C pathway towards 2050 through both supply side (food production) and demand side (diets) actions (35).

At the centre of the food systems transformation discussions are behaviour change related to food and diets. An overwhelming amount of research now shows that dietary shifts away from current patterns (especially those in the Global North) and towards more healthy and sustainable patterns would benefit both human and planetary health (44-46). However, the nature of food system transformations required to deliver those diets would differ from place-to-place given existing food system challenges in individual countries and regions (47). In most high income countries (HICs), overnutrition and diet related non-communicable diseases are the main cause of death and disability and so dietary shifts away from red and processed meat, processed fats and sweets consumption towards an increase in fruits, vegetables and nuts consumption is the main focus of food system transformation (44, 48). However, in many

LMICs where consumption of animal-source foods is lower than recommended levels and undernutrition co-exist with an emerging overweight and obesity, the solution is not as straightforward. An important determining factor for making dietary recommendations for health and sustainability is the baseline diet and associated production systems. For example, environmental footprints of tomatoes produced in urban areas of Benin (with high food loss) were 2-23 folds greater than tomatoes produced in European farming systems (with low food loss) (49). Further, a recent analysis showed that, in HICs, replacing animal-source foods with plant-based foods was especially effective for improving nutrient levels, lowering mortality, and reducing some environmental impacts, particularly greenhouse gas emissions (reductions of up to 84%). It did, however, increase freshwater use (up to 16%) and was ineffective in countries with low or moderate consumption of animal-source foods (such as LMICs) (50).Therefore, a blanket recommendation (45), often derived from HICs for changing diets to meet health and sustainability goals is unlikely to work everywhere and can be a source of food system maladaptation to climate change. Hence the need for context-specific solutions.

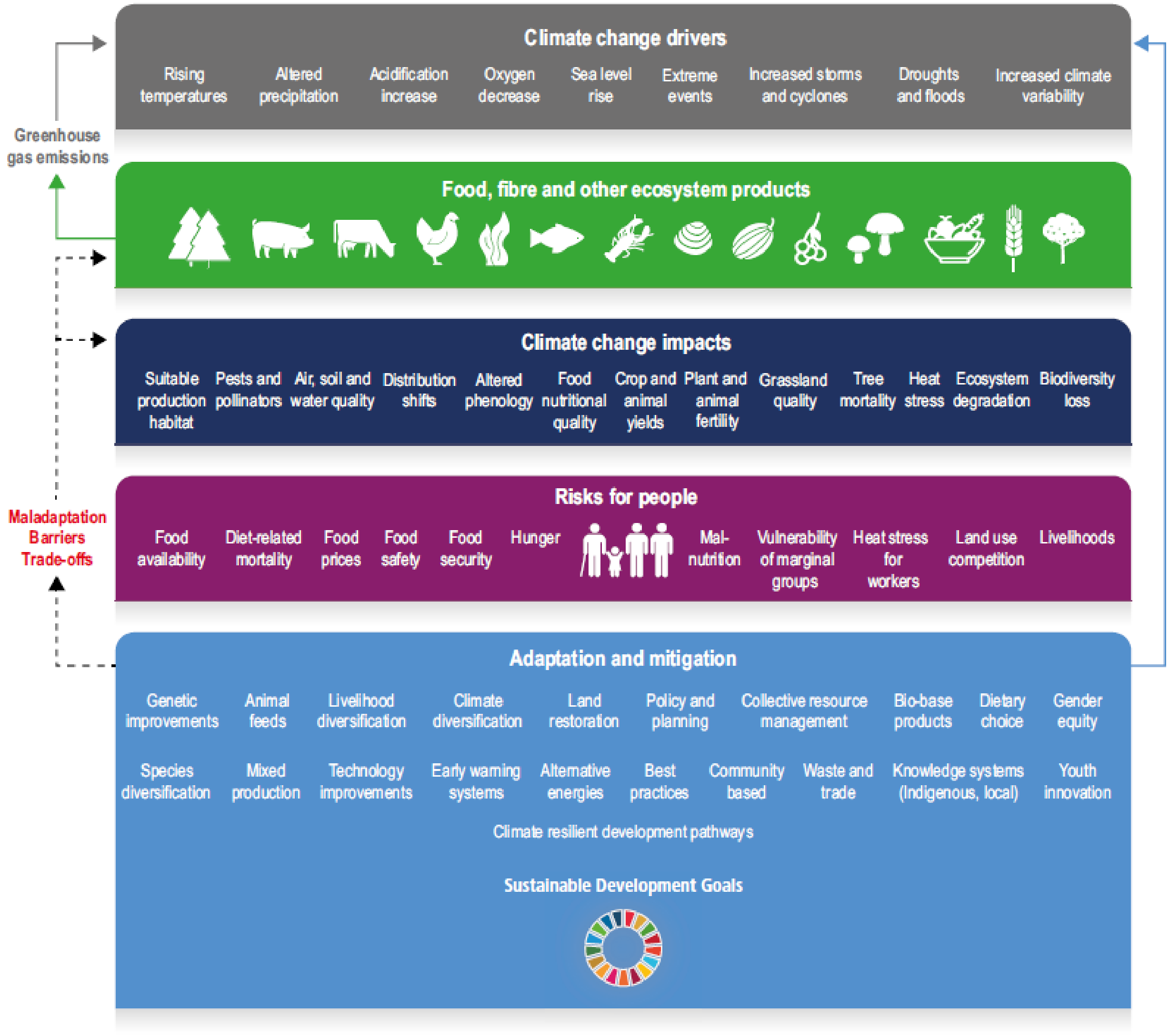


**Figure 1. 2:** Conceptual framework of the relationship between food systems and climate change. Source: IPCC (2022)[2]

[2] Bezner Kerr, R., T. Hasegawa, R. Lasco, I. Bhatt, D. Deryng, A. Farrell, H. Gurney-Smith, H. Ju, S. Lluch-Cota, F. Meza, G. Nelson, H. Neufeldt, and P. Thornton, 2022: Food, Fibre, and Other Ecosystem Products. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [doi:10.1017/9781009325844.007].

### *1.3 PhD contexts: The Gambia, Ghana, and Bangladesh*

**Nutritional and socioeconomic factors**

The studies in this PhD are based on three low-income countries: The Gambia, Ghana, and Bangladesh. The Gambia and Ghana have a combined population of less than 35 million people as compared to Bangladesh with 166 million people according to recent estimates (51). The countries are similar in many nutritional, food systems and economic indicators and share common successes and challenges over the past two decades including vulnerability to climate change (**Table 1.1**). All three countries reduced the prevalence of under-five stunting by half within the last 20 years – even though almost a third of children are still stunted in Bangladesh. The prevalence of undernourishment (a measure of food insecurity (7)) has also reduced in all countries with Ghana currently having the least number of people going hungry at only 4% as compared to 11% and 22% in Bangladesh and The Gambia respectively (**Table 1.1**). However, the supply of nutritionally important fruits and vegetables is still sub-optimal (below the 400g/person/day WHO recommended intake level (52)) in all three countries. Yet overall daily food energy exceeds 2500kcal (except for The Gambia where it is ~2500kcal/person/day). The consumption of red meat which is associated with increased negative effects on the environment (53) is on average within sustainable levels. Within a 4-year period, obesity among the adult population increased in all three countries by at least ~1 percentage point. In 2016, Bangladesh had the least prevalence of obesity (3.6%) compared to more than 10% in The Gambia and Ghana (**Table 1.1**).

**Climate vulnerability and effects**

While the nutritional and socio-economic indicators show similar trends in the three countries, the climate experiences and implications are more diverse. Sub-Saharan Africa and South Asia are very vulnerable global regions to climate change effects due to less capacity to adapt to increasing climate change events (54). In this thesis, The Gambia and Ghana are used as case studies from Sub-Saharan Africa and Bangladesh from South Asia for a deeper understanding. Vulnerability to climate change is highest in Bangladesh and The Gambia while

Ghana has a relatively low vulnerability according to Notre Dame's climate vulnerability scores (ND-GAIN scores) (54). Climate extremes are already having negative implications on child stunting and food insecurity in all three countries (55, 56). Additionally, excessive rainfall also increases the risk of infectious diseases such as malaria, parasitic and diarrheal diseases, that affect food utilization (57).

The Gambia and Ghana have two main seasons: the rainy and dry seasons which also correspond with food production patterns as most production is rainfed. The rainy season is longer in most parts of Ghana (April-November) as compared to The Gambia (June-October). But both countries are known for having less availability of food during the rainy season when the previous season's harvests are depleted (the so called *hunger season*) (58). In recent years the typical hunger season is less obvious in both countries due to increasing reliance on food purchase (often with remittances) instead of relying mainly on own food stores (59). Irregular rainfall patterns (including flooding) and longer periods of droughts are the main climate factors affecting agricultural production and livelihoods in The Gambia and Ghana.

In contrast, Bangladesh experiences almost year-round availability of rains, peaking between June and August. The Bangladeshi climate has four main seasons: pre-monsoon (March–May), monsoon (June–August), post-monsoon (September–November) and winter (December–February) (60). As Bangladesh is a relatively large country, rainfall patterns differ across different regions. The northwestern part of the country receives about 1400 mm of rainfall while the northeast receives more than 4400 mm of annual rainfall (61). Most crop production, particularly rice, takes place between the pre-monsoon and post-monsoon periods. The recent climate uncertainties that have led to gradual delays in the coming of the monsoon is causing disruptions in crop production and unexpected floodings in previously known post-monsoon seasons (62). Due to its geographical location, Bangladesh has been designated one of the countries which is more susceptible to climate extremes (floods, cyclones, tidal storms, tornados, hailstorms, and droughts) by the Intergovernmental Panel on Climate Change (IPCC) (63). For example, when Cyclone Sidr hit in 2007, its combined agricultural and livelihood costs amounted to an estimated US$ 1.7 billion loss to the Bangladeshi economy and pushed many households into poverty and food insecurity (64).

The increased vulnerability of these three countries to the effects of climate change and the existence of subsistence and rainfed agriculture, additional pressures from future climate extremes and other shocks is expected to negatively impact food production, food security and undernutrition (65-67). Therefore, there is an urgent need to understand the diet and hence food system approaches that build resilience of the food system to shocks (climate change, pandemics) while delivering healthy and sustainable diets.

**Table 1. 1:** Comparison of basic nutritional, socio-economic and climate vulnerability indicators in The Gambia, Ghana and Bangladesh[a]

| Indicator | Year | The Gambia | Ghana | Bangladesh |
|---|---|---|---|---|
| Under-5yrs stunting (%)[b] | 2000 | 24.1 | 35.5 | 51.1 |
| | 2020 | 16.1 | 14.2 | 30.2 |
| Undernourishment (%)[c] | 2004 | 21.7 | 11.2 | 14.2 |
| | 2021 | 21.6 | 4.1 | 11.4 |
| Obesity (>18yrs) (%)[d] | 2012 | 8.7 | 9.4 | 2.1 |
| | 2016 | 10.3 | 10.9 | 3.6 |
| Fruit and vegetables (g/capita/day)[e] | 2019 | 78.8 | 225.3 | 279.7 |
| Red meat (g/capita/day)[e] | 2019 | 6.6 | 14.6 | 8.1 |
| Total food energy (kcal/capita/day)[e] | 2010 | 2663 | 3042 | 2411.0 |
| | 2019 | 2483 | 3114 | 2626.0 |
| Population living below 3.20 USD/day (%)[f] | 2021 | 29.8 | 24.1 | 31.8 |
| Total population (million)[f] | 2021 | 2.49 | 31.73 | 166.30 |
| Climate vulnerability index[g] | 2022 | 39.2 | 44.0 | 36.9 |

[a] Source of table: author compilation, 2022. Data sources are detailed below.
[b] Joint UNICEF-WHO-The World Bank malnutrition estimates: https://data.unicef.org/resources/jme-report-2021/
[c] FAO's 2022 state of food security in the world estimate: https://doi.org/10.4060/cc0639en
[e] FAOSTAT estimate of food supply: https://www.fao.org/faostat/en/#data/FBS
[f] World Bank estimate: https://databank.worldbank.org/source/world-development-indicators#
[g] ND-GAIN country vulnerability to climate change index. High scores indicate less vulnerability to climate change and vice-versa: https://gain.nd.edu/our-work/country-index/

## Section 2: PhD Rationale, aims and objectives

### *2.1 PhD rationale*

The quest to end malnutrition in all forms has proved challenging despite numerous efforts. With emerging threats that could stall or even reverse previous gains, researchers and policymakers are seeking a more holistic solution. The food systems transformation agenda has so far emerged as the best way to build resilience within food systems and ensure the provision of healthy and sustainable diets. However, food systems transformation will require substantial cross-sectoral collaborations away from the current siloed approach to tackling malnutrition.

Historically, the worlds of nutrition, agriculture and environment have operated largely in silos with little cross-fertilisation which could partly explain the slow progress made on ending malnutrition (68). Nutritionists have typically focused on infant and young child feeding and maternal nutrition as a niche to solving malnutrition (69). This leaves certain important life stages with less attention such as school-age children and adolescents (70).

Food production has also been led by agriculturists, with much focus on food supply and caloric increase than overall food security (29). There is evidence of the occurrence of famines in societies with widespread food availability in sections of the same society (71). Even today, the world produces enough food to meet the caloric needs of everyone (72), yet many people go hungry and 3 billion people cannot afford healthy diets (8). This may partly be the result of limited involvement of nutritionists and other relevant disciplines such as economists in the planning of food production and supply.

Further, environmental scientists including ecologists and climatologists have also worked very distantly from nutritionists and agriculturists despite the close relevance of these fields to food and nutrition (73, 74). Hence, there is little understanding on how best to produce foods that meet dietary requirements while maintaining environmental sustainability.

This PhD presents a set of multidisciplinary studies covering undernutrition and diets and examines the potential that environmental shocks could have on diets as well as how diets and food production could also impact on food system resilience in three LMICs.

### *2.2 PhD aims and objectives*

**Overall aim:** To determine the individual, household and national risk factors that threaten diets and dietary sustainability and propose evidence-based strategies for food system transformation to deliver healthy and resilient diets in low-income settings.

**The specific objectives of the PhD are:**

1. To determine the individual and household factors (not related to food system shocks) that predispose vulnerable groups (children and adolescents) to inadequate dietary intake and undernutrition as leverage points to improve diets and nutritional status in a low-income setting.

2. To identify specific vulnerabilities to food system shocks (such as climate change, crop failure or disease outbreak) of distinct dietary patterns to build dietary resilience in a low-income setting.

3. To identify food system vulnerabilities at national level in low-income settings using open-source data on food supply, political, economic, demographic, and nutrition and health data to inform resilience planning.

4. To assess sustainability of diets by mapping their deviations from sustainable and healthy dietary targets and develop a context-specific metric for evaluating diets for health and sustainability in a low-income setting.

5. To propose recommendations for improving dietary and food systems sustainability and resilience to shocks in low-income settings for evidence-based decision-making.

### *2.3 Publications presented in the thesis*

The papers are also referred to throughout the thesis according to numbers assigned below (**Paper 1 to 6**):

1. **Ali Z**, Saaka M, Adams A-G, Kamwininaang SK, Abizari A-R. The effect of maternal and child factors on stunting, wasting and underweight among preschool children in Northern Ghana. BMC Nutrition. 2017;3(1):31.

2. Abizari A-R, **Ali Z**. Dietary patterns and associated factors of schooling Ghanaian adolescents. Journal of Health, Population and Nutrition. 2019;38(1):5.

3. **Ali Z**, Scheelbeek PFD, Dalzell S, Hadida G, Segnon A, M'boob S, Prentice AM, Green R. Socio-economic and food system drivers of nutrition and health transitions in The Gambia from 1990-2017. (**Under review: Global Food Security).**

4. **Ali Z**, Scheelbeek PFD, Sanin KI, Thomas TS, Ahmed T, Prentice AM, Green R. Characteristics of Distinct Dietary Patterns in Rural Bangladesh: Nutrient Adequacy and Vulnerability to Shocks. Nutrients. 2021;13(6).

5. **Ali Z**, Scheelbeek PFD, Felix J, Jallow B, Palazzo A, Segnon AC, Havlík P, Prentice AM, Green R. Adherence to EAT-Lancet dietary recommendations for health and sustainability in The Gambia. Environmental Research Letters. 2022;17(10):104043.

6. **Ali Z**, Green R, Zougmoré RB, Mkuhlani S, Palazzo A, Prentice AM, Haines A, Dangour AD, Scheelbeek PFD. Long-term impact of West African food system responses to COVID-19. Nature Food. 2020;1(12):768-70.

## Section 3: Logical links between papers in the thesis

### *3.1 Thematic linkages of papers presented*

The studies presented in this thesis all look at diets and vulnerability which logically links the papers. Each individual paper has a specific focus with the theme of healthy diets and resilience, ranging from individual to national level investigations of diets and food system resilience in three LMIC settings. The combination of studies offers a rare opportunity to understand the dietary and food system challenges and examine how cross-cutting food system solutions might work to improve diets and environmental sustainability.

Briefly, **Paper 1** identifies individual level determinants of undernutrition and dietary intake in children. As children do not control their diets, **Paper 2** investigates dietary choices of adolescents who are relatively independent in their food choices and due to schooling at this age, most adolescents are often exposed to different food environments than the rest of the household (75, 76). **Paper 3** expands on the individual/household level investigations of diets and assesses national level trends in food supply and availability considering more system level factors that operate beyond individual control (urbanisation, GDP, food imports and aid, crop yields and remittances) on diets. Using national aggregate data, Paper 3 demonstrates strong dietary inadequacy. **Paper 4** introduces an environmental component to diets and nutrition and investigates vulnerability to environmental/climate shocks of various dietary patterns. Given the bidirectional link between diets and environment, **Paper 5** assesses how diets – in turn – might also impact on the environment and health. Finally, **Paper 6** presents a set of policy recommendations for transforming food systems to deliver healthy and sustainable diets in low-income settings while ensuring resilience to shocks such as climate change and pandemics.

The linkages between the papers are further summarised in **Figure 3.1**. The figure shows a framework for the theoretical connections between the papers and presents the underlying logic upon which the studies are linked. It shows how key insights of one paper lead to the question addressed in the next paper (joined by solid arrows). Key findings of one paper also lead to key insights which inform the next question (linked by dashed arrows).

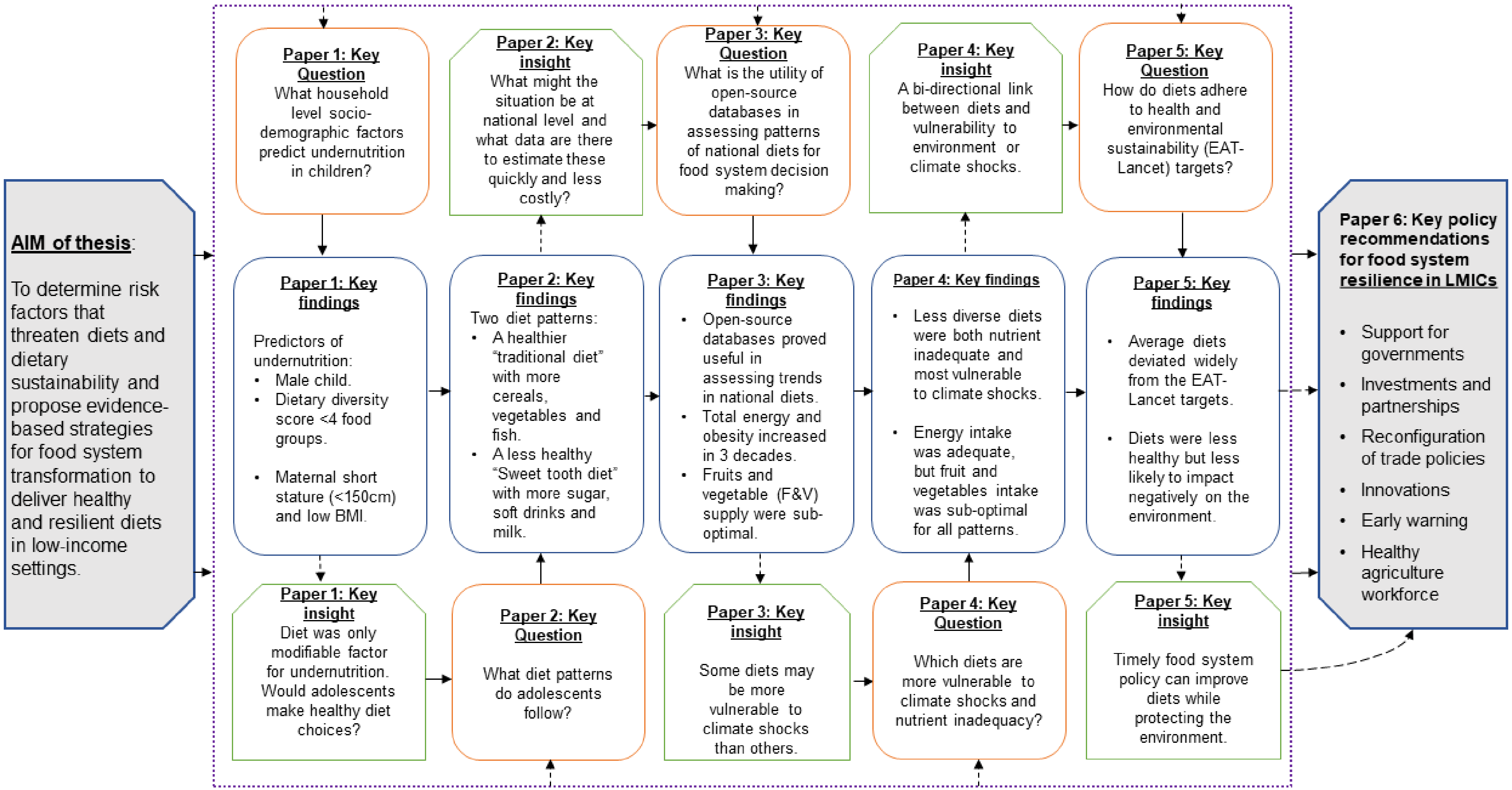


**Figure 3. 1:** Thematic framework of key findings and linkages between papers

## Section 4: Critical evaluation of publications: Context, contributions to the literature, and advancements to date

In this section, I evaluate the papers presented in the thesis in more detail. I have provided a landscape assessment and discussed the papers providing the context under which they were developed and how key findings addressed research gaps at the time and how the field has advanced since the publication of each paper. I briefly note the original contribution to knowledge that each publication has made.

The evaluations take a more global perspective while also reflecting on potential local implications. Limitations already stated in the papers are not repeated. Instead, I have explained how potential methodological limitations of one study are addressed or improved upon by the next study or other studies in the wider literature.

The potential impacts that each paper has made towards the development of new research and advancements of the literature are briefly stated using simple and publicly verifiable metrics where relevant (**Annex 1** explains the rationale behind the choice of metrics used).

### *4.1 Critical evaluation: Paper 1*

**Context for paper development**

In 2015, the MDGs officially ended. As was the case for many West African nations, Ghana achieved the MDG 1 target of cutting by half the number of people going hungry and extreme poverty (77). Yet, the most recent government statistics at the time showed that the prevalence of stunting in children under-five years was 19.0% (a 5-percentage point reduction since 2000) with wide sub-national disparities. The Northern region had the worse prevalence, estimated at 33.0% (78). The three northern regions of Ghana (Northern, Upper East and Upper West) have historically been more prone to child undernutrition compared to the rest of the country due to high poverty levels and other socio-economic inequalities (79, 80). At this time, the Northern region was far below expectation, the two neighbouring regions had recorded remarkable improvements in child stunting at 14.4% and 22.2% respectively for Upper East and Upper West regions (compared to 33.0% in the Northern region) (78). It was against this backdrop that Paper 1 was conducted to investigate a wide range of potential factors which could explain the increased risk of undernutrition, particularly stunting in children in the Northern region of Ghana.

**Key contribution of paper to the literature**

Paper 1 contributes to the literature by highlighting the role of child factors such as: sex and dietary diversity as key risk factors for undernutrition as well as maternal stature as a determinant of undernutrition in an impoverished region of Ghana. By assessing predictive factors for stunting, wasting and underweight, the paper reveals insights into the factors that could be relevant for different nutritional indicators including those indicators sharing common predictive factors which could be tackled to achieve concurrent results. Having been cited over 100 times, the contribution of Paper 1 to the generation of new knowledge in the field of child feeding and nutrition since its publication in 2017 is likely substantial.

**Strengths and limitations of paper**

The study findings on the consumption of some specific food groups (animal source foods, legumes, staples, and eggs) and lower height-for-age Z-score (HAZ) was not discussed in the paper. The evidence for a positive association between animal source food consumption and reduction in stunting (<-2 HAZ) is now strong (81, 82). The negative association found in Paper 1 was likely the effect of a "reverse causality", where mothers or healthcare providers possibly noticed inadequate growth in a child and advised mothers to improve the child's diet. This was likely the case given that consumption of these same food groups rather led to an increase in WHZ or reduced the likelihood of wasting because wasting is the result of a short-term nutritional deprivation. Short-term changes in feeding practices are more likely to impact WHZ than HAZ. Targeted repeated assessment of both consumption of the animal-source foods and HAZ could have been the best way to track growth patterns and understand the associations, but this was impossible given the cross-sectional nature of the data.

Another limitation of Paper 1 was the use of a wide age range (6-59 months) which led to only analysis of a small sub-sample of children aged 6-23 months for whom most of the WHO IYCF indicators apply (83).

**Key advances in the field since publication of the paper**

Several advancements have been made since the publication of Paper 1. A key advance is the renewed emphasis on male susceptibility to undernutrition compared to female children. Two well conducted systematic reviews were published in 2020 and confirmed the increased risk of undernutrition among male children (84, 85). One of them included a meta-analysis and showed that boys had higher odds of being wasted than girls (pooled OR 1.26, 95% CI 1.13 - 1.40), among stunted children, boys were 1.3 times more likely to be stunted compared to girls (pooled OR 1.29 95% CI 1.22 to 1.37) and were also 1.1 times more likely to be underweight than girls (pooled OR 1.14, 95% CI 1.02 to 1.26) (85). These are consistent with Paper 1 which showed that male children were more likely to be stunted and wasted than girls but found no association for underweight which has now been made clear in pooled analysis. However, despite numerous studies exploring male-female differences in undernutrition risk, the potential underlying biological mechanisms and the social or gendered factors that explain the male susceptibility to undernutrition remain understudied.

A second advance is the revision of WHO's minimum diet diversity (MDD) indicator in 2021 to include breastfeeding as part of the previously 7 food groups (83). The indicator is now measured based on the proportion of children who consumed at least 5 out of eight defined food groups during the previous day (83).

Two newly introduced indicators of interest (to this thesis) are the "Zero vegetable or fruit consumption" indicator (measured as the proportion of children who did not consume any vegetables or fruits during the previous day), and the "Sweet beverage consumption" indicator (measured as the proportion of children who consumed a set of sugar sweetened beverages during the previous day) (83).

Low fruit and vegetable intake and the consumption of sugar sweetened beverages are associated with increased non-communicable disease risk in adults (86). Childhood diet patterns with low fruit and vegetables are shown to influence dietary choices in adolescence and later life (87). While the new indicator on zero fruit or vegetable consumption by children does not make explicit links to environmental benefits, it is consistent with environmental sustainability considerations. Diets high in fruits and vegetables have a less effect (on per calories bases) on the environment compared to diets dominated by animal-source foods (88). This demonstrates a convergence in the aims of dietary change in both children and adults globally.

Finally, there is increasing prominence for adapting food systems to work for children and adolescents (89, 90). In 2018, UNICEF and the Global Alliance for Improved Nutrition (GAIN) led a global consultation on addressing poor quality diets in children through a food system approach, and developed the Innocenti framework on food systems for children and adolescents (**Figure 4.1**) (91). The framework comprises the drivers, determinants, influencers, and interactions that explain children's and adolescents' diets.

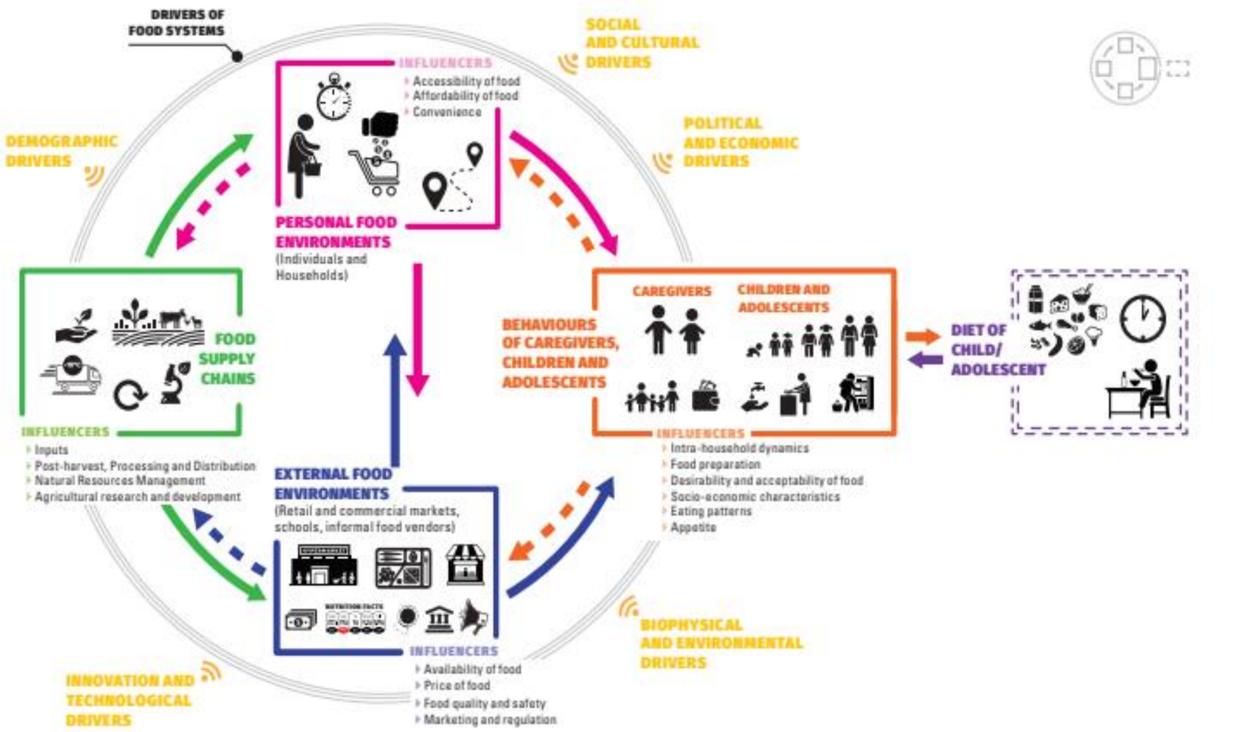


**Figure 4. 1**: The Innocenti framework on food systems for children and adolescents

Source: UNICEF (2018)[3]

[3] UNICEF, GAIN. Food systems for children and adolescents working together to secure nutritious diets. UNICEF Office of Research Innocenti Florence, Italy: UNICEF; 2018. Available from: https://www.unicef.org/media/94086/file/Food-systems-brochure.pdf.

### *4.2 Critical evaluation: Paper 2*

**Context for paper development**

A growing concern globally about the pervasive neglect of adolescent (aged 10-19 years) health and wellbeing was high at the time of the development of this study (92). Researchers and the development community had traditionally focused more attention on children (0-5 years) and women of reproductive age (WRA) (15-49 years). This attention on children and WRA was not without justification; given scare resources, policymakers often look to invest where there will be greatest returns. The "first 1000 days of life" – from conception through 2 years of age is one such life stages shown to give more positive returns on investments (93, 94). Additionally, mortality among children and WRA were consistently higher while adolescents were viewed as having the least needs across the life course (95). Gains in child and maternal health and nutrition over the years now outstripped those of adolescents, despite their perceived better health (96). In 2013, mortality in children and WRA was by over 80% lower than in 1980 as compared to a 60% reduction among adolescents (97). Mortality among older and male adolescents was also higher than in children (97). These comparisons prompted more attention on adolescents. Around the same time, evidence was growing on the importance of optimal nutrition during adolescence for the potential for catch-up growth – previously thought as only possible during the first 1000 days of life (98). Further, the publication of the first *Lancet Commission on Adolescent Health and Wellbeing* (92) also highlighted the importance of the adolescence period for forming important and lifelong habits including dietary behaviours which could be utilised to impact the next generation's health.

Locally, in Ghana, where Paper 2 was developed, UNICEF, WFP and other development partners were collaborating with the government through various ministries to roll out large scale interventions with the potential to impact adolescent health and nutrition. In 2018, the government expanded school feeding to cover secondary levels (both junior and senior). The programme previously provided for only primary and lower levels with one hot lunch meal aimed at improving nutrition and educational participation (enrolment, attendance, and retention) (99-101). This was now extended to the secondary levels. In the same year (2018), UNICEF and partners also initiated a complementary programme giving weekly iron-folic acid supplements for anaemia prevention among adolescent girls in schools – 'The Girls' Iron–Folic Acid Tablet Supplementation (102).

These programmes, particularly the school feeding programme, possibly gave more control to adolescents over any pocket money given for additional meals at school (100). With little parental control on adolescent food choices, adolescents have more control over their food choices and diets. Possible influencing factors of food choice such as the availability of less healthy but cheap sugar-sweetened beverages and fizzy drinks flooded the typical Ghanaian school environment. There was also rising overweight and obesity among school going adolescents which prompted attention on adolescent diets (103-105). Therefore, knowledge on patterns of adolescent diets and the potential factors driving them was critical for public policy to improve adolescent nutrition and health. It was against this backdrop that Paper 2 was developed.

**Key contribution of paper to the literature**

This paper contributes to the literature through its focus on adolescent diets at a time when much attention was on children and WRA in Ghana. Paper 2 highlighted a potential cause for concern on adolescent diets through the identification of two diet patterns of varying levels of healthiness. The study has influenced the development and progression of new research on adolescent diets and nutrition since its publication in 2019. It has now been cited by over 25 times and accessed >5500 times globally.

**Strengths and limitations of paper**

I think the findings of Paper 2 could have been easier to communicate if latent class analysis (LCA) were used instead of principal component analysis (PCA) in deriving the dietary patterns. LCA allows individuals to be exclusively assigned to diet patterns while in PCA, individual assignment to pattens is not exclusive and so there is partial membership in each identified diet pattern (106). Paper 4 uses LCA to derive dietary patterns and provides a comprehensive discussion on the usefulness of the approach over other methods.

**Key advances in the field since publication of paper**

Adolescent nutrition has continued to receive substantial global and local attention by researchers and policymakers.

At the local level, there has been more attention and research into the wider food environment with further investigations into unhealthy foods and beverages that are advertised in deprived urban neighborhoods and schools in Ghana (107, 108). There has also been specific policy considerations to limit advertising and sale of unhealthy foods (109). Moreover, with financial and technical support from FAO, Ghana's Ministry of Food and Agriculture recently developed and launched the first Ghana Food Based Dietary Guidelines (FBDG) (110). The FBDG has placed specific attention on limiting the availability and intake of unhealthy foods including sugar-sweetened beverages (111).

At the global level, there have been considerable advances too. Advocacy and collaborations aimed at improving adolescent nutrition and diets has continued to grow. From consortia on adolescent school health and nutrition (112, 113), an adolescent nutrition resource bank (114), a data hub (115), a special issue of ENN's Field Exchange on adolescent nutrition (116), to a new Lancet Series on adolescent nutrition (published in 2021) (117). Clearly, the advances have been substantial and broad, the details of which are beyond the scope of this section. But briefly, I think the advances could be summed into three broad themes: 1) data availability on adolescent diets and nutrition; 2) standardisation of metrics and anthropometric indicators of nutritional status in adolescence; and 3) adolescent diets from sustainable food systems.

The first advance is on adolescent specific data availability. Previously, routine surveys such as DHS and Multiple Indicator Cluster Surveys (MICS) often included adolescents in wide age ranges (15-49 years) together with adults. This has been a missed opportunity to quantify the burden of adolescent nutrition and monitor progress across settings and time. There is now substantial progress in this area. Many global open-source databases now include age and sex-disaggregated data on adolescents (118, 119). In fact, the next round of DHS surveys (DHS-8) will now include age and sex-disaggregated data on adolescent nutrition (120). **Annex 2** presents a comprehensive list of the different sources now providing adolescent nutrition data for LMICs (118).

Second, along with the need for adolescent specific age and sex-disaggregated data has been the search for standardised and valid anthropometric indicators of nutritional status in adolescence (121). Unlike in children (0-5 years) where the WHO provides standardised growth charts for global use (122), there has been little agreement on anthropometric indicators for adolescents. In this area, progress has been slow. The most significant advance might be the consistent realisation and calls for consensus on the need for standardised indicators. A recent opinion piece in the Lancet Child and Adolescent Health reinforces this call for consensus (123).

Lastly, advances have also been geared towards adolescent diets from sustainable food systems (89). For adolescents, an area of increasing advance for research and practice on food systems has centred on finding ways to harness adolescents' voices and agency in tackling climate change and food system transformation (124). Food system specific interventions in adolescents have to date, focused on the food environment and restrictions to the availability, marketing and sale of unhealthy foods targeted at adolescents. Recent studies have adopted a more inclusive approach of co-creation of interventions with adolescents themselves as key partners and not merely receivers (125). Today's adolescents want to have a say in what they eat, including what institutions provide for them. Given this opportunity, they could drive positive food system transformation (124).

### *4.3 Critical evaluation: Paper 3*

**Context for paper development**

Following relatively low success (as compared to global targets (126)) in tackling malnutrition, the double burden of malnutrition (DBM) defined as the simultaneous occurrence of undernutrition and overweight and obesity, continues to rise rapidly, affecting LMICs the most (127). The focus over the years in LMICs has been on reducing undernutrition through food production and rural development.

In addition to the difficulty in reducing stunting with siloed interventions, there is now an increase in overweight and obesity and associated non-communicable diseases in LMICs (128). To concurrently address the DBM and emerging threats to food systems such as climate change and pandemics, a more systems level approach has been proposed. The implementation of the food systems approach could be guided by a food systems framework, developed by FAO's High Level Panel of Experts on Food Security and Nutrition (HLPE) in 2017 (129). The food systems framework recognises the complexity of food systems and includes a wide range of factors that act together to shape food environments, food security and nutrition and health outcomes (129). It consists mainly of five core drivers of food systems: biophysical and environmental drivers; innovation, technology, and infrastructure drivers; political and economic drivers; socio-cultural drivers; and demographic drivers (**Figure 4.2**). Following its development, there have been calls for further research to better understand how food systems will affect diets, nutrition, and health outcomes in different contexts, under different drivers, and with various political and societal transitions, as well as the potential implications for the environment and overall planetary health (130).

To help policymakers and development partners identify areas for action to improve a country's food system, a context-specific understanding of these drivers and associated factors is important. However, there is scarcity of data on the drivers in LMICs and even when data are available, they are not hosted at one place or presented in user-friendly formats to help in decision-making. Meanwhile, various institutions and databases are increasingly making data available on most of the drivers of food systems which could be harnessed in building a country's "food systems profile" but are currently underutilised. For example, the World Bank has been funding and hosting a large amount of data collection on different economic, demographic and development data over many years in LMICs (131). Similarly, the FAO collects, curates and hosts estimates of national food and agriculture production, food availability, food trade and associated environmental factors globally (132). Other emerging databases also host more specific data on food system outcomes such as non-communicable disease burden and risk factors (e.g., NCD-RisC and the GBD Collaborators database), malnutrition indicators (UNICEF/World Bank and WHO joint estimates) and dietary intake (Global Dietary Database). These data on their own can tell only a small aspect of the food system, but together, they present a more comprehensive overview of a country or region or global food systems while also highlighting areas requiring action. Against this backdrop, Paper 3 was developed to evaluate the possibility of harnessing global open-source databases for building a country's food system profile in LMICs using The Gambia as a case study.

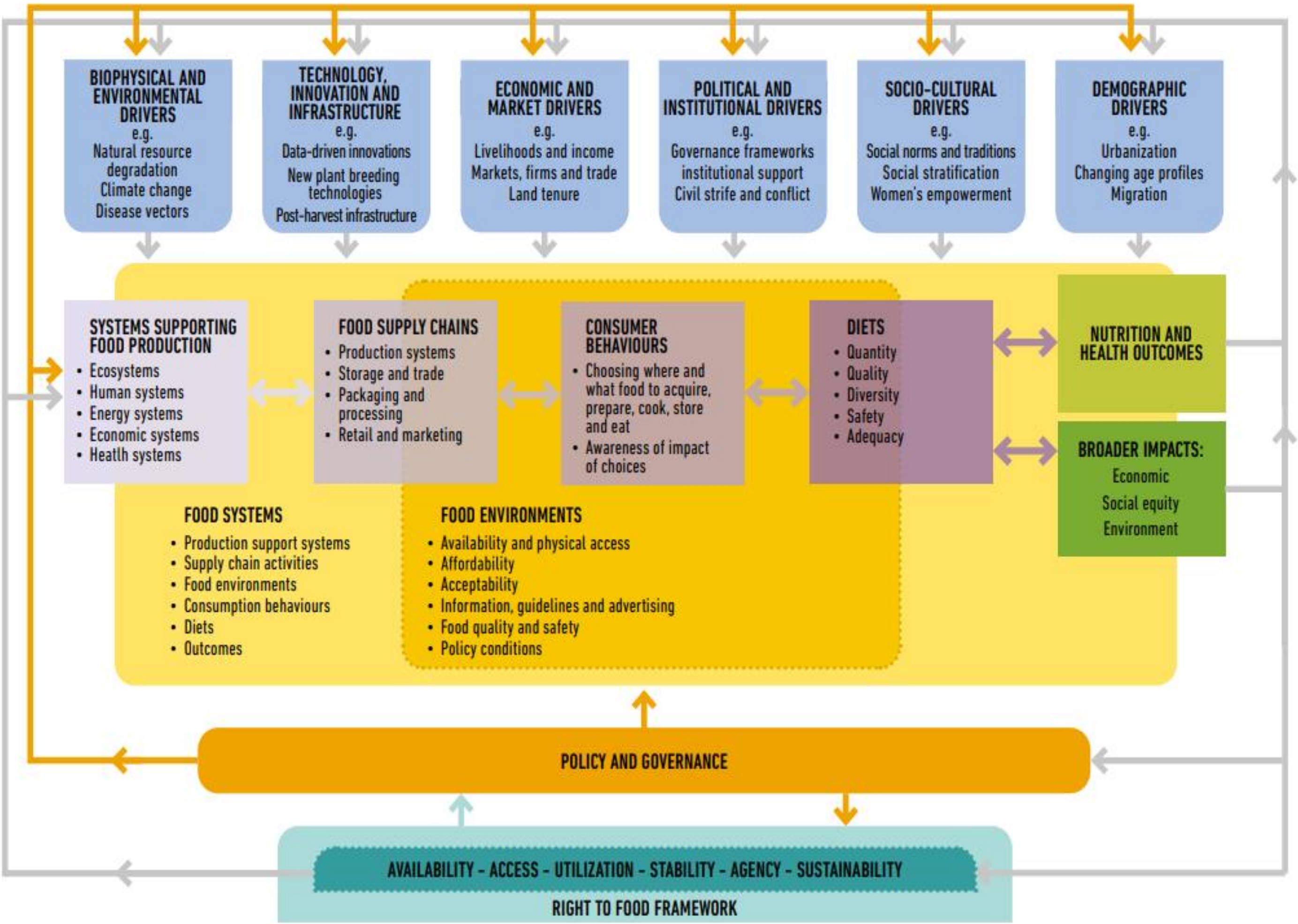


**Figure 4. 2**: The sustainable food system framework. Source: FAO (2020)[4]

[4] HLPE. Food security and nutrition: building a global narrative towards 2030. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security. Rome; 2020. Available from: https://www.fao.org/3/ca9731en/ca9731en.pdf

## Key contribution of paper to the literature

This paper contributes to the literature by demonstrating the utility of open-source data for efficiently building a country's food system profile which could reveal areas for policy and action. As this method is a relatively cheap approach, it could be used as a means to monitor progress over time among countries, regions and globally. A key contribution of Paper 3 is the food system profile built for The Gambia.

The country profile approach used in this study allows for more careful data triangulation and choice of the most representative data for a specific driver. By highlighting limitations in certain databases, studies of this nature could lead to improvements of the original databases.

## Strengths and limitations of paper

A key limitation of Paper 3 is the lack of specific guidance on the types and quality of data to include in the food systems profile. For example, data on the biophysical and environmental drivers such as land use change, rainfall, drought, and temperature patterns are important for food production and food availability, but these were not included in the analysis.

## Key advances in the field since publication of paper

Many institutions continue to work to make food system data available and more user friendly. Some databases attempt to create country profiles by showing data on different food system drivers and outcome indicators. The 3 most significant databases that have advanced food systems country profiling are discussed below. Their approach has been compared to the methods used in Paper 3.

First, the Global Nutrition Report (GNR), this is a multistakeholder initiative which started in 2014 and has since provided independent yearly reports on the state of global nutrition and tracking progress over time (133). The GNR provides data on various nutrition indicators for all ages and compares these with global health and nutrition targets. For example, at national, regional and global levels, estimates such as low birth weight and stunting, wasting and anaemia for children <5 years are compared with the WHO targets on maternal and child nutrition which have now been extended from 2025 to 2030 to align with the SDGs deadline (126). The GNR also tracks progress on WHO's NCD and dietary targets. The data can be disaggregated to view country level progress through the "country profile" tab on the web version of the report. The estimates provided by GNR are essential food system outcome data which could be combined with data on the drivers of food systems for better understanding for why there has, or has not, been progress on the targets tracked. At present, the GNR website is a useful resource for policymakers to see what progress they are making but it is less useful in helping them to understand the viable areas to take action to improve upon the situation.

Second, the Food Systems Dashboard (FSD) (134), launched in 2020, in many aspects builds on the GNR by providing data on different drivers of food systems and policy recommendations. The tool aims "to assess challenges for improving diets, nutrition and health; and to guide its users to set priorities and decide on actions" (134). The FSD provides data for many aspects of food systems at global, regional and national levels ranging from food production, food consumption and nutrition outcomes in a more user friendly format in terms of ease of interpretations (135). The FSD has a more global focus and global governance of food systems, policies, and actions. It has now only recently started providing country-level policies and actions aimed at food systems transformation. The FSD relies on existing data from other sources including from published papers to build country profiles and for a global outlook of food systems. The main setback of the FSD is its focus on global food systems drivers which may not apply well at a local level. The global scale of drivers also limits the inclusion of certain aspects of food systems which do not play at a global scale. For example, in terms of economic drivers of food and nutrition, it makes more sense to use gross domestic product (GDP) in the FSD, but in many LMICs, receipt of remittances may be more useful for diets and nutrition than a country's GDP. A more tailored and country focused analyses such as the one performed in Paper 3 allows an initial scoping for which variables might best suit each food system driver for better understanding of local food systems.

Finally, Our World in Data database (136). This is a user-contributed database which makes it more dynamic depending on what is provided. However, it provides key data and trends of various food system drivers and outcomes. This database is the most advanced and user-friendly database of the three discussed. Like the FSD, Our World in Data takes a more global level approach with the possibility to filter by country. It mostly does not make policy recommendations but includes a more diverse set of data to reflect various aspects of the food system as well as associated environmental effects.

All three databases discussed above use data from more generic data sources such as the FAO, World Bank and from published literature. The data are often pulled together and managed through automated processing with little triangulation to check how they reflect the local context. For example, in building global profiles of sugar consumption per country, the FSD uses FAO food supply data to compute consumption for all countries (135). While at global level, estimates may look plausible, national level estimates can vary widely and even be unrealistic. For example, the FSD reports a global level fruit and vegetable intake in 2017 to be 270 grams/person/day and only 80 grams/person/day (less than a medium sized banana) in The Gambia (135). Similarly, the GNR estimates global consumption of fruit and vegetables in 2019 to be 260 grams/person/day but only 79 grams/person/day in The Gambia within the same period (133). This is not unexpected because the GNR uses food consumption data from the Global Dietary Database (GDD) which provides modelled estimates of dietary intake meant to reflect actual food consumption (137). But in many LMICs, the GDD input data are largely dependent on FAO food supply data (132). Therefore, even though the FSD and GNR are different databases, they report almost the same data.

A different picture is painted when little effort is made into verifying the representativeness of these data at national level. Comparing the Gambia’s estimates of fruit and vegetables in the FSD and GNR to a national survey in 2015/6, the national average is 216 grams/person/day

(138) which is 75% higher than was estimated for The Gambia by both FSD and GNR. In more country specific profile analysis such as done in Paper 3, it is easy to spot these errors from a local perspective and based upon triangulation with existing data. Such analysis can also highlight lapses in more generic food system databases for improvement.

### *4.4 Critical evaluation: Paper 4*

**Context for paper development**

The food systems approach recognises the bi-directional relationship between diets and environmental sustainability. Domestic food production in Bangladesh has increased over the past decades and the country is food sufficient in staple foods mainly rice and other cereals. Due to changing demographics such as increased urbanisation and incomes, eating patterns have also changed over time in Bangladesh (139). The DBM is now on the rise in a society where overweight was not a common occurrence or was the reserve for only affluent people (140). Therefore, certain diets would be less healthy in pockets of the society. Additionally, due to the country's elevated level of vulnerability to climate extremes such as flooding and cyclones which threaten agricultural production and livelihoods, these events also affect existing diets and diet patterns. As different diet patterns drive various production systems, external shocks to food production and supply are expected to affect diets differently. Climate change is already happening in Bangladesh and the country has less capacity to adapt, making research on which diet patterns are more vulnerable to shocks important. Paper 4 was developed to identify different diet patterns and assess the specific characteristics of diets that make them more vulnerable to climate shocks compared to others.

**Key contribution of paper to the literature**

This paper contributed a new perspective on assessing diet vulnerability by examining which combinations of diets make them vulnerable or resilient to external shocks.

In addition to assessing diet vulnerability, the paper examined how different diets, regardless of their vulnerability status, also met healthy eating guidelines set by the WHO. Through this, the study made an important finding, namely the concept of “double vulnerability” which was coined to describe the fact that the diets that were nutrient deficient were also those that were most vulnerable to external shocks. This gives policymakers an incentive to focus on improving certain specific aspects of diets such as diet diversity to concurrently improve nutrient adequacy and resilience of diets to shocks. Strategies to achieve dietary resilience may include improving food trade to complement domestic supply (141) and developing food based dietary guidelines which emphasis consumption of a diverse number of food groups to address the demand side of food system transformation.

**Strengths and limitations of paper**

An important source of limitation of Paper 4 is on the method used in assessing the vulnerability of diets. The paper used a simple count of staple foods and food diversity as a measure of vulnerability. This may be an advantage as it can be relatively simple and easy to compute to assess diet vulnerability in different settings without requiring extra data beyond data collected in routine national surveys such as DHS and MICs. However, the simplicity may also mean it is less comprehensive in capturing less apparent factors that contribute to vulnerability or resilience of diets. Factors such as existence of government subsidies, national food stocks, national food buffers, external food trade diversity and international food aid could be important in understanding diet vulnerability but were not considered in computing dietary vulnerability to shocks. Stakeholder engagements and mappings could be a better way to assess the existence or lack of some of these factors and elicit a comprehensive set of context-specific factors that could affect vulnerability of diets.

Other important aspects of diets such as affordability, acceptability implications of the most resilient diets were not assessed. These pieces of information could be important for policymakers in making decisions on what it would mean to switch to more resilient diets in Bangladesh. For example, Paper 4 found that reliance on single staples made diets more vulnerable than others with more staples. As rice is a traditional staple in Bangladesh, it would be important to consider what it might take to shift to a more diverse source of staples and which staples are key candidates considering certain factors such as climatic suitability, local acceptability, cost, and convenience.

**Key advances in the field since publication of paper**

The World Bank recently commissioned an analysis into the health and sustainability of diets in Bangladesh by combining national surveys conducted between 2000 and 2016 (142). Consistent with Paper 4, the World Bank analysis found that diets in Bangladesh did not meet health targets set by the Bangladeshi FBDGs. The diets also deviated from environmental sustainability targets set by the EAT-Lancet Commission. The study showed that to meet the FBDG targets, fruit and vegetables intake and the consumption of other essential food groups will have to increase, resulting in a 10% increase in greenhouse gas emissions. On the other hand, to meet environmental sustainability targets, there will be a 23% increase in greenhouse gas emissions of the resulting diet (142). Paper 4 shows that high diet diversity increases dietary resilience to shocks, in comparison with the World Bank findings, it could mean that, achieving dietary resilience through dietary diversification will also impact negatively on the environment. These seemingly conflicting results can make it difficult for policymakers to take action to improve diets. In this situation, Paper 6 advocates for improvements in the efficiency of food production and supply systems such as reducing long food haulage and adopting agriculture innovation including sustainable intensification to reduce greenhouse gas emissions associated with food systems.

### *4.5 Critical evaluation: Paper 5*

**Context for paper development**

The primary context for the development of Paper 5 was the increasing recognition of the effect of diets on climate change and the fact that certain dietary choices could serve as promoters of both human and planetary health (143). The EAT-Lancet Commission's report on the effects of diets in the Anthropocene set the scene for discussions on diets and planetary health (45). Briefly, the commission proposed a global reference diet (EAT-Lancet diet) which, when consumed, can help sustainably feed the future population, reduce diet-related mortality while keeping the planet within limits that sustain life on earth. The reference diet is largely plant-based and emphasises consumption of vegetables, fruits, wholegrains, legumes and nuts, and unsaturated oils. It recommends low consumption of animal-source foods in general, less added sugar, refined grains, and starchy foods (45).

While it is generally agreed that existing diets around the world contribute to climate change, predominantly through agricultural related activities, the dietary changes required to address environmental impacts have been contentious. This is could be due to long standing dietary habits that have their roots in culture, values, norms and social status of people around the world (144, 145). Moreover, in many LMIC contexts with widespread food insecurity and micronutrient deficiencies coupled with less availability of nutrient-rich plant sources to meet nutritional demands, recommending consumption of a healthy diet that is *also* intending to lower environmental footprints (often characterised by low consumption of animal-source food) is not always affordable (146) and/or available and could further complicate an adequate nutritional intake (147, 148). Nonetheless, to facilitate dietary change to meet both health and sustainability targets such as those advanced by the EAT-Lancet Commission, an important first step is to understand how existing/actual diets compare with such recommendations. To date, most research on how diets compare with health and sustainability targets have mainly come from HICs (149-154), leaving a huge gap in our understanding about the situation in LMICs.

Therefore, Paper 5 was developed to assess how diets in an LMIC (The Gambia) adhere to the EAT-Lancet reference diet. It also developed a more context-specific metric for scoring diets for health and sustainability in LMICs.

**Key contribution of paper to the literature**

Paper 5 is among a few early studies (155, 156) to examine the role of diets in LMICs (with The Gambia as case study) to both human and environmental sustainability. The paper advances knowledge through the development of the "Sustainable and Healthy Diet Index (SHDI)" which helps to adapt the global reference diet (EAT-Lancet diet) to an LMIC context considering existing food availability, consumption patterns and nutritional challenges. The SHDI could be constructed in similar LMICs and used to identify factors that are associated with healthy and sustainable diets.

The key findings of this study support the view that diets in various parts of The Gambia affect population health and the environment in varying degrees and hence needs to change differently. The study shows that, the average Gambian diet is typically high in food groups that are less healthy but low in food groups known to impact most on the environment. Hence, to advance in both a healthy and sustainable way, future efforts could focus on increasing the availability, affordability, and consumption of healthy foods, while keeping the consumption of foods with a high environmental footprint stable. In practical terms, this will require slightly increasing the consumption of animal-sourced foods to optimal levels in the general population but not beyond levels that are detrimental to the environment.

This approach to food system transformation will be different in an HIC setting where existing diets are high in food components that impact negatively on both human health and environmental sustainability. In such settings, food systems transformation needs to focus on reducing animal-source foods consumption to levels that maintain human and environmental health (50). Therefore, this study underscores the need to find more local and context-specific food system priorities for action.

**Strengths and limitations of paper**

The use of the EAT-Lancet reference diet to assess the health and sustainability of diets globally has many implications. As a first of its kind, it assumes that the environmental and health impacts of individual dietary items are similar all around the world. Despite the increasing globalisation of diets (141), most diets in LMICs are still dominated by locally sourced components (157) whose nutrient composition (the basis for health implications) and farming practices (the basis for environmental implications), could be completely different from a global average. Despite this important setback of using a global average (often derived from studies skewed towards the Global North), it may still be useful to use a global average in the absence of a comprehensive set of context-specific data on nutrient and environmental footprints of diets. It is important to note this underlying limitation of using the EAT-Lancet reference diet which is often easily missed. For example, the use of global estimates could limit local level research into the understanding of context-specific priorities for food systems. Moreover, using a global reference could also limit evidence-based decision-making where local evidence is required (158).

On the other hand, there is no denial of the increasing globalisation of food systems through improved food trade (157). Diets in LMICs are often produced in both HICs and LMICs (157, 159). But increased trade is not without associated trade-offs for the environment in both consuming and producing countries (141, 160). This interlinked trade relationship makes the assessment of dietary footprints on the environment more complex than "just" looking at farming practices in a single target country (161). For example, The Gambia relies heavily on imported food (141), and hence the origins of food and the associated systems of production in producing countries are important determinants of environmental sustainability of diets in The Gambia which were not accounted for in Paper 5 (an important limitation).

**Key advances in the field since publication of paper**

The most important advance since the development of Paper 5 is possibly the ongoing discussions to build upon the EAT-Lancet recommendations through what the Commissioners call the "EAT-Lancet 2.0" (162).The commission is engaging in active global consultations to update the current version of the EAT-Lancet reference diet.

Following the publication of the first version of the EAT-Lancet recommendations (45), it has received feedback on the possible utility and pitfalls of the recommendations from a wide range of stakeholders including from researchers, country governments and the public (146, 147, 163-165). This feedback together with the additional global consultations could help in shaping the next version of the recommendations under review.

With efforts such as those presented in Paper 5, it is hoped that the expanded work of the EAT-Lancet recommendations would focus on creating regional and country specific priorities and guidelines to improve uptake of the recommendations across settings.

### *4.6 Critical evaluation: Paper 6*

**Context for paper development**

The first draft of this paper was developed in April 2020. This was peak of the global lockdowns in response to the COVID-19 pandemic which had already reached many countries and governments were looking for measures to contain it (166). At a period when governments grappled to contain the spread of local infections, it also coincided with the main cropping season across West Africa. It was feared that infection control measures could hinder regular cropping practices. Globally, major food producers also worried about food security within their own countries and threatened to reduce the amount of food exported (167).

Even during the pre-pandemic period, many LMICs were already struggling to provide enough food for the general population and undernourishment was widespread. Further disruptions to health systems, service work and agricultural productivity was going to impact negatively on diets and nutrition (168). Therefore, the most important determinant of ensuring food security and continual provision of healthy diets depended largely on pre-pandemic resilience of local food systems. It was already late to build resilience of local food systems in the middle of the pandemic, but the pandemic highlighted the weaknesses of current food systems and drew the attention of policymakers to the need to transform them to be more resilient to future threats including climate change.

Against this background, Paper 6 was developed to provide policymakers and development partners with evidence-based interventions to transform food systems to be more resilient to shocks while delivering healthy and sustainable diets.

**Key contribution of paper to the literature**

This paper provided timely and evidence-based solutions for food systems transformation to deliver healthy and sustainable diets while being resilient to shocks in LMICs. A set of five core interrelated policy recommendations were proposed: investments and partners; agricultural innovation; food trade; investments in early warning systems; and ensuring a healthy agricultural workforce.

At the global food systems policy level, findings of Paper 6 were used and cited by the Scientific Group for the UN Food Systems Summit on Action Track 5: “Building Resilience to Vulnerabilities, Shocks and Stresses” (169). In addition, the paper has now been cited 28 times with over 4900 accesses. The study also attracted media attention, appearing in two media outlets and it generated a lot of social media discussion (Altmetric score: 38).

**Strengths and limitations of paper**

This paper used a landscape design to provide timely and concise recommendations for food systems transformation during a time when governments needed quick scientific evidence to make decisions globally. Models of scientific publication advanced during this period to give way for science to reach users in a timely manner. For example, scientific publications related to COVID-19 were concurrently published in preprint servers for quicker access and use which proved very useful. Therefore, publishing Paper 6 as a comment piece allowed quick communication of concise findings to reach users.

Despite undergoing the traditional peer-review process, the use of a comment style did not permit a comprehensive discussion of the proposed policy recommendations. In addition, the method does not allow ruling out the possibility to miss important interventions which could have improved the recommendations.

**Key advances in the field since publication of paper**

Globally, the UN Food Systems Summit is one of the key steps taken towards transforming food systems. The Summit brought together relevant stakeholders to plan the transformation of food systems to deliver healthy and sustainable diets. It started with country level food systems dialogues to identify priorities for investment to improve diets and nutrition. These were later presented as country specific pledges at the Summit. For example, the first of Ghana's 8 core pledges to transform food systems was to "increase by 40% the production of climate-resilient varieties of diverse vegetables and legumes, fruits, and bio-fortified staple crops using sustainable agricultural practices" (170). This recommendation is very consistent with Paper 6's recommendation on the need for "innovations" in the agriculture sector including promoting the adoption of climate-smart agricultural practices.

Locally, many countries and development partners are taking action to improve diets through food system transformation. For example, the FAO is currently supporting countries such as Ghana and The Gambia to develop FBDGs. The approach this time is slightly different from the traditional way of FBDG development which focused only on individual messages for healthy eating. The new FBDGs move beyond making individual level recommendations to include food system level recommendations to go along individual level recommendations. For example, an individual level recommendation which asks people to increase daily consumption of fruit and vegetables would go with recommendations at the food systems level that break structural barriers to make fruit and vegetables more available.

Resilience to climate extremes and shocks are key guiding principles in the new FBDGs which ensures that dietary recommendations are, as much as possible, resilient.

### *4.7 Summary of evaluations*

Below, I have summarised the key advances and debates in the literature emanating from the paper evaluations.

1) Child and adolescent diets and nutrition can better be improved through food system actions which consider children and adolescents as key stakeholders in their development using a food systems framework for children and adolescents. In addition, data on adolescent diets and nutrition are increasingly being made available but there are currently no standardised and validated anthropometric indicators of nutritional status in adolescence (**Paper 1 & 2**).
2) Open-source data on different drivers of food systems could be useful in building country food system profiles which allow the identification of priorities for action. More user-friendly databases are now available, but there is the need for more data quality checks to ensure that trends presented in databases on a country's food system situation reflect the situation on the ground (**Paper 3**).
3) The use of a simple count of food groups and diversity in staple foods is useful in determining dietary vulnerability to shocks in LMICs. However, the method will need validation through qualitative engagements with stakeholders to identify and account for other crucial factors of dietary resilience such as government subsidies, food stocks, trade, and international aid (**Paper 4**).
4) There is general recognition that current diets and food systems are impacting negatively on both human and environmental sustainability. There is, however, less agreement on using global model diets for determining what is healthy and sustainable across populations. The evidence and trends to date point to the need for more regional or national specific guidelines on healthy and sustainable diets and

hence the ongoing revisions to the EAT-Lancet recommendations are commendable (**Paper 5**).

5) Food systems in LMICs are relatively more vulnerable to shocks (climate extremes and disease outbreaks). Evidence-based actions can transform food systems to become more resilient to shocks while also delivering healthy and environmentally sustainable diets (**Paper 6**).

# Section 5: General discussion

In this section, I have summarised the key results of the thesis and discussed the interlinking implications of the findings for policy and practice. I have also provided directions for future research.

An important premise of this thesis is that, food system failures leading to poor diets and undernutrition manifest more on vulnerable groups such as children and adolescents (171). Identifying the risk factors at individual and household levels could be important in finding solutions to poor diets and undernutrition. Moreover, vulnerability of the general food system to shocks such as climate extremes and pandemics also affect dietary intake and nutrition. Therefore, to holistically address poor diets and undernutrition in the population, this thesis considers both individual and household level factors as well as the more structural level factors that operate beyond the individual and household together to identify key leverage points for building resilience of food systems to deliver healthy and sustainable diets (**Figure 5.1)**.

## *5.1 Summary of key PhD findings*

The thesis shows that various risk factors at individual and household levels affect dietary intake and nutrition of children and adolescents. In Paper 1, I found that among children where undernutrition is a key risk factor for optimal growth and development, inadequate dietary diversity, being a male child and maternal short stature (<150cm) were associated with undernutrition. However, among adolescents, there are different nutritional priorities. Undernutrition is not a major problem, instead, unhealthy dietary choice is a key factor for future dietary behaviour and non-communicable disease risk (172). In Paper 2, I show that household level socio-economic factors (access to pocket money and living in a wealthy household) were the main determinants of adolescent diets.

In addition, I investigated how more structural level factors such as the composition of food supply, political, economic, and demographic factors interact in many ways to influence food system vulnerability to shocks. In Paper 3, I found that measures of economic development, particularly GDP, were positively related with supply of cereals and animal-source foods but not the more nutritionally important food groups such as fruits, vegetables, and nuts. In Paper 4, I identified the concept of "double vulnerability" in which the most nutrient inadequate diets were also those most vulnerable to shocks. I also showed that diverse diets, particularly those relying on more than single staple foods were associated with low vulnerability to shocks. Together, the findings of Paper 3 and 4 implies that regular economic growth is likely to reduce the vulnerability of diets to shocks by increasing the supply of staple foods, but it will require targeted effort to increase the supply of nutritionally important food groups such as fruits, vegetables, and nuts.

Given that population diets influence food production systems that affect human and planetary health, I investigated how diets in LMICs relate to health and environmental sustainability targets using The Gambia as a case study. In Paper 5, I found that average diets deviated widely from health and environmental sustainability targets set by the EAT-Lancet Commission. The deviations of diets from health and sustainability targets were due to high consumption of food groups that are less healthy (refined grains, sugar, and oil) and low consumption of nutrient-rich food groups (wholegrains, fruits and vegetables, pulses, and nuts). However, average diets were low in food groups known to be highly damaging to the environment (such as beef and lamb, dairy, and pork) (47). I developed the "Sustainable and Healthy Diet Index (SHDI)," a context-specific metric for assessing the adherence of diets to health and sustainability targets. The SHDI can easily be adapted for use in different LMIC contexts because of its emphasis on local level food system priorities in assessing diets and judging adherence of diets to health and sustainability goals.

Finally, I studied how food systems in LMICs could be transformed to be more resilient to shocks while also delivering healthy and sustainable diets. In Paper 6, I identified five key strategies to help policymakers and practitioners achieve a "no regret" food system transformation in LMICs. The recommendations include the following: 1) encouraging investments and partnerships for food system transformation; 2) adoption of agricultural innovation practices such as climate-smart agriculture as a means to adapt to climate change; 3) configuring food trade to be more equitable and sustainable in order to bridge gaps in domestic production and mitigate against climate change (e.g., through shortening long food haulage whenever possible by importing from neighbouring countries); 4) investing in early warning systems to reduce crop failure and protect livelihoods of agricultural workers; and 5) ensuring a healthy agricultural workforce to enable continued food production and supply in the face of increasing climate extremes and disease outbreaks. **Figure 5.1** summarises the key messages of the PhD.

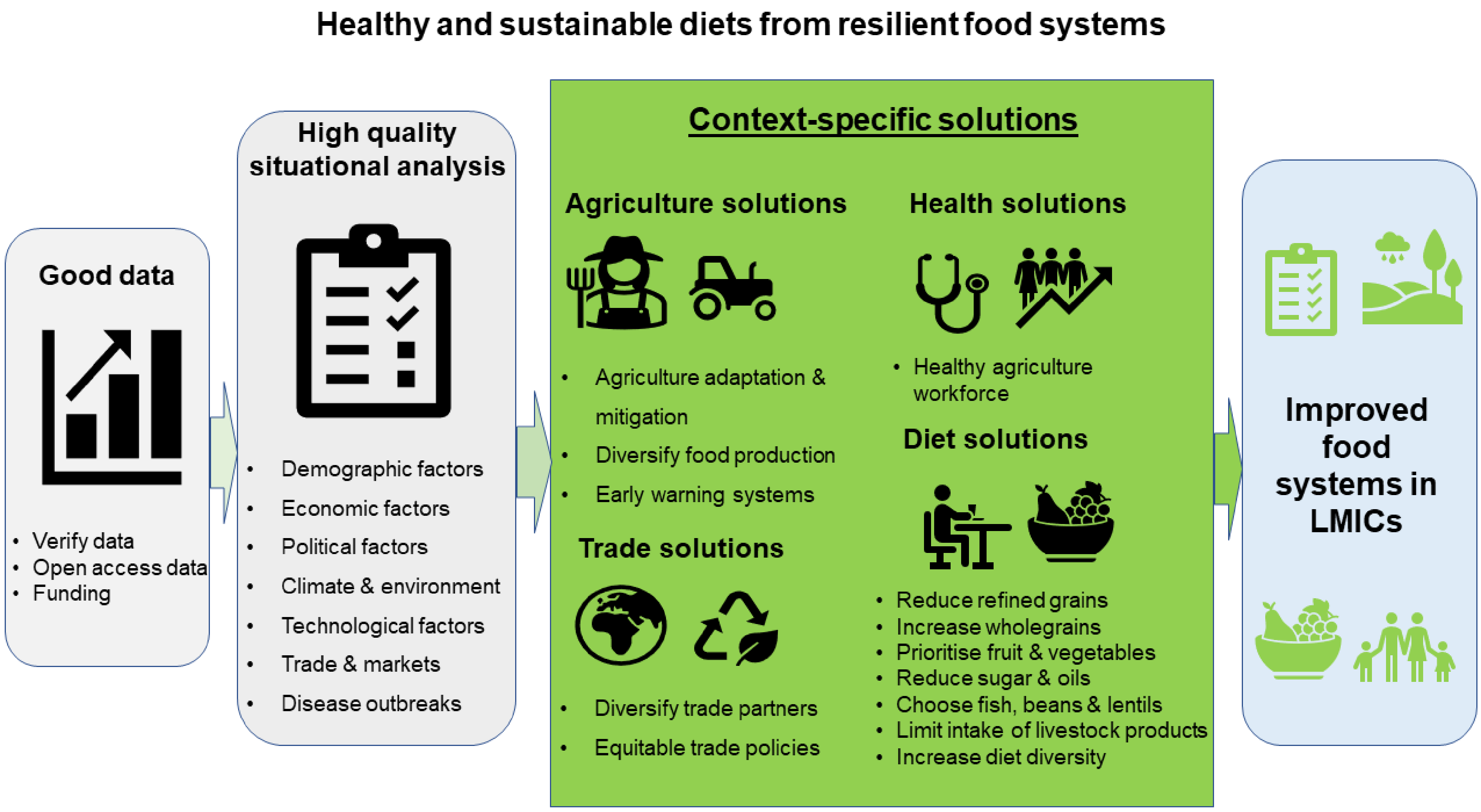


**Figure 5. 1:** Framework of key PhD summaries

### *5.2 Reflections and directions for further research*

**Food systems for children and adolescents**

The diets and nutritional implications of children and adolescents could be an effective way to understand household level food availability and distribution as well as the implications of the food environment outside of the home (through adolescent diets). Another advantage of focusing on child and adolescent diets is the gradual shift in direction for assessing diets from individualised approaches towards a food system approach (89, 91). While the food system approach to assessing and understanding diets in children and adolescents is increasing, there is more work to be done to incorporate it into large scale and routine national surveys such as the DHS and Multiple Indicator Surveys (MICS). For example, a guideline on how to translate the Innocenti framework on food systems for children and adolescents has been published but is currently underutilised (173). The slow transition to a food system approach to assessing child and adolescent diets may be due to resource constraints for performing the more holistic assessments involving the sources and means of production of household food, ways of preparation to the disposal of food waste. Moreover, the evidence bases for how climate change might affect child and adolescent nutrition is only now building up (174, 175) which could increase attention on food systems for children and adolescents and improve adoption by policymakers and practitioners.

Further, this is a social media age with influencers (social media role models) which can be utilised more positively. However, social media is already being used wrongly through (often unethical) user data extraction to target children and adolescents with unhealthy food adverts (176). There is the need for innovative ways to harness social media's potential to influence positive dietary habits. It is also important to study the potential role of adolescent voices and agencies in the climate change debate. There could be mental health benefits for engaging young people in asking for change and the ability to take part in actions that are aimed to improve the climate (177). However, this should be planned well to prevent potential unintended and undesirable consequences on adolescent dietary habits (178). Adolescent girls in developed settings such as the United Kingdom (UK) are already eating less animal-source food such as milk and are at increased risk of iodine deficiency (179). Additional concern for the environment and potential self-blame resulting from “climate guilt” or “climate shame” (180, 181) may lead to unhealthy dietary practices especially those that result in less or no animal-source food intake without appropriate nutrient-rich plant-based alternatives. The findings from Paper 5 showing which food groups contribute to health and which ones are more damaging to the environment along with consumption patterns could be particularly useful for adolescents who want to change their diets to meet health and sustainability targets. The results make it easy to understand which aspects of diets need changing to be within health and environmental goals.

**Food system profiling for informed decision-making in LMICs**

In Paper 3, I showed how various data from open-source databases could be harnessed for food system decision-making in LMICs. I also demonstrated, through these data, how a combination of demographic, political and economic data could help our understanding of food systems resilience in LMICs. However, the landscape of food system country profiling is fast evolving and needs quality checks to help policymakers in making informed decisions about food systems. There is the need to develop guidelines for data reporting (i.e., guidelines for data holders/owners on how the data should be constructed) and for checking levels of data quality and sources to include (i.e., a guideline for users on which types of data to include in a country profile). Briefly, guidelines for data owners such as government departments could be a simple checklist on which data are important and the form in which they should be provided. Guidelines for end users can take the form of existing guides for studies but should be adapted to assess data quality and representativeness before inclusion. Numerous guidelines and checklists already exist for different study designs such as STROBE for observational studies, CONSORT for randomised control trials and PRISMA for systematic reviews. While the STROBE checklist (182) seems the most relevant for the type of analysis reported in Paper 3, it is more applicable for observational studies using a single dataset such as analyses presented in Papers 4 and 5. The STROBE checklist currently lacks sufficient details to elicit and guide data quality and reporting for the type of analysis reported in Paper 3 which combines various aggregate data. Therefore, there is the need to develop a separate checklist or extend an existing one to foster more transparency and accountability in reporting such studies, including the interpretations of the resulting evidence.

In addition, databases such as FSD and GNR need to do more to verify the food systems data with local partners to confirm the plausibility of such data on the ground. This will require more effort and resources but would be worth it to better inform users. One way is to form more diverse country level partnerships. Guidelines that mandate databases to verify data for local representativeness or plausibility and provide some measure of data accuracy and confidence level (e.g., medium accuracy, high agreement) are needed. Such guidelines would help researchers and policymakers to identify data that need improvement and how much inference could be made from specific data on a country's food system profile.

Further, there is the need to find better ways to incentivise government agencies and development partners to deposit routinely collected data in existing open-source databases. From my experience in The Gambia and Ghana, many surveys conducted by government departments do not get deposited as open access online. Mostly only reports are published on departmental websites or internally. Microdata is normally hosted internally and hardly deposited in the public domain. Without improved archiving facilities, these datasets eventually get lost due to staff turnover or system failures. Sometimes, there are simply no opportunities to share the data or data owners lack the incentive to share their expensive datasets in the public domain. Exceptions occur when surveys or projects are funded by external partners who may have a responsibility to share the data with the public. The extra work required to curate data for public deposition often gets little or no funds allocated in projects and surveys. Data sharing from government departments could be facilitated through capacity building and support with extra budgetary allocation to make data available to the public post-survey. These could improve estimates made by databases such as the FSD and GNR.

Finally, existing, and upcoming databases on food systems need to provide opportunities for data uploads from the public and relevant stakeholders. A good example is the University of Washington's Institute for Health Metrics and Evaluation (IHME) database which encourages and makes provision for users to upload microdata via their Global Health Data Exchange (GHDx) platform. The institute also has an extensive network of over 3600 external partners globally who facilitate data verifications (183). Therefore, it is not surprising that the IHME's Global Burden of Disease (GBD) estimates of risk factors for health, diseases and disability are more widely accepted despite some disagreements (184).

**Healthy and sustainable diets from resilient food systems**

In Papers 4 to 6, I identified common risks to dietary resilience from food system shocks and showed that in settings such as The Gambia with existing food insecurity in pockets of the population, diets may be less healthy but not necessarily jeopardising environmental sustainability. At the individual and household levels, there were opportunities to promote health and environmental sustainability through simple dietary choices such as the replacement of refined grains by wholegrains, increasing fruit and vegetable intake and reductions in added sugar. At the food systems level, I showed that: encouraging investments and partnerships; using modern agricultural innovation; configuring equitable food trade agreements; investing in early warning systems; and maintaining a healthy agricultural workforce could improve the resilience of food systems to external shocks while delivering healthy and environmentally sustainable diets.

Food systems in LMICs are relatively more vulnerable to the effects of shocks due to lower adaptive capacity to cope and recover quickly from events such as climate extremes and disease outbreaks. At the same time, there is increasing pressure on food systems in LMICs to produce sufficient food to meet the demands of growing populations. Consequently, the environmental footprints of diets may not always be an immediate priority for governments (despite ambitious targets) due to food insecurity and limited budgets (i.e. it becomes more important to ensure there is enough food than what sort of food it is) (185).

However, globally, food production has enormous impact on environmental sustainability (143). Local production systems could play a critical role in the sustainability of production (186, 187). Issues that particularly jeopardise sustainability of production include: the level of intensification of the production system (188), the nature of land use before it became agricultural land (189) and the inputs used by the farming system (190). Recent projections show that, expected increase in food demand in Africa will also increase croplands between 34% and 40%, largely at the expense of forested land by 2050 (191). Production of cash crops and commercial farms producing nutritious fresh vegetables in LMICs whose main consumers are based in HICs such as the UK are responsible for the majority of agricultural land use change in Africa (192). Even LMIC settings with extreme climate vulnerability in terms of water stress or biodiversity loss such as South Africa, Morocco and Chile are increasingly producing foods for HIC markets (193, 194). This further threatens environmental sustainability in LMIC settings (195, 196). Of course, some level of import dependence by HICs on LMICs is unavoidable, given some comparative advantages such as exports of tropical crops which would be hard to substitute with local produce in temperate settings such as the UK (193).There are possible gains in terms of environmental sustainability that could be made through improved practices by large agribusinesses that are often located in HICs (197), but also a substantial proportion in LMICs (198). Improved practices such as adopting climate adaptation and mitigation strategies by smallholder or subsistence farmers collectively, could also help environmentally. However, at the individual farmer level this can be difficult to achieve due to limited resources (199). Consuming HICs need to take more responsibility in supporting efforts in their producing partners based in LMICs towards the mitigation of, and adaptation to, the effects of environmental change on local food systems. Paper 6 recommends increased investments among trading partners into building resilience in producing countries as a "win-win" solution for food system transformation. Overall, global food trade and equitable partnerships could be a source of improving food security (200), and adaptation and mitigation to climate change (161, 201).

Further, the availability and consumption of fruits and vegetables seem to be the main driver of much of health and environmental sustainability of diets across the globe due to their high importance for health and less stress on the environment (50). In Paper 5, I discussed what it might take to increase fruit and (non-starchy) vegetable availability and consumption in The Gambia such as through promotion of urban horticulture, social behaviour change communication and balancing food trade to fill supply gaps. However, more generally, it is important to consider the implications of switching to a diet dominated by fruits and vegetables. In LMICs, addressing postharvest loses and improving cold chain facilities would be important to ensure year-round supply of fruit and vegetables (202). There are also enormous gains that could be made from reducing the reliance on livestock products. For example, if most of the world's population (especially HIC populations) were to adhere to recommended levels of consumption of livestock products, this could release a large amount of land which is currently being used for producing cereals and other food crops to feed livestock (203). At present, roughly 800 million tonnes of cereals (one-third of total cereal production) are used for animal feed and this is projected to reach over 1.1 billion tonnes by 2050 (203). Without changes to current trends, a majority of the increase in feed demand will be met by LMICs and therefore changes now will present opportunities to grow more healthy and environmentally sustainable foods such as fruit and vegetables (204).

On sustainable diets, there is a growing concern about the effects of diets on health and the environment among the public in many HIC settings. There is evidence to show that diets in HICs are diversifying over time to include more fruits and vegetables with declining levels of intake of animal-source foods and sugar over the last five decades (205). As countries in the Global North currently produce the largest amounts of animal-source foods (with feed produced mainly in LMICs (186, 187, 198)) (**Annex 3**), it is important to understand how ongoing dietary shifts away from animal-source foods in these settings might translate in LMICs. Depending on the nature of food systems change that would occur in HICs, there could be more "dumping" of excess animal-source foods from HICs into LMICs markets. While this may be good in the short-term for closing the wide protein gap between the Global

North and the Global South, in the long-term, this will have more negative consequences. It could out-compete small-scale local producers, shape dietary preferences wrongly towards animal-source foods and increase environmental footprints of diets in LMICs (206). On the other hand, a higher demand for plant-based foods in HICs will have to be partly provided by production in LMICs which could result in “nutrient drains” from climate vulnerable settings. This is already noticeable in certain HICs. For example, a recent analysis of UK’s fruit and vegetables supply showed that over time, the proportion of fruit and vegetable imports into the UK from climate-vulnerable countries, and countries projected to be water-stressed in the future, has significantly increased (194). Therefore, global food system policies such as the UN Food Systems Summit need to ensure that dietary shifts towards more healthy options in HICs do not lead to either a dumping of environmentally unsustainable foods on LMIC markets or disproportionate drainage of nutrient-rich sources from LMICs.

Finally, the resilience of food systems in LMICs to shocks particularly the more unpredictable events such as pandemics and other social disruptions have largely been understudied, but are thought to be lower than those in HICs (195). There are lessons about resilience to learn from how food systems in LMICs responded to the COVID-19 pandemic. Despite causing significant disruptions to livelihoods and the bleak projections that were made about COVID-19’s potential effects on food systems in LMICs (207), the pandemic has not really affected food systems in LMICs (more specifically West Africa) that much compared to projections at the beginning of the pandemic in 2020 (207). Several factors possibly accounted for the incredible resilience of West African food systems to COVID-19 of which I have discussed the key reasons below. At the global and regional level, food trade continued as governments made exemptions for food trade despite travel bans. Contrary to expected restrictions on food exports, only 22 countries announced or imposed a temporally export ban on food at the beginning of the pandemic, by July 2020 most bans were already lifted (208). The continuation of cross-border food trade relieved extra pressure that local producers would have faced if global food trade collapsed. In this case, global food governance and coordination was key to ensuring local food system resilience. At national levels in West

Africa, subsistence food production also continued largely unaffected. However, medium-to-large scale producers faced challenges and up to 13% reported stopping food production due to the pandemic (challenges included scarce farm labour, middlemen, inputs, etc,.) (209).These food systems resilience insights could be useful for planning the type of support required to ensure food system resilience from national to global levels. For example, at the national level, we now understand that medium-to-large scale producers are more vulnerable to social disruptions and so these could be prioritised to ensure continued production especially if global cross-border food trade is also affected.

### *5.3 Conclusion*

This thesis demonstrates how population diet could be an important entry point for ensuring food systems' sustainability and resilience.

The thesis shows a changing paradigm towards configuring food systems for children and adolescents. It finds that among children, poor diet diversity influence undernutrition. Among adolescents, diets are determined by household level socio-economic factors (access to pocket money and living in high wealth households) (Paper 1 and 2).

At the national level, I have shown how daily per capita caloric supply could be adequate while the supply of nutritionally important food groups (fruits, vegetables, nuts, and wholegrains) is suboptimal. I also identified the concept of "double vulnerability" where diets that are more nutrient inadequate are also more likely to be most vulnerable to shocks (Paper 3 and 4).

The thesis advances understanding of sustainable food systems in LMICs. I investigated the adherence of national diets to health and environmental sustainability targets and developed a metric for assessing healthy and sustainable diets in LMICs. I have shown that dietary deviations from health and sustainability targets in LMICs is more related to sub-optimal intake of nutritionally important food groups and high intake of less healthy food groups, but not necessarily the overconsumption of food groups known to impact negatively on the environment (Paper 5).

The thesis also identifies evidence-based strategies to support food systems transformation to deliver healthy and sustainable diets while being resilient to external shocks (Paper 6). Opportunities for food system transformation in LMICs include:1) encouraging investments and partnerships for food system transformation; 2) adoption of agricultural innovation practices such as climate-smart agriculture; 3) configuring food trade to be more equitable and resilient in order to bridge gaps in domestic production 4) investing in early warning systems to reduce production failures; and 5) ensuring a healthy agricultural workforce to enable continued food production and supply in the face of increasing climate extremes and disease outbreaks.

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# PORTFOLIO OF PUBLICATIONS

**Paper 1:** The effect of maternal and child factors on stunting, wasting and underweight among preschool children in Northern Ghana

# RESEARCH PAPER COVER SHEET

**Please note that a cover sheet must be completed <u>for each</u> research paper included within a thesis.**

## <u>SECTION A – Student Details</u>

| | | | |
|---|---|---|---|
| **Student ID Number** | 1800648 | **Title** | Mr |
| **First Name(s)** | Zakari | | |
| **Surname/Family Name** | Ali | | |
| **Thesis Title** | Resilient and healthy food systems in low-income settings | | |
| **Primary Supervisor** | Prof. Andrew Prentice | | |

**If the Research Paper has previously been published please complete Section B, if not please move to Section C.**

## <u>SECTION B – Paper already published</u>

| | | | |
|---|---|---|---|
| Where was the work published? | BMC Nutrition | | |
| When was the work published? | 4th April 2017 | | |
| If the work was published prior to registration for your research degree, give a brief rationale for its inclusion | This paper is thematically linked to the aims of my PhD. | | |
| Have you retained the copyright for the work?* | **Yes** | Was the work subject to academic peer review? | **Yes** |

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**The effect of maternal and child factors on stunting, wasting and underweight among preschool children in Northern Ghana**

SPRINGER NATURE

**Author:** Zakari Ali et al
**Publication:** BMC Nutrition
**Publisher:** Springer Nature
**Date:** Apr 4, 2017

**SECTION D – Multi-authored work**

| | |
|---|---|
| For multi-authored work, give full details of your role in the research included in the paper and in the preparation of the paper. (Attach a further sheet if necessary) | I conceptualised the study idea and co-designed it with assistance from Dr Mahama Saaka. I designed the questionnaire and participated in data collection from the field (interviews and anthropometric measurement of children and women). I led the data entry into SPSS and cleaning with Abdul-Ganiyu Adams and Stephen K. Kamwininaang. I performed the statistical analysis and interpretation of results with support from my supervisors (Dr Mahama Saaka and Dr Abdul-Razak Abizari). I wrote the first full draft and received comments from supervisors. I incorporated their feedback and produced an updated draft. All co-authors contributed to reviewing the draft and checking for language consistency and manuscript structure. I prepared the manuscript according to the journal requirements and led the submission. I was corresponding author and responded to reviewer comments in consultation with Dr Mahama Saaka. |

**SECTION E**

| | |
|---|---|
| **Student Signature** | [redacted] |
| **Date** | 2nd August 2022 |

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| **Supervisor Signature** | [redacted] |
| **Date** | 12th October 2022 |

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RESEARCH ARTICLE Open Access

# The effect of maternal and child factors on stunting, wasting and underweight among preschool children in Northern Ghana

Zakari Ali*, Mahama Saaka, Abdul-Ganiyu Adams, Stephen K. Kamwininaang and Abdul-Razak Abizari

## Abstract

**Background:** Undernutrition among preschool children in Northern region is the highest in Ghana. However, there is scarcity of data on the factors that determine undernutrition in these children. This study investigated the effect of maternal and child factors on undernutrition among preschool children in Northern Ghana.

**Methods:** This study was a community based analytical cross-sectional survey on a sample of 425 mother- child pairs drawn from 25 clusters. A semi- structured questionnaire was used to collect data on maternal and child socio-demographic characteristics, feeding practices and anthropometry. Anthropometric indices of Height-for-age Z-scores (HAZ), Weight-for-height Z-scores (WHZ) and Weight-for – age Z-scores (WAZ) were used to classify child stunting, wasting and underweight respectively. Bivariate and multivariate analyses were performed to determine associations between explanatory variables and undernutrition.

**Results:** The prevalence of stunting, wasting and underweight were 28.2, 9.9 and 19.3% respectively. Multiple logistic regression analysis showed that, the odds of stunting was higher among male children [AOR = 1.99; 95% CI (1.26–3.13); $p = 0.003$], children of mothers less than 150 cm in height [AOR = 3.87; 95% CI (1.34–11.20); $p = 0.01$], mothers 155–159 cm tall [AOR = 2.21; 95% CI (1.34–3.66); $p = 0.002$], and older children aged 12–23 months [AOR 9.81; 95% CI (2.85–33.76); $p < 0.001$]. Wasting was significantly higher among male children [AOR = 2.40; 95% CI (1.189–4.844); $p = 0.015$], consumption of less than four food groups [AOR = 3.733; 95% CI (1.889–7.376); $p < 0.001$] and among children of underweight mothers [AOR = 3.897; 95% CI (1.404–10.820); $p = 0.009$]. Male children [AOR = 2.685; 95% CI (1.205–5.98); $p = 0.016$] and having low birth weight [AOR = 3.778; 95% CI (1.440–9.911); $p < 0.001$] were associated with higher odds of underweight in children.

**Conclusion:** Maternal height associated negatively with stunting but not wasting. Factors that affect low height –for-age z-score (HAZ) may not necessarily be the same as stunting. Infant and child feeding practices as measured by dietary diversity score associated positively with weight-for-height Z-scores than length-for-age Z-scores of young children. Surprisingly, consumption of some specific food groups including, animal source foods, legumes, staples and eggs were associated with lower HAZ but with increased likelihood of higher WHZ among children 6–59 months.

**Keywords:** Preschool children, Stunting, Wasting, Underweight, Child factors, Dietary diversity, Ghana

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## Background

Malnutrition is of public health importance in developing countries and is responsible for over half of child deaths each year from preventable causes [1]. Stunting is defined as height-for-age below minus two standard deviations (−2SD) from the median of WHO reference population [2] and considered an indicator of long-term nutritional inadequacy [3]. Stunting in children, especially in the first 2 years of life has long term effects on adult height, income, school attainment [4], and a predisposition to adult chronic diseases [5].

Although over the past decades child stunting has decreased worldwide, it has remained high in Sub-Saharan Africa and Asia and afflicts an estimated 165 million children globally [6]. In Ghana, there has been a decline in stunting prevalence but still remains high in children under 5 years. The Ghana demographic and health survey (GDHS) reports indicate a decrease in child stunting from 28% in 2008 [2] to 19% in 2014 [7]. Though this is an encouraging reduction nationally, there are wide disparities among the regions [8, 9], with most southern regions having lower prevalence and the northern regions with higher prevalence [9]. Stunting in Northern region is the highest in Ghana with a prevalence of 33% among preschool children [7].

Despite the high prevalence of stunting among children, its determinants are poorly established and understood [10] and limited studies have been undertaken especially in the Northern region to identify the determinants of malnutrition among children [11]. As Ghana strives to attain the Sustainable Development Goals (SDGs) by the year 2030, ensuring nutritional well-being is key [8]. Government and non-governmental organizations in response to the high prevalence of stunting among children in the Northern region have initiated some interventions to decrease it [9]. For these interventions to have the most impact on stunting, data on the predictors and the strong determinants of stunting affecting these children is critical. Moreover, data is scarce especially in the Northern region on the determinants of wasting and underweight in children. This study therefore investigated maternal and child factors that are associated with stunting, wasting and underweight among preschool children in the Central Gonja district of Northern Ghana.

## Methods

### Study area

The study was conducted in the Central Gonja District which is located at the south-western part of the Northern Region of Ghana with its administrative capital at Buipe. The District covers approximately 7555 $km^2$ land area which represent 11.0% of the total land area of the region and shares boundary with the southern parts of Ghana. The district is divided into five sub- districts for administrative purposes with a total population of 87,877 with 49.9% as males and 50.1% as females. The population of the district is largely youthful with children aged 0–4 years forming the largest part representing 17.6% of the total population. The main economic activity of the people is agriculture (74.2%) involving crop production, livestock and fish farming. Some of the crops cultivated are maize, sorghum, millet, groundnut, cowpea, soy beans, yam, rice, as well as cassava. Fishing and livestock are considered supplementary activities to crop farming [12].

### Study design, population and sampling

A community-based analytical cross-sectional design was used in this study. The target population was children under five years and their mothers/primary caregivers. In households with more than one eligible child, one child was chosen at random to participate in the study. An eligible child and its mother were all present at the point of data collection for inclusion.

A sample size of 425 was determined on the assumption that the prevalence of stunting in the study district was unknown and so 50% was assumed with 5% marginal error and 95% confidence interval (CI) and a none response rate of 10%.

The study used a multi-stage cluster sampling procedure which involved selecting communities and households. To make valid conclusions in a community- based cluster study, a minimum of 25 clusters is usually required [13, 14]. This study used this minimum number of clusters by randomly choosing 25 communities from a list of communities from four sub-districts across the Central Gonja district using Excel generated random numbers. The primary sampling units in selected clusters was households. With a required sample size of 425 and 25 clusters, the minimum sample required for each cluster was 17 households. Systematic sampling technique was used to select the required number of households in each cluster. A list of all households with an eligible child (a child aged 6–59 months) in a selected cluster was compiled and numbered in ascending order. The sampling interval for the cluster was then determined by dividing the total number of households 17. A number within the sampling interval was randomly selected to get the first household to visit. Subsequently, households to visit were identified by adding the sampling interval to the number selected. This was done until the 17 household required from a cluster was obtained. In households with more than one eligible child mother pairs, one was selected for interview using simple random sampling technique.

### Data collection procedures

Face-to-face interviews were conducted in homes using pre-tested and validated structured questionnaires to collect representative data on socio-demographic characteristics, illness history, nutritional status, health and nutrition behaviors of mothers/caretakers. Information on the economic well-being of families (e.g. household wealth index) was also collected (see Additional fie 1 for study questionnaire).

### Variables measured

Both potential proximal and distal determinants of stunting were investigated. The proximal determinants relate to biological functions of both mother and child or to specific maternal practices that influence food intake, health, and caregiving. These included child's gender, age in months, birth weight, birth interval, breastfeeding status, dietary intake, diarrhoea and fever in the last two weeks, mother's nutritional status, mother's age, maternal health seeking behaviors such as prenatal and postnatal care for mothers, and caring practices for children. The distal determinants are the resources necessary for achieving adequate food security, care, and a healthy environment. The distal determinants assessed included household socioeconomic status, maternal education, access to safe water and access to sanitary toilet facilities.

Briefly, a description of main independent variables is as follows:

### Nutritional status assessment

#### *Age*

The exact age of the child was recorded in months, based on date of birth information contained in child health records booklets, birth certificates and baptismal cards.

#### *Weight*

The weight of children was assessed with Seca Electronic UNISCALE (SECA 890). Weight was measured to the nearest gram. Weighing scale was calibrated to zero before taking every measurement. The children were weighed with minimal clothing, without shoes and with minimal movement on the scale. Tare weighing was performed for children who could not stand well on the scale to take a meaningful measure.

#### *Length*

The length measurements of children less than two years of age (i.e. up to and including 23 months) were taken following WHO standard procedures. A specialized wooden device (that is, an infantometer) was used to take the measurement in a supine position. This was done by placing the child on its back between the slanting sides with the head placed gently against the fixed top end. The knees were gently pushed down by a helper while the foot-piece is moved toward the child until it presses softly against the soles of the child's feet and the feet are at right angles to the legs. The length was then read to the nearest 0.1 cm. For children who were more than two years, height was measured using the infantometer in standing position.

Anthropometric data were then transformed into Z-scores for height-for-age Z-score (HAZ), weight-for-length Z-score (WLZ) and weight-for-age Z-score (WAZ). Categorical variables were stunting, wasting and underweight which reflect HAZ, WAZ and WLZ below −2 standard deviations below the population median.

#### *Body Mass Index (BMI)*

BMI is a simple index of weight-to-height commonly used to classify underweight, overweight and obesity in adults. It is defined as the weight in kilograms divided by the square of the height in metres ($kg/m^2$). Weight of mothers was measured with a Seca electronic weighing scale to the nearest 0.1 kg. Height of mothers was measured with a Seca microtoise to the nearest 0.1 cm.

#### *Bilateral edema*

This was diagnosed by placing both thumbs on the upper side of the feet and applying pressure for about three seconds. Edema was considered to be present if a skin depression remained on both feet after the pressure was released.

### Assessment of dietary intake

Overall dietary quality was assessed using the dietary diversity score. The WHO validated 7-item food groups frequency questionnaire (FFQ) was used to quantify child dietary intake [15]. Food that was fed to the children was assessed using a structured 24-h food frequency questionnaire. Mothers were asked to recall the number of times, in the past 24 h, a child had received anything to eat, aside from breast-milk, including meals and snacks. The dietary diversity score therefore ranged from 0 to 7 with minimum of 0 if none of the food groups is consumed to 7 if all the food groups are consumed.

The WHO defined minimum dietary diversity as the proportion of children aged 6–23 months who received foods from at least four out of seven food groups [15, 16]. The seven food groups used in defining children's minimum dietary diversity indicator are:

(i) grains, roots and tubers; (ii) legumes and nuts; (iii) dairy products; (iv) flesh foods (meats/fish/poultry) (v) eggs (vi) vitamin A rich fruits and vegetables; and (vii) other fruits and vegetables.

WHO Infant and young child feeding (IYCF) indicators [minimum dietary diversity (MDD), minimum meal frequency (MMF), minimum acceptable diet (MAD)] were the main dietary intake indicators for children. These indicators were measured by recall of food and liquid consumption during the previous day or night preceding survey as per WHO/UNICEF food frequency questionnaire (FFQ) [17]. Minimum meal frequency is the proportion of children who received complementary foods at least the minimum recommended number of times in the last 24 h. A child is judged to have taken 'adequate number of meals if he/she received at least the minimum frequency for appropriate complementary feeding (that is, 2 times for 6–8 months and 3 times for 9–11 months, 3 times for children aged 12–23 months) in last 24 h. For non-breastfed children, the minimum meal frequency is 4.

### Assessment of socio-economic status

A household wealth index based on household assets and housing quality was used as a proxy indicator for socio-economic status (SES) of households.

Absolute household wealth index was calculated from information collected on housing quality (floor, walls, and roof material), source of drinking water, type of toilet facility, the presence of electricity, type of cooking fuel, and ownership of modern household durable goods and livestock (e.g. bicycle, television, radio, motorcycle, sewing machine, telephone, cars, refrigerator, mattress, bed, computer and mobile phone) [18–21]. These facilities or durable goods are often regarded as modern goods that have been shown to reflect household wealth. A household of zero index score for example means that household had not a single modern good. The scores were thus added up to give the proxy household wealth index. The median score of 7 was used as the cut-off point to define low and high household wealth index.

### Data quality assurance

A number of measures were used to ensure that accurate and reliable data were collected and analyzed. These included extensive practical training of data enumerators, pre-testing of data collection tools and extensive monitoring of the field teams. Field supervisors provided on-the-spot assistance to interviewers. Data were checked for completeness and consistency by field supervisors in the field and during data entry in order to ensure good quality.

### Statistical analysis

Data analyses was performed with PASW/SPSS, version 21.0 for Windows using procedures in SPSS complex samples module for Windows. Design weights were added to perform weighted analysis. This module of SPSS takes into account the complex nature of the cluster sample design.

The Z- scores for weight-for-age (WAZ), weight-for-height (WHZ), height-for-age (HAZ) and prevalence underweight, wasting and stunting were calculated using the 2006 World Health Organization (WHO) growth standards.

WHO Anthro software was used to convert height, weight and age measurements to Height- for- age Z-scores (HAZ), weight- for –height Z- scores (WHZ) and weight-for – age (WAZ) which were used to classify stunting, wasting and underweight respectively. Child undernutrition was defined as Z- scores below −2 standard deviations below the median of the reference population.

Bivariate and multivariate analyses were both performed to identify the determinants of stunting, wasting and underweight. Chi-square ($\chi^2$) tests were performed to identify the predictors of stunting, wasting and underweight significant at $p < 0.05$. ANOVA was used to compare mean anthropometric Z-scores and selected predictors.

The association between undernutrition and the independent variables was determined using binary logistic regression modeling. This test statistic was used because stunting, wasting and underweight were coded into two categories (that is: stunted and normal, wasted and normal, and underweight and normal). All of the potential predictors of stunting, wasting and underweight that were significant at $p < 0.05$ in bivariate analysis using Chi-square ($\chi^2$) tests were included in the regression modeling.

The association between selected factors and HAZ was determined using multiple linear regression modeling. This test statistic was used because the dependent factor (HAZ) is a continuous variable.

Before testing for associations between independent variables and the dependent outcomes, the data were cleaned and outliers removed. Z-scores which were outside the WHO flags: WHZ −5 to 5; HAZ −6 to 6; and WAZ −6 to 5 were excluded from the data set.

### Ethics consideration

Permission to carry out this study was sought from the district health directorate and the study protocol was approved by the School of Allied Health Sciences, University for Development Studies, Ghana. Informed consent was verbally obtained from participant mothers after needed information and procedures were explained. Participation was voluntary and participants signed or thumb printed a statement of an informed consent before being interviewed.

## Results

### Socio-demographic characteristics of the sample

The mean age ± SD of mothers was 30.3 ± 6.0 years with the majority (75.3%) in the 18–34 age groups. The majorities of the respondents had no formal education (78.1%), were married (91.3%), practiced Islamic religion (93.4%) and mostly from the Gonja ethnic group (53.6%). Sixty-three percent of mothers were from low wealth households.

Children had mean age ± SD of 25.14 ± 13.6 months; male children (50.8%) were slightly more than the female children (49.2%) with most of the children found in the age group 12–23 months (32.5%). Majority of the children had adequate birth weight ≥ 2.5 and a mean birth weight of 2.97 ± 0.49 (Table 1).

### Nutritional status and dietary intake of children under-five years

The nutritional status and dietary practices of children are presented in Table 2. The negative z-scores for the entire study population indicate that the children in the study sample are less well-nourished relative to the WHO standard population. The prevalence of chronic, acute and underweight was 28.2, 9.9 and 19.3% respectively. The mean dietary diversity score (DDS) was 3.58 ± 1.58 and less than 50.0% of the children met the minimum dietary diversity (≥4 food groups) and minimum acceptable diet. Children who met the acceptable diet and also started complementary feeding at six months were considered to have appropriate complementary feeding. Therefore, the overall appropriate complementary prevalence was only 15.5%.

### Predictors of mean HAZ and WHZ among children aged 6–59 months

Bivariate analysis of the predictors of mean height- for- age Z-score (HAZ) and weight-for-height Z-scores (WHZ) are shown in Tables 3 and 4. Infant and young child feeding (IYCF) practices indicators better explain weight-for-height Z-scores (WHZ) than height-for-age Z-scores (HAZ).

Whereas, HAZ associated negatively with minimum dietary diversity as well as the consumption of some specific food groups including, animal source foods and legumes, WHZ associated positively with these variables. Other variables that were tested but were not in any way associated with HAZ and WHZ were the educational level of the mother, initiation and frequency of ANC attendance.

### Predictors of stunting among children

A host of explanatory variables were tested for their association with child stunting. The variables tested included age and sex of child, type of residence, current breast feeding status, diarrhoeal infection, utilization of antenatal care services, birth interval, parity, birth weight, maternal height, maternal educational level, household wealth index, source of drinking water, type of toilet facility, bottle feeding, minimum dietary diversity score and number of under five children in household.

Bivariate analysis revealed that, stunting was significantly higher among male children than their female counterparts. Stunting was less prevalent among children whose mothers attended antenatal care (ANC) services for at least 4 times during pregnancy. In addition, stunting was significantly higher among children who were born low birth weight (<2.5 kg) compared to children with adequate birth weight. The prevalence of stunting decreased as maternal height increased, and children who lived in households without a toilet facility were also more likely to be stunted (Table 5).

**Table 1** Socio- demographic characteristics of the study population

| Characteristics | Mean (± SD) | Frequency (n) | Percentage (%) |
|---|---|---|---|
| Mean age (years) | 30.26 ± 6.02 | | |
| Age groups (years) | | | |
| 18–34 | | 320 | 75.3 |
| At least 35 | | 105 | 24.7 |
| Education | | | |
| None | | 332 | 78.1 |
| Low (primary/junior high school) | | 79 | 18.6 |
| High (at least sec school) | | 14 | 3.6 |
| Marital status | | | |
| Married | | 388 | 91.3 |
| Currently unmarried | | 37 | 8.7 |
| Ethnicity | | | |
| Gonja | | 228 | 53.6 |
| Dagomba | | 115 | 27.1 |
| Others | | 82 | 19.3 |
| Religion | | | |
| Islam | | 397 | 93.4 |
| Other religions | | 28 | 6.6 |
| Household wealth | | | |
| Low | | 268 | 63.1 |
| High | | 157 | 36.9 |
| Child characteristic | | | |
| Mean age (months) | 25.14 ± 13.56 | | |
| Age groups (months) | | | |
| 6–11 | | 72 | 16.9 |
| 12–23 | | 138 | 32.5 |
| 24–35 | | 108 | 25.4 |
| 36–47 | | 70 | 16.5 |
| 48–59 | | 37 | 8.7 |
| Sex | | | |
| Male | | 216 | 50.8 |
| Female | | 209 | 49.2 |
| Mean birth weight (kg) | 2.97 ± 0.49 | | |
| Birth weight (kg) | | | |
| < 2.5 | | 23 | 11.9 |
| ≥ 2.5 | | 170 | 88.1 |

**Table 2** Nutritional status and dietary intake of children under-five years

| Characteristics | Mean ± SD | Frequency (n) | Percentage (%) |
|---|---|---|---|
| Nutritional status | | | |
| Height-for age-z-score (HAZ) | −1.33 ± 1.2 | | |
| Weight-for-height-z-score (WHZ) | −0.64 ± 1.1 | | |
| Weight-for-age-z-score (WAZ) | −1.18 ± 1.1 | | |
| Stunted (HAZ < −2) | | 120 | 28.2 |
| Wasted (WHZ < −2) | | 42 | 9.9 |
| Underweight (WAZ < −2) | | 82 | 19.3 |
| Overweight (WHZ > 2) | | 8 | 1.9 |
| Feeding practices | | | |
| Currently breastfeeding | | 217 | 51.1 |
| Timely initiation of breast feeding within one hour | | 211 | 49.6 |
| Introduction of complementary foods at 6 months | | 162 | 38.1 |
| Received colostrum | | 375 | 88.2 |
| *Minimum meal frequency (children aged 6–23 months) | | 141 | 64.7 |
| *Minimum dietary diversity (≥4 food groups) | | 100 | 45.9 |
| *Minimum Acceptable diet (children aged 6–23 months) | | 91 | 41.7 |

*Sample size (n) for children 6–23 months = 218

### Predictors of stunting and mean HAZ

Factors that affect low height –for-age z-score (HAZ) may not necessarily be the same as stunting (Tables 6 and 7).

Multiple logistic regression analysis showed that, age of child, low maternal height and gender of the child were the three significant consistent predictors of stunting. This set of variables accounted for 13.8% of the variability of stunting (Nagelkerke R Square = 0.138).

Male children were 1.9 times more likely [AOR = 1.99; 95% CI (1.26–3.13); $p = 0.003$] of being stunted compared to female children.

Compared to mothers with heights at least 160 cm, others who were less than 150 cm in height were about 3.9 times more likely to have a stunted child [AOR = 3.87; 95% CI (1.34–11.20); $p = 0.01$] and mothers 155–159 cm tall also had significantly higher odds of having a stunted child [AOR = 2.21; 95% CI (1.34–3.66); $p = 0.002$]. Older children aged 12–23 months were 9.8 times greater odds [AOR 9.81; 95% CI (2.85–33.76); $p < 0.001$] of being stunted, compared to children aged 6–8 months.

As age increases ($\beta = -0.521$, $p < 0.001$), HAZ score decreases (Table 7). Having introduced complementary food at 6 months ($\beta = 0.097$, $p = 0.026$) was associated with a higher HAZ score whereas continued breastfeeding ($\beta = -0.256$, $p < 0.001$) was associated with a lower HAZ score. Higher maternal height ($\beta = 0.172$, $p < 0.001$) and improved water sources ($\beta = 0.100$, $p = 0.020$) are also associated with a higher HAZ score. Wasted children ($\beta = -0.113$, $p = 0.011$) were associated with lower values of HAZ. The adjusted R-square for the set of predictors of HAZ was 0.216 (21.6%).

### Predictors of wasting among children

Table 8 presents the bivariate analysis of predictors of wasting in children. Acute malnutrition was associated with sex of child, child age group, birth weight, minimum dietary diversity, consumption of vitamin A rich fruits and vegetables, consumption of flesh foods, and the presence of other children under five years in the household and maternal body mass index. Younger children were more likely to experience wasting than their older counterparts. Children who consumed vitamin A rich fruits and vegetables, and flesh foods (meat, chicken and fish) were less likely to experience acute malnutrition. The presence of other children under six months of age was also associated with acute malnutrition in children.

In multivariate analysis, sex of child, meeting the daily minimum dietary diversity and maternal body mass index were found associated with wasting in children. These variables in the model equation explained 13.4% of the variance (Nagelkerke R Square = 0.134) in wasting. Compared to female children, male children were 2.4 times more likely to experience wasting [AOR = 2.40; 95% CI (1.189–4.844); $p = 0.015$]. The odds of wasting was higher among children who did not meet the minimum dietary diversity. Compared to children who met the minimum dietary diversity, children who did not meet it were 3.7 times more likely to be wasted [(AOR = 3.733; 95% CI (1.889–7.376); $p < 0.001$]. The odds of child wasting was significantly higher among underweight mothers [AOR = 3.897; 95% CI (1.404–10.820); $p = 0.009$] compared to mothers who had normal body mass index (Table 9).

### Predictors of underweight among children

In bivariate analysis, sex of child, birth weight, maternal body mass index, possession of toilet facility predicted underweight in children. Children who lived in households with a toilet facility were less likely to be underweight. Underweight mothers were also more likely to have an underweight child (Table 10).

Only two of the predictors of underweight significant in bivariate analysis were able to reach significance in multivariate analysis. Sex of child and birth weight were associated with child underweight in multivariate analysis. These factors accounted for 10.9% of the variability (Nagelkerke R Square = 0.109) in underweight in children. Implying that other factors not in the equation, probably not measured in this study also explain underweight in children. Male children were 2.7 times more likely to be underweight [AOR = 2.685; 95% CI (1.205–5.98);

**Table 3** Relationship between mean height –for-age z-score (HAZ) and selected variables among children aged 6–59 months

| Indicator | N | Mean HAZ | Std. Deviation | 95% Confidence Interval for Mean | | *p* value |
|---|---|---|---|---|---|---|
| | | | | Lower Bound | Upper Bound | |
| Child currently breastfeeding? | | | | | | |
| No | 208 | −1.4115 | 1.17570 | −1.5722 | −1.2508 | 0.2 |
| Yes | 217 | −1.2504 | 1.25697 | −1.4186 | −1.0822 | |
| Age of child (months) | | | | | | |
| 6–8 | 46 | -.1770 | 1.44827 | -.6070 | .2531 | <0.001 |
| 9–11 | 30 | -.6190 | 1.42657 | −1.1517 | -.0863 | |
| 12–23 | 142 | −1.5582 | 1.15160 | −1.7493 | −1.3672 | |
| 24–59 | 207 | −1.5311 | .97958 | −1.6653 | −1.3969 | |
| Gender of child | | | | | | |
| Male | 216 | −1.4953 | 1.32478 | −1.6730 | −1.3177 | 0.004 |
| Female | 209 | −1.1576 | 1.07576 | −1.3043 | −1.0109 | |
| Timing of first complementary food at 6 months | | | | | | |
| No | 263 | −1.4068 | 1.11418 | −1.5421 | −1.2716 | 0.09 |
| Yes | 162 | −1.2032 | 1.36677 | −1.4153 | -.9911 | |
| Minimum meal frequency | | | | | | |
| No | 190 | −1.2549 | 1.27073 | −1.4367 | −1.0730 | 0.3 |
| Yes | 235 | −1.3893 | 1.17502 | −1.5403 | −1.2383 | |
| Minimum dietary diversity | | | | | | |
| Less than 4 groups | 154 | −1.0892 | 1.37680 | −1.3083 | -.8700 | 0.002 |
| At least 4 groups | 271 | −1.4656 | 1.09919 | −1.5971 | −1.3342 | |
| Minimum acceptable diet | | | | | | |
| No | 251 | −1.2239 | 1.32109 | −1.3882 | −1.0597 | 0.03 |
| Yes | 174 | −1.4811 | 1.03980 | −1.6367 | −1.3255 | |
| Classification of household wealth index | | | | | | |
| Low | 268 | −1.4153 | 1.12989 | −1.5512 | −1.2794 | 0.06 |
| High | 157 | −1.1823 | 1.34907 | −1.3950 | -.9696 | |
| Maternal height (cm) | | | | | | |
| < 150 | 17 | −1.8812 | 1.04163 | −2.4167 | −1.3456 | 0.004 |
| 150–154 | 57 | −1.4512 | 1.41418 | −1.8265 | −1.0760 | |
| 155–159 | 129 | −1.5319 | 1.07278 | −1.7188 | −1.3450 | |
| At least 160 | 222 | −1.1379 | 1.22944 | −1.3005 | -.9753 | |
| Classification of birth weight | | | | | | |
| Normal (≥2.5 kg) | 170 | −1.1429 | 1.25864 | −1.3335 | -.9524 | <0.001 |
| Low birth weight (<2.5 kg) | 23 | −2.1230 | 1.06457 | −2.5834 | −1.6627 | |
| Consumption of staples in the past 24 h prior to study | | | | | | |
| No | 43 | -.7381 | 1.15345 | −1.0931 | -.3832 | <0.001 |
| Yes | 382 | −1.3958 | 1.20973 | −1.5175 | −1.2741 | |
| Consumption of animal source foods in the past 24 h prior to study | | | | | | |
| No | 94 | -.9859 | 1.31444 | −1.2551 | -.7166 | 0.002 |
| Yes | 331 | −1.4267 | 1.17454 | −1.5537 | −1.2997 | |
| Consumption of legumes foods in the past 24 h prior to study | | | | | | |
| No | 211 | −1.1699 | 1.30031 | −1.3463 | -.9934 | 0.007 |
| Yes | 214 | −1.4864 | 1.11425 | −1.6365 | −1.3362 | |

**Table 4** Relationship between mean weight –for-height z-score (WHZ) and selected variables among children aged 6–59 months

| Indicator | N | Mean WHZ | Std. Deviation | 95% Confidence Interval for Mean | | *p* value |
|---|---|---|---|---|---|---|
| | | | | Lower Bound | Upper Bound | |
| Child currently breastfeeding? | | | | | | <0.001 |
| No | 208 | −0.41 | 0.94 | −0.54 | −0.28 | |
| Yes | 217 | −0.87 | 1.20 | −1.03 | −0.71 | |
| Age of child (months) | | | | | | <0.001 |
| 6–8 | 46 | −0.82 | 1.02 | −1.12 | −0.52 | |
| 9–11 | 30 | −1.32 | 1.27 | −1.79 | −0.85 | |
| 12–23 | 142 | −0.76 | 1.197 | −0.96 | −0.57 | |
| 24–59 | 207 | −0.43 | 0.98 | −0.56 | −0.29 | |
| Gender of child | | | | | | 0.06 |
| Male | 216 | −0.74 | 1.19 | −0.90 | −0.59 | |
| Female | 209 | −0.54 | 1.01 | −0.68 | −0.40 | |
| Timing of first complementary food at 6 months | | | | | | 0.8 |
| No | 263 | −0.64 | 1.059 | −0.76 | −0.51 | |
| Yes | 162 | −0.66 | 1.18 | −0.84 | −0.48 | |
| Minimum meal frequency | | | | | | 0.7 |
| No | 190 | −0.62 | 1.09 | −0.77 | −0.46 | |
| Yes | 235 | −0.67 | 1.12 | −0.81 | −0.52 | |
| Minimum dietary diversity | | | | | | <0.001 |
| Less than 4 groups | 154 | −0.98 | 1.17 | −1.17 | −0.79 | |
| At least 4 groups | 271 | −0.45 | 1.02 | −0.58 | −0.33 | |
| Minimum acceptable diet | | | | | | 0.13 |
| No | 251 | −0.71 | 1.13 | −0.85 | −0.57 | |
| Yes | 174 | −0.55 | 1.06 | −0.71 | −0.39 | |
| Classification of household wealth index | | | | | | 0.3 |
| Low | 268 | −0.60 | 1.07 | −0.73 | −0.47 | |
| High | 157 | −0.72 | 1.16 | −0.91 | −0.54 | |
| Maternal height (cm) | | | | | | 0.2 |
| < 150 | 17 | −0.56 | 1.12 | −1.14 | 0.02 | |
| 150–154 | 57 | −0.91 | 1.20 | −1.23 | −0.60 | |
| 155–159 | 129 | −0.54 | 1.08 | −0.72 | −0.35 | |
| At least 160 | 222 | −0.65 | 1.09 | −0.79 | −0.50 | |
| Classification of birth weight | | | | | | 0.1 |
| Normal (≥2.5 kg) | 170 | −0.56 | 1.03 | −0.71 | −0.40 | |
| Low birth weight (<2.5 kg) | 23 | −0.90 | 1.06 | −1.36 | −0.44 | |
| Consumption of staples in the past 24 h prior to study | | | | | | 0.1 |
| No | 43 | −0.93 | 1.26 | −1.32 | −0.54 | |
| Yes | 382 | −0.61 | 1.08 | −0.72 | −0.50 | |
| Consumption of animal source foods in the past 24 h prior to study | | | | | | <0.001 |
| No | 94 | −1.01 | 1.20 | −1.25 | −0.76 | |
| Yes | 331 | −0.54 | 1.06 | −0.66 | −0.43 | |
| Consumption of legumes foods in the past 24 h prior to study | | | | | | <0.001 |
| No | 211 | −0.84 | 1.08 | −0.99 | −0.69 | |
| Yes | 214 | −0.45 | 1.10 | −0.60 | −0.30 | |

**Table 5** Bivariate analysis of predictors of chronic malnutrition among children aged 6–59 months

| Characteristic | N | Classification of stunting | | p value |
|---|---|---|---|---|
| | | Normal n (%) | Stunted n (%) | |
| Age of child (months) | | | | <0.001 |
| 6–11 | 72 | 65 (90.3) | 7 (9.7) | |
| 12–23 | 138 | 88 (63.8) | 50 (36.2) | |
| 24–35 | 108 | 69 (63.9) | 39 (36.1) | |
| 36–47 | 70 | 52 (74.3) | 18 (25.7) | |
| 48–59 | 37 | 31 (83.8) | 6 (16.2) | |
| Classification of ANC visits | | | | 0.03 |
| < 4 | 147 | 96 (65.3) | 51 (34.7) | |
| ≥ 4 | 278 | 208 (74.8) | 70 (25.2) | |
| Birth weight classification | | | | <0.001 |
| < 2.5 Kg | 23 | 9 (39.1) | 14 (60.9) | |
| ≥ 2.5 Kg | 170 | 129 (75.9) | 41 (24.1) | |
| Gender of child | | | | 0.005 |
| Male | 216 | 142 (65.7) | 74 (34.3) | |
| Female | 209 | 163 (78.0) | 46 (22.0) | |
| Type of toilet facility | | | | 0.03 |
| No facility (open defecation) | 377 | 264 (70.0) | 113 (30.0) | |
| Pit latrine/flush | 48 | 41 (85.4) | 7 (14.6) | |
| Maternal height (cm) | | | | 0.01 |
| < 150 | 17 | 9 (52.9) | 8 (47.1) | |
| 150–154 | 57 | 40 (70.2) | 17 (29.8) | |
| 155–159 | 129 | 83 (64.3) | 46 (35.7) | |
| ≥ 160 | 222 | 173 (77.9) | 49 (22.1) | |

$p = 0.016$] compared to female children. The odds of underweight was significantly higher among children who were born low birth weight than those born of adequate birth weight. Compared to children born of adequate birth weight, children born low birth weight were 3.8 times more likely to be underweight [AOR = 3.778; 95% CI (1.440–9.911); $p < 0.001$]. Table 11 presents the results of multivariate analysis of the determinants of underweight in children in the study sample.

## Discussion

This study sought to investigate the maternal and child factors that determine child stunting, wasting and underweight among children aged 6–59 months in Northern Ghana. The main findings were that maternal height associated negatively with stunting but not wasting. The factors that are associated with low height- for-age z-score may not necessarily be the same as stunting. In addition, infant and child feeding practices as measured by dietary diversity score associated positively with weight-for-height Z-scores than length-for-age Z-scores of young children and the consumption of some specific food groups including, animal source foods and legumes and eggs were associated with lower HAZ but with increased likelihood of higher WHZ among children. Stunting was associated with sex, maternal height and age of child, whereas wasting was associated with dietary diversity, sex and body mass index of mother. Child underweight was associated with sex and birth weight of children.

The prevalence of child malnutrition indicators measured in present study were lower than the regional prevalence of 33.1, 20.0 and 6.3% for stunting, underweight and wasting respectively in the recent Ghana demographic and health survey report [7], except for wasting where children in the study sample recorded slightly higher prevalence (9.9% versus 6.3% respectively). This implies that, though stunting and underweight are decreasing in the region, household food security does not seem to improve, as reflected in the higher prevalence of wasting found in present study. The lower prevalence of stunting and underweight recorded in this study compared to those reported in the 2014 demographic and health survey has also been documented by recent studies in the Northern region [9, 22].

**Table 6** Multivariate analysis of the determinants of child stunting

| | p value | AOR | 95% C.I. for AOR | |
|---|---|---|---|---|
| | | | Lower | Upper |
| Male child | 0.003 | 1.99 | 1.26 | 3.13 |
| Maternal height (Reference: At least 160 cm) | 0.004 | | | |
| <150 cm | 0.01 | 3.87 | 1.34 | 11.20 |
| 150–154 cm | 0.24 | 1.50 | 0.76 | 2.97 |
| 155–159 cm | 0.002 | 2.21 | 1.34 | 3.66 |
| Age of child (Reference: 6–8 months) | 0.001 | | | |
| 9–11 | 0.14 | 3.24 | 0.69 | 15.10 |
| 12–23 | <0.001 | 9.81 | 2.85 | 33.76 |
| 24–59 | 0.005 | 5.87 | 1.73 | 19.94 |
| Constant | 0.000 | 0.031 | | |

**Table 7** Predictors of Mean HAZ (Multiple Linear Regression)

| Model | Standardized Coefficients | t | p value | 95.0% Confidence Interval for β | |
|---|---|---|---|---|---|
| | Beta | | | Lower Bound | Upper Bound |
| (Constant) | | −2.861 | 0.004 | −1.66 | −0.31 |
| Female child | 0.113 | 2.590 | 0.010 | 0.07 | 0.48 |
| Prevalence of wasting | −0.113 | −2.540 | 0.011 | −0.82 | −0.11 |
| Currently breastfeeding? | −0.256 | −4.413 | <0.001 | −0.90 | −0.35 |
| Classification of maternal height | 0.172 | 3.991 | <0.001 | 0.13 | 0.37 |
| Protected drinking water | 0.100 | 2.328 | 0.020 | 0.04 | 0.45 |
| Timely introduction of complementary foods | 0.097 | 2.235 | 0.026 | 0.03 | 0.46 |
| Age groups of children | −0.521 | −9.096 | <0.001 | −0.79 | −0.51 |

**Table 8** Bivariate analysis of predictors of wasting among children

| Characteristic | N | Classification of wasting | | p value |
|---|---|---|---|---|
| | | Normal n (%) | Wasted n (%) | |
| Sex | | | | 0.013 |
| Male | 216 | 187 (86.6) | 29 (13.4) | |
| Female | 209 | 196 (93.8) | 13 (6.2) | |
| Age group of child (months) | | | | 0.001 |
| 6–11 | 72 | 59 (81.9) | 13 (18.1) | |
| 12–23 | 138 | 117 (84.8) | 21 (15.2) | |
| 24–35 | 108 | 102 (94.4) | 6 (5.6) | |
| 36–47 | 70 | 69 (98.6) | 1 (1.4) | |
| 48–59 | 37 | 36 (97.3) | 1 (2.7) | |
| Birth weight | | | | 0.036 |
| < 2.5 Kg | 23 | 18 (78.3) | 5 (21.7) | |
| ≥ 2.5 Kg | 170 | 158 (92.9) | 12 (7.1) | |
| BMI of mother | | | | 0.015 |
| Underweight | 27 | 20 (74.1) | 7 (25.9) | |
| Normal | 306 | 279 (91.2) | 27 (8.8) | |
| Overweight | 92 | 84 (91.3) | 8 (8.7) | |
| Other children under 3 years in household | | | | 0.030 |
| Yes | 341 | 302 (88.6) | 39 (11.4) | |
| No | 84 | 81 (96.4) | 3 (3.6) | |
| Minimum dietary diversity | | | | <0.001 |
| Yes | 271 | 256 (94.5) | 15 (5.5) | |
| No | 154 | 127 (82.5) | 27 (17.5) | |
| Consumption of vitamin A rich fruits and vegetables | | | | 0.012 |
| Yes | 286 | 265 (92.7) | 21 (7.3) | |
| No | 139 | 118 (84.9) | 21 (15.1) | |
| Consumption of flesh foods | | | | <0.001 |
| Yes | 331 | 309 (93.4) | 22 (6.6) | |
| No | 94 | 74 (78.7) | 20 (21.3) | |

A higher proportion of children in the study sample consumed a diversified diet from at least four food groups. Nearly sixty- four percent of the children met the minimum dietary diversity recommendation with an average dietary diversity score of 3.6. A study among children under five years in the Central region of Ghana however reported lower minimum dietary diversity scores [23]. Dietary diversity score was associated with higher mean WHZ and lower HAZ of children. This finding suggests that, increasing the diversity of child diet may have greater and immediate impact on WHZ and subsequently wasting. As dietary diversity is measured by 24 h recall, its negative association with HAZ suggests that there was a recent increase in dietary diversity of children, particularly stunted children which was unlikely to have an immediate effect on HAZ as stunting is a result of long term dietary inadequacy. This finding implies that, increasing dietary diversity of children, particularly those experiencing stunting may not lead to immediate improvements in HAZ. Surprisingly, the consumption of specific food groups including staples and eggs associated positively with WHZ but were negatively associated with HAZ. This further

**Table 9** Multivariate analysis of the determinants of wasting in children

| | p value | AOR | 95% C.I. for AOR | |
|---|---|---|---|---|
| | | | Lower | Upper |
| Sex of child | | | | |
| Female | | | Reference | |
| Male | 0.015 | 2.400 | 1.189 | 4.844 |
| Minimum dietary diversity | | | | |
| Yes | | | Reference | |
| No | <0.001 | 3.733 | 1.889 | 7.376 |
| BMI of mother | 0.032 | | | |
| Normal | | | Reference | |
| Underweight | 0.009 | 3.897 | 1.404 | 10.820 |
| Overweight | 0.811 | 1.109 | .474 | 2.597 |
| Constant | 0.000 | .030 | | |

**Table 10** Bivariate analysis of predictors of underweight among children

| Characteristic | N | Classification of underweight | | p value |
|---|---|---|---|---|
| | | Normal | Underweight | |
| Sex | | | | 0.005 |
| Male | 216 | 163 (75.5) | 53 (24.5) | |
| Female | 209 | 180 (86.1) | 29 (13.9) | |
| Birth weight | | | | 0.008 |
| < 2.5 Kg | 23 | 14 (60.9) | 9 (39.1) | |
| ≥ 2.5 Kg | 170 | 145 (85.3) | 25 (14.7) | |
| BMI of mother | | | | 0.009 |
| Underweight | 27 | 19 (70.4) | 8 (29.6) | |
| Normal | 306 | 240 (78.4) | 66 (21.6) | |
| Overweight | 92 | 84 (91.3) | 8 (8.7) | |
| Toilet | | | | 0.041 |
| Pit latrine/flush | 48 | 44 (91.7) | 4 (8.3) | |
| No facility | 377 | 299 (79.3) | 78 (20.7) | |

imply that, the infant feeding indicators relate better to WHZ than HAZ.

The association between older age and stunting is consistent with data from Ethiopia [24] and Bangladesh [25] which showed increase in stunting levels with increasing child age starting from first year and peaking at three years. Present study results show that, male children were 9.8 times more likely to experience stunting. This may be due to inadequate complementary feeding and repeated infections exposed to children in this age group. As these children gradually become less dependent on breast milk and become increasingly reliant on complementary foods, infections are more likely to occur especially in households where hygiene and sanitary practices are poor. Male children were also more likely to be stunted compared to female children. This relationship has been reported in the literature from developing countries including Ghana [14, 26], Tanzania [27], Ethiopia [24], Cambodia [3] and India [28]. In spite of this widespread identification of the male susceptibility to stunting, the exact factors underlying it have yet to be well understood [14] but likely to be biological [29]. Short maternal stature was associated with higher odds of child stunting in present study. This relationship has been reported by earlier studies. For example, in an analysis of data of 5 birth cohorts, it was established that short mothers were more likely to have a stunted child [30]. Data from other studies from countries of varying economic development have also shown this relationship [31–33]. The relationship may be explained by the intergenerational cycle of malnutrition [34], where stunted children grow to become stunted mothers who give birth to children who also become stunted. Present study results also show that being wasted, higher maternal height, protected drinking water source and introduction of complementary foods at 6 months were associated with positive HAZ, while being a wasted child, continued breastfeeding and increased age of child were associated negatively with HAZ. The results show that the factors that affect HAZ may not necessarily be the same as stunting.

**Table 11** Multivariate analysis of the determinants of underweight in children

| | p value | AOR | 95% C.I. for AOR | |
|---|---|---|---|---|
| | | | Lower | Upper |
| Sex | | | | |
| Female | | | Reference | |
| Male | 0.016 | 2.685 | 1.205 | 5.981 |
| Birth weight | | | | |
| ≥ 2.5 Kg | | | Reference | |
| < 2.5 Kg | 0.007 | 3.778 | 1.440 | 9.911 |
| Constant | 0.000 | .099 | | |

Wasting was associated with sex of child, minimum dietary diversity and maternal body mass index. Male children had higher odds of acute malnutrition. This finding is consistent with earlier studies among preschool children [35, 36]. Children who did not meet the minimum dietary diversity were more likely to experience wasting. Wasting reflect current nutritional inadequacy therefore it is understandable that the consumption of at least four food groups in the previous day was associated with less risk of wasting. The association between maternal body mass index and wasting in children has been reported in Bangladesh [37]. Wasting decreased with increasing body mass index of child. This suggests that in households where there is enough food for mothers to maintain optimal nutritional status, there is equally enough for adequate child nutrition.

Underweight was high in the study sample, however only two factors were associated with it in multivariate analysis. These factors however explained an appreciable amount (10.9%) of the variance in underweight among children in the study sample. Obviously no single study can identify all the factors related to malnutrition considering the different contexts within which children find themselves. Sex and birth weight of child were associated with underweight in children. Male children were as well more likely to experience underweight than their female counterparts. The high likelihood of underweight among male children has been reported earlier [35]. Children born of adequate weight were less likely to be underweight than those who were born with low birth weight. This finding is consistent with an earlier study in Bangladesh [38]. This finding suggests that, nutritional well-being during pregnancy which is translated into adequate birth weight is important and may be protective against subsequent malnutrition.

This study is limited by the cross-sectional nature of the data, therefore causal conclusions were not possible. Our study has however, thrown more light on the maternal and child factors that determine undernutrition in children.

## Conclusion

Maternal height associated negatively with stunting but not wasting. Factors that affect low height –for-age z-score (HAZ) may not necessarily be the same as stunting. Infant and child feeding practices as measured by dietary diversity score associated positively with weight-for-height Z-scores than length-for-age Z-scores of young children in rural Northern Ghana. Surprisingly, consumption of some specific food groups including, animal source foods, legumes, staples and eggs were associated with lower HAZ but with increased likelihood of higher WHZ among children 6–59 months.

## Additional file

**Additional file 1:** Study questionnaire. (DOCX 28 kb)

### Abbreviations

ANC: Antenatal care; ANOVA: Analysis of variance; AOR: Adjusted odds ratio; CI: Confidence interval; HAZ: Height-for-age Z-score; SD: Standard deviation; WAZ: Weight-for-age Z-score; WHO: World Health Organization; WHZ: Weight-for-height Z-score

### Acknowledgements

We thank the Management of the Health Directorate of Central Gonja District for granting the permission to carry out this study in the district and the mothers who sacrificed their time to participate in the study.

### Funding

We did not receive external funding for this research.

### Availability of data and materials

The data supporting the conclusions of this article are included within the manuscript. The dataset is also available from the corresponding author on reasonable request.

### Authors' contributions

ZA, SKK and A-GA were responsible for the overall research plan, participated in its design and data collection from the field. ZA and MS analyzed and interpreted the data. ZA drafted the manuscript and was deeply involved in revising it critically for important intellectual content. MS and A-RA provided technical support for the study design and critically commented on the draft manuscript. All authors read and approved the final manuscript.

### Competing interests

The authors declare that they have no competing interests.

### Consent for publication

Not applicable.

### Ethics approval and consent to participate

Permission to carry out this study was sought from the district health directorate and the study protocol was approved by the School of Allied Health Sciences, University for Development Studies, Ghana. Informed consent was verbally obtained from participant mothers after needed information and procedures were explained. Participation was voluntary and participants signed or thumb printed a statement of an informed consent before being interviewed.

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***Supplementary material for paper 1***

## QUESTIONNAIRE

## INFORMED CONSENT

Good morning / afternoon / evening. I am a nutrition researcher from the University for Development Studies. I am conducting a study on (topic and explanation of measurements). I would like to have an interview with you on the topic and would very much appreciate your participation in this study. You and your child have been selected to be part of the study to respond to a questionnaire which will take about 30 minutes of your time. All of the answers you will give will be confidential and no one can trace them to you. If I should come to any question you don't want to answer, just let me know and I will go on to the next question.
Your participation in the study is purely voluntary and so you are at liberty to opt out. We would however be grateful if you agree to participate since your views are important. May I now ask that you and your (NAME OF CHILD) participate in the interview?
Now please tell me if you agree to take part in the study.

Agreed: (sign or thumb print) ---------------------------------------------------
Declined: (tick) -------------------------------------------------------------------- [ ]

**IDENTIFICATION**

1. Date of interview: _ _/ _ _/ 2016 (dd/mm/yyyy)
2. Name of Region ………………………………………………………
3. District Name ……………………………………………………………..
4. Sub-district Name ……………………………………………………
5. Cluster Name …………………………………………………………
6. Household Name …………………………………………………….
7. Child's Name …………………………………………………………
8. Questionnaire No …………………………………………………….

**SECTION A: SOCIO-DEMOGRAPHIC CHARACTERISTICS OF SAMPLE**
**(Administer to the mother / Caregiver with children 6-59 months)**

1. Age of mother/caregiver …………………………………………………(years)
2. What is your Religion?
1. Christianity
2. Islam
3. ATR
4. Others (specify):

5. Marital Status

1. Single
2. Married
3. Divorced
4. Widow
5. Separated
6. Others (specify) …………………………………

7. Ethnicity of respondent?
1. Gonja
2. Dagomba
3. Sissala
4. Eve
5. Other (specify)…………………………………..

8. Aside from your own housework what do you do to earn income?
1. Trader/vendor
2. Agricultural worker (e.g. farmer)
3. Office worker (Civil Servant)
4. Service worker (e.g. Hair-dresser, seamstress)
5. Education/research (e.g. Teacher)
6. Healthcare (e.g. Nurse)
7. Nothing
8. Others (specify):

9. Mother's highest educational level completed:
1. None
2. Primary
3. Middle/J.H.S
4. S.H.S/Vocational training
5. Tertiary
6. Others (specify)
7. How many children under five years of age live in your household? ………………..

**SECTION B: PAST OBSTETRIC DATA AND MEDICAL HISTORY**

1. Number of pregnancies-----------------------------------------------------------------
2. Number of live deliveries--------------------------------------------------------------

3. At what gestational age (months of pregnancy) did you start the antenatal clinic visits?......................................
4. Have you had any problems with this pregnancy? [1] Yes [2] No
5. If yes what was/were the problem(s)
[1] Bleeding [2] dizziness [3] abdominal pains [4] waist pains
[5] Headache [6] swollen feet [7] others (specify) ………………………..
6 Record from the mother's antenatal card the number of times she visited a health care center for prenatal care services during pregnancy with [child's name]……………………

7. Where did you deliver (Name of child)?
1. At home
2. CHPS Compound
3. Clinic

4. Maternity home
5. Health centre
6. Hospital
7. Traditional Birth Attendant

## SECTION C: HEALTH STATUS ASSESSMENT

1. Blood pressure at recruitment (first trimester)……………………….
2. Blood pressure at 36 weeks gestation………………………………..
3. Number of Malarial infections during last pregnancy…………………….
4. Had candidiasis during pregnancy? ....................................................

5. Complete the table below for maternal Hb during the pregnancy with (Child's Name) using mother's ANC book

| **Stage of pregnancy** | **Haemoglobin level in g/dl** |
|---|---|
| First trimester | |
| Second trimester | |
| Third trimester | |

## SECTION D: DIETARY INTAKE OF CHILD

1. Yesterday did [child's name] eat any solid or semi-solid foods?
1. Yes
2. No

2. How many times did (Name of child) eat solid or semi-solid food or soft foods other than liquids yesterday during the day or at night? ……………………………

3a Please, mention all the foods and drinks that were eaten by (Name of child) over the past 24 hours whether at home or outside the home. (Hint: start with meal eaten at supper yesterday).

| Eating moment | Name of dish | Ingredients |
|---|---|---|
| Breakfast | | |
| Snack before lunch | | |
| Lunch | | |
| Snack before dinner | | |
| Dinner | | |
| Snack after dinner | | |
| Drinks | | |

3. b. From the meals mentioned by the mother, indicate whether (Name of child), ate from the following food groups during the past 24hours whether at home or outside the home. (YES=1, NO=0)

| Food group | Examples | YES | NO |
|---|---|---|---|
| Grain, roots, and tubers | Cereals, White tubers and roots | | |
| Dairy products | Milk and milk products | | |
| Flesh foods | Organ meat, Flesh meats and Fish | | |
| Eggs | Eggs | | |
| Legumes | Legumes, nuts, and seeds | | |
| Vitamin A- rich fruits and vegetables | Dark green leafy vegetables,Fresh vitamin A-rich fruits, Vitamin A-rich vegetables and tuber and Oils and fats | | |
| Other fruits and vegetables | Dried fruits and vegetables | | |

**SECTION E: INFANT AND YOUNG CHILD FEEDING (IYCF) PRACTICES**

1. After delivery of (Name of child), how long did it take you to breastfeed him/her for the first time?

1. Within first hour of delivery
2. 2 to 23 hours after delivery
3. The next day (More than 24 hours)
4. Do not remember

2. Before putting (Name of child) to the breast for the first time after delivery, what was child given to drink? (Multiple responses possible)

1. Nothing
2. Milk (other than breast milk)
3. Plain water
4. Sugar or glucose water
5. Gripe water
6. Sugar-salt-water solution
7. Fruit juice
8. Infant formula
9. Tea / coffee
10. Honey
11. Other (specify) _____________

3. When you delivered (Name of child) what did you do with the first yellowish breast milk?

(1) Gave it to the baby (2) Discarded it (3) Other (Specify) _____________

4. Is (child's name) currently breastfeeding?

(1) Yes (2) No

5. Yesterday did [child's name] have anything to drink from a bottle with a nipple during the day or night? (1) Yes (2) No

6. Is child currently eating other foods apart from breast milk? (1) Yes (2) No

7. At what age did you first give solid or semisolid food to [child's name]?

1. Before 6 months
2. At Six months

3. Seven to 9 months
4. After nine months
5. Yet to start
6. Don't know

**SECTION F: CHILD MORBIDITY AND UTILIZATION OF HEALTH SERVICES**

1. Has (Name of child) had an illness with a cough that comes from the chest at any time in the last two weeks? (1).Yes (2). No (3). Don't know

2. Did (Name of child) get diarrhoea in the past two weeks? (Diarrhoea is having loose watery stools more than 3 times). (1). Yes (2). No (3). Don't know

3. Has (Name of child) had Fever/Malaria: High temperature with shivering/ suspected malaria in the last two weeks? (1) Yes (2) No (3) Don't know

**SECTION G: WATER, SANITATION AND HYGIENE**

1. What is the main source of drinking water for members of your household? (Only one response)
1. Piped water
2. Borehole
3. Protected well
4. Unprotected well
5. Surface water ( river, stream, dam, lake, pond, canal, irrigation channel)
6. Rain water
7. Other (Specify) ………………………………………………………………..
8. Are you satisfied with the drinking water supply in this community? (IF ANSWER IS 2,3 OR 4 GO TO question 4)
1. Yes
2. No
3. Partially
4. Don't know
5. What is the main reason you are not satisfied with the water supply?
1. Not enough
2. Long waiting queue
3. Long distance
4. Irregular supply
5. Bad taste
6. Water too warm
7. Bad quality
8. Have to pay
9. Other (specify)
10. Don't know

11. What kind of toilet facility does this household use?
1. Flushed type
2. Simple pit latrine with floor/slab
3. Pit latrine without floor/slab
4. No facility, field, bush, plastic bag

5. Do you have children under three years old? ( IF ANSWER IS 2 GO TO question 7)
1. Yes
2. No

3. The last time (Name of Youngest Child) passed stools, what was done to dispose of the stools?
1. Child used toilet/latrine
2. Put/rinsed into toilet or latrine
3. Buried
4. Thrown into garbage
5. Put/rinsed into drain or ditch
6. Left in the open
7. Other
8. Don't know

9. At what moments did you wash your hands in the last 24 hours? (Multiple answers possible) (Probe; "Any other times?")
1. Before preparation of food
2. After going to toilet
3. Before eating food
4. After eating food
5. Before feeding a child
6. Other (Specify) ………………………………………..

**SECTION H: SOCIO-ECONOMIC STATUS ASSESSMENT**

1. What type of house do members of the household dwell in?
1. Block house (2) Brick house (3) Mud house (4) Others (specify) ………
2. What kind of toilet facility do members of the household usually use?
1. Own flush toilet
2. Public or shared flush toilet
3. Own pit toilet
4. Public or shared pit toilet
5. No facility (bush)
6. What is the main source of lighting for the household?
1. Electricity (2) Solar (3) Kerosene (4) Others (specify) ……..……

2. What type of fuel does your household mainly use for cooking?
1. Electricity
2. LPG
3. Charcoal
4. Kerosene
5. Firewood
6. Others (specify) ……………………………………

7. Does your household have any of these assets? (Tick Yes(1) or No(0))

| ITEM | YES | NO |
|---|---|---|
| Radio | | |
| Color/black TV | | |
| Satellite dish | | |
| Sewing Machine | | |
| Mattress | | |
| Refrigerator | | |
| DVD/VCD | | |
| Computer | | |
| Electric Fan | | |

| | | |
|---|---|---|
| Mobile Telephone | | |
| Bicycle | | |
| Motorcycle/Tricycle | | |
| Animal-drawn cart | | |
| Car/Truck | | |

**SECTION I: ANTHROPOMETRY MEASUREMENT (MOTHER)**

Height: ……………………………..cm

Weight: ……………………………..kg

BMI...................................................kg/m$^2$

Gestational age at delivery…………………………………… (Completed weeks)

**SECTION J: INFANT ANTHROPOMETRY**

Sex of child: (1). Male (2). Female

Date of birth: ___/___/____ (dd/mm/yyyy)

Date of birth verified from:

1. Birth certificate
2. Health records booklet
3. Community register
4. Other document (specify)…………………..
5. Could not verify

Age of child (months):____________

Baby's birth weight (record from child health records booklet)…………………… (kg)

Weight of child: __ __.__ (kg)

Height of child: __ __ __ .__ (cm)

Presence of bilateral pitting oedema? (1) Yes (2). No

**THANK YOU, END OF INTERVIEW**

**Paper 2:** Dietary patterns and associated factors of schooling Ghanaian adolescents

# RESEARCH PAPER COVER SHEET

**Please note that a cover sheet must be completed <u>for each</u> research paper included within a thesis.**

## SECTION A – Student Details

| | | | |
|---|---|---|---|
| **Student ID Number** | 1800648 | **Title** | Mr |
| **First Name(s)** | Zakari | | |
| **Surname/Family Name** | Ali | | |
| **Thesis Title** | Resilient and healthy food systems in low-income settings | | |
| **Primary Supervisor** | Prof. Andrew Prentice | | |

**If the Research Paper has previously been published please complete Section B, if not please move to Section C.**

## <u>SECTION B – Paper already published</u>

| | | | |
|---|---|---|---|
| Where was the work published? | Journal of Health, Population and Nutrition | | |
| When was the work published? | 6th February 2019 | | |
| If the work was published prior to registration for your research degree, give a brief rationale for its inclusion | This paper is thematically linked to the aims of my PhD. | | |
| Have you retained the copyright for the work?* | **Yes** | Was the work subject to academic peer review? | **Yes** |

*If yes, please attach evidence of retention. If no, or if the work is being included in its published format, please attach evidence of permission from the copyright holder (publisher or other author) to include this work.

SPRINGER NATURE

**Dietary patterns and associated factors of schooling Ghanaian adolescents**

**Author:** Abdul-Razak Abizari et al

**Publication:** Journal of Health, Population and Nutrition

**Publisher:** Springer Nature

**Date:** Feb 6, 2019

**SECTION D – Multi-authored work**

| | |
|---|---|
| For multi-authored work, give full details of your role in the research included in the paper and in the preparation of the paper. (Attach a further sheet if necessary) | This research paper resulted from a secondary analysis of baseline data which I led on. I participated in study design, questionnaire development and pre-testing. I supervised the data collection in schools and coordinated data entry and cleaning. I co-designed the study together with Dr Abdul-Razak Abizari. I was responsible for running the Principal Component Analysis (PCA) and the regression models using outputs from the PCA in SPSS with guidance from Dr Abdul-Razak Abizari who had prior experience doing similar analysis. I wrote the first draft of the manuscript with inputs from Dr Abdul-Razak Abizari. I contributed to revising the manuscript to respond to reviewer comments. |

**SECTION E**

| | |
|---|---|
| **Student Signature** | [redacted] |
| **Date** | 2nd August 2022 |

| | |
|---|---|
| **Supervisor Signature** | [redacted] |
| **Date** | 12th October 2022 |

Abizari and Ali *Journal of Health, Population and Nutrition* (2019) 38:5
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Journal of Health, Population and Nutrition

RESEARCH ARTICLE Open Access

# Dietary patterns and associated factors of schooling Ghanaian adolescents

Abdul-Razak Abizari* and Zakari Ali

## Abstract

**Background:** Assessment of single nutrients or foods does not normally reflect the diet of population groups. Dietary pattern analyses are useful in understanding the overall diet and its relationship with disease conditions. The objective of the present study was to determine the dietary patterns and associated factors among schooling adolescents in Northern Ghana.

**Methods:** A cross-sectional study involving 366 pupils in 10 junior high schools in the Tamale metropolis was conducted. A Food Frequency Questionnaire (FFQ) which consisted of 60 commonly consumed foods was used to assess pupils' 7-day intake. Foods grouped (14) from FFQ data based on shared nutritional value were used to identify dietary patterns using principal component analysis (PCA). Bivariate and multivariate logistic regression analyses were used to determine the association between identified patterns and sociodemographic, anthropometric status, and household characteristics of pupils.

**Results:** Half of the pupils were female (50.3%) and average age was 15.6 ± 2.0 years. PCA identified two dietary patterns which in total explained 49.7% of the variability of the diet of pupils. The patterns were sweet tooth pattern (STP) with high factor loadings for sugar sweetened snacks, energy and soft drinks, sweets, tea and coffee, and milk and milk products, and a traditional pattern (TP) which showed high factor loadings for cereals and grains, local beverages, nuts, seeds and legumes, vegetables, and fish and seafood. Logistic regression showed that pupils who lived with their parents [AOR = 1.95; 95% CI (1.1–3.4); $p = 0.019$], those who went to school with pocket money [AOR = 4.73; 95% CI (1.5–15.0); $p = 0.008$], and those who lived in the wealthiest homes [AOR = 3.4; 95% CI (1.6–7.5); $p = 0.002$)] had higher odds of following the STP. The TP was associated with high dietary diversity ($p = 0.035$) and household wealth [AOR = 3.518; 95% CI (1.763–7.017); $p < 0.001$)]. None of the patterns was associated with anthropometric status of pupils.

**Conclusion:** Adolescents in the present study followed a sweet tooth or a traditional diet pattern which associated more with household- and individual-level factors but not anthropometric status.

**Keywords:** Adolescents, Dietary pattern, School children, Anthropometric status, Ghana

## Background

Increasing urbanization, changing diets, and decreasing physical activity levels are core indicators of the nutrition transition experienced by nations worldwide [1]. The nutrition transition is increasingly driving the world's population towards an obese one, which is burdened with chronic diseases [1]. Despite an existing communicable disease burden and malnutrition in low- and middle-income countries [2], the developing world is not spared of non-communicable diseases [3] previously thought of as a problem of the developed world. The nutrition transition is thought to be a major driver of the rise in non-communicable diseases in developing countries [3, 4].

Ghana is among a few sub-Saharan African countries at a later stage of the nutrition transition where diet changes are already affecting the health of majority of the population [5]. Changing dietary intake and habits among the Ghanaian population was noticed earlier in the 1990s and described [6]. These changing patterns relate more to giving away traditional foods (which are

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mostly plant based and less processed) towards convenient foods (including fast and processed foods).

There is evidence of coexisting burden of underweight and overweight and obesity in schooling adolescents in resource poor settings including Ghana [7]. While there has been 18.3 percentage points decrease in underweight among schooling adolescents in Ghana between 2007 and 2015, there has been an increase in overweight and obesity from 8.7% in 2007 to 13% in 2015 [7, 8]. Associations between sociodemographic, household factors [9, 10] and anthropometric status [11], and dietary patterns of adolescents have been reported in different settings.

Dietary intake of adolescents in developing countries including Ghana [12] is a concern as traditional diets (predominantly cereal and tuber based, fresh fruits and vegetables, and foods low in fat) are gradually giving way to more Westernized diets which lack diversity and are high in calorie-rich processed foods [13]. As adolescents spend most time in school coupled with the autonomy to make food choices on their own while in school, the school environment is an important factor in shaping dietary patterns. It may present an opportunity to encourage physical activity and steer dietary intake of adolescents towards healthier options [14] or lead to poor dietary habits [15]. Identifying patterns of dietary intake therefore, could be a reliable way to understand the dietary behavior of adolescents and inform interventions for improved dietary intake.

However, most studies in the past have assessed only single nutrients or single food intake which do not normally reflect the overall diet of population groups. Available data on food intake of adolescents and school children in Ghana have also focused on individual food items and nutrients [12, 16]. Dietary pattern analysis has emerged as a useful epidemiological approach to assessing the overall diet and its relation with disease conditions [17]. Adolescent dietary patterns have been useful in understanding long-term adiposity [18] and occurrence of chronic diseases [19, 20]. Dietary patterns also have an added advantage of being easily understood and used by the general population. The objective of the present study was to determine the dietary patterns and associated factors among schooling adolescents in Northern Ghana.

## Methods

### Study design and area

The present study uses baseline data from the Ramadan cohort study conducted in junior high schools (JHSs) in May 2017 in Ghana. The baseline data was collected through a cross-sectional survey among schooling adolescents before Ramadan fasting. Details of the Ramadan cohort study have been described and published elsewhere [21]. There are 15 educational circuits in the metropolis with a total of 72 JHSs. The metropolis has a youthful population where about 36.4% are aged younger than 15 years. For the school going age (older than 3 years), enrolment in primary schools is about 60,000. The JHS also enroll 26,936 of these pupils [22].

### Study population and sampling

Adolescents (aged 10–19 years inclusive) in junior high school (JHS) were the target population for this survey. We used simple random sampling technique to select half (7) of the educational circuits in the Metropolis. Junior high schools in the selected circuits were pooled together from which 10 were randomly selected for the present study. Three hundred and sixty-six pupils were selected from the 10 schools using probability proportional to size methodology. The required sample from each school was selected from a list of eligible participants by simple random sampling technique using excel-generated random numbers. Participation was voluntary, no monetary incentives were given, and selected pupils also gave signed informed consent before data collection.

### Data collection

Data was collected using pre-tested semi-structured questionnaire. The questionnaire elicited responses on socio-demographic characteristics of pupils such as sex, age, ethnicity, class, means to school, pocket money to school (pupils who usually go to school with pocket money for at least 3 out of 5 school days), and living with parents (defined as pupils who live with their biological parent(s)). The questionnaire also elicited responses on household characteristics such as parental educational level and occupation. Educational level of parents was assessed as the highest level of education parents completed, and parental occupation was assessed as the primary occupation of parents. We also assessed household possession of some durable household items. Data collection staff were first-degree nutritionists and received training on questionnaire administration, dietary assessment, and anthropometric measurements before data collection. Each school also had a field supervisor who provided onsite checks on questionnaire, and incomplete questionnaire and measurement errors were corrected the same day.

### Dietary assessment

We assessed dietary diversity using a qualitative 24-h recall. We used the Food and Agricultural Organization's (FAO) food groups for dietary diversity and their standard procedure for assessing individual dietary diversity [23]. Foods consumed both at home and school during the previous day were recalled by pupils. Based on 14 food groups, we calculated the dietary diversity score

(DDS) for each pupil which was a count of food groups pupils consumed during the previous day preceding the survey. Pupils had a score of 0 if none of the food groups was consumed and 14 if all food groups were consumed. The 14 food groups used in the DDS calculation were cereals; white roots and tubers; vitamin A rich vegetables and tubers; dark green leafy vegetables; other vegetables; vitamin A-rich fruits; other fruits; organ meat; flesh meats, eggs; fish and seafood; legumes, nuts and seeds; milk and milk products; and oils and fats (Additional file 1).

We also used a 7-day Food Frequency Questionnaire (FFQ) consisting of 60 food items commonly consumed in Ghana (see Additional file 2). The foods in this questionnaire were similar to those used previously in the northern region [24]. Pupils recalled how often they have had, on average, a particular food item in the week preceding the assessment. Consumption scores ranged from 0 (when they had never or hardly ever taken a particular food for the past week) to 7 (if they had a particular food for more than 6 days in the past 1 week). The foods were regrouped into 14 sub-groups for use in principal component analysis (PCA) by adding scores of foods belonging to similar food groups (foods with shared nutritional value). The 14 food groups include cereals and grains; tubers and plantain; local beverages with added sugar; tea and coffee; sugared snacks; sweets; meats, poultry and eggs; fish and seafood; milk and milk products; nuts, seeds and legumes; fruits and fruit juices; vegetables; energy and soft drinks; fats, oils and fat-based foods.

### Anthropometric status assessment

Weight and height measurements were taken following World Health Organization (WHO) standard procedure [25]. Weight was measured using an electronic weighing scale (seca 874) to the nearest 0.1 kg. Height was measured with seca stadiometer to the nearest 0.1 cm. Data collection staff received training before the assessment. Age, sex, height, and weight data were used in WHO AnthroPlus software to generate *Z*-scores on BMI-for-age and sex (BMIA). The *Z*-scores were categorized into normal (BMIA $\leq$1SD), overweight (BMIA >1SD), and obese (BMIA > 2SD) [26].

### Data analysis

Data analysis was performed using SPSS for Windows version 20 (IBM Inc.). Categorical variables have been presented as frequencies and percentages while means and standard deviations are used for continuous variables. The reliability of items in the questionnaire for PCA was checked using Cronbach's alpha test statistic. Data collected using FFQ was used in PCA to assess dietary patterns of pupils. The 14 food groups were used to find foods that correlate highly to describe particular dietary patterns in PCA. Orthogonal rotation method using Varimax was used to maximize loadings of variables on extracted factors while minimizing loading on other factors; ensuring easy interpretation of the results. We used Kaiser's stopping rule which considers factors with eigenvalues greater than 1.0 to be retained [27]. We also examined scree plots to confirm adequacy of number of factors retained in the analysis. Food groups that had factor loadings ≥ 0.4 were considered as making significant contribution [28] to a particular pattern. Sample adequacy of data suitable for PCA was assessed by Kaiser-Meyer-Olken (KMO) measure test which showed acceptable cut-off (> 0.9). Bartlett's test of sphericity (BTS) performed on the data set did not show evidence of identity of correlation matrix; therefore, the data set was considered appropriate for PCA. Dietary patterns derived from PCA were labeled appropriately based on food items that correlated highly to account for variation in the diet. Factor scores of the identified patterns were used for further analysis. Calculation of pattern-specific factor scores were obtained as the sum of factor loading coefficients and the standardized consumption of the foods related to the dietary pattern. Factor scores were divided into four quartiles on the basis of their contribution to each pattern and assuming an increase from Q1 to Q4 [18, 29]. Q1 and Q2 were combined to represent low followers while Q3 and Q4 were combined to represent high followers of identified patterns. Household wealth status was assessed from possession of 14 durable items including radio, color/black TV, satellite dish, sewing machine, mattress, refrigerator, DVD/VCD, computer, electric fan, mobile telephone, bicycle, motorcycle/tricycle, animal-drawn cart, and car/truck. Based on these, the wealth index was determined using PCA and categorized into quintiles (poorest, poor, medium, wealthy, and wealthiest) [30, 31]. Factors associated with the identified patterns were determined using chi-square test at the bivariate level. Factors with $p \leq 2.0$ at the bivariate analysis were included in a multivariable logistic regression model. Statistical significance was set at $p < 0.05$ for all analyses.

## Results

### Background characteristics of participating pupils

Half of the pupils were female (50.3%), were aged at least 15 years (52.2%), and were in JHS 1 (51.4%). More than 8 in 10 of adolescents in this sample had normal anthropometric status (88%), while only 6% were either overweight or obese. The pupils belonged to the Dagomba ethnic group (87.2%), lived with their parents (78.4%) in extended family homes (58.5%), and went to school with pocket money (92.6%). More than half (53.3%) of the fathers had no formal education and engaged in farming activities (32.8%). Most mothers (70%) had no formal education

**Table 1** Background characteristics of participating pupils ($n = 366$)

| Characteristic | Frequency | Percentage |
|---|---|---|
| Sex | | |
| Male | 182 | 49.7 |
| Female | 184 | 50.3 |
| Age (years) | | |
| ≤ 15 | 175 | 47.8 |
| > 15 | 191 | 52.2 |
| Class of pupil | | |
| JHS 1 | 188 | 51.4 |
| JHS 2 | 178 | 48.6 |
| Anthropometric status (BMI-for-age) | | |
| Underweight | 23 | 6.3 |
| Normal | 321 | 87.7 |
| Overweight/obese | 22 | 6.0 |
| Ethnicity | | |
| Dagomba | 319 | 87.2 |
| Gonja | 26 | 7.1 |
| Others | 21 | 5.7 |
| Live with parents? | | |
| Yes | 287 | 78.4 |
| Family type | | |
| Nuclear | 152 | 41.5 |
| Extended | 214 | 58.5 |
| Go to school with pocket money | | |
| Yes | 339 | 92.6 |
| Father's education | | |
| None | 195 | 53.3 |
| Primary/junior high school | 98 | 26.8 |
| Senior high school/tertiary | 73 | 19.9 |
| Father's occupation | | |
| Farmer | 120 | 32.8 |
| Trader | 74 | 20.2 |
| Civil servant | 33 | 9.0 |
| Others | 139 | 38.0 |
| Mother's education | | |
| None | 256 | 69.9 |
| Primary/junior high school | 83 | 22.7 |
| Senior high school/tertiary | 27 | 7.4 |
| Mother's occupation | | |
| Farmer | 35 | 9.6 |
| Trader | 261 | 71.3 |
| Civil servant | 6 | 1.6 |
| Others | 64 | 17.5 |
| Household wealth quintile | | |
| Poorest | 74 | 20.2 |
| Poor | 76 | 20.8 |
| Medium | 70 | 19.1 |
| Wealthy | 73 | 19.9 |
| Wealthiest | 73 | 19.9 |

and were mostly traders (71.3%). Most of the pupils (59%) were from households of at least a medium wealth classification (Table 1).

### Dietary patterns of participating pupils

KMO (0.917) and BTS (approx chi (1836.92) $p < 0.001$) showed that the data was adequate for PCA. The items also showed high reliability (Cronbach's alpha = 0.869). The items had communality values well above 0.3 indicative of the appropriateness of the number of components retained. Two dietary patterns were identified which together explained 49.7% of dietary intake of pupils. The components were labeled *sweet tooth pattern* (STP) and *traditional pattern* (TP). The STP, which explained most (32.5%) of variance, was characterized by intake of sugar sweetened snacks, energy and soft drinks, sweets (chewing gums and toffees), tea and coffee, milk and milk products, and fats and high fat-based foods. The TP which explained the rest of the variance (17.2%) was characterized by consumption of cereals and grains, local beverages, nuts, seeds and legumes, vegetables, and fish and seafood (Table 2).

### Determinants of dietary patterns of participating pupils

The bivariate chi-square results show that, sex of pupil is not associated with either of the dietary patterns ($p > 0.05$). Even though older pupils were more likely to have high scores of the diet patterns, the difference was not significant. Pupils who lived with their parents were more likely to have high STP (53.3% vs 38.0%, $p = 0.016$). Living with parents was not associated with the TP ($p = 0.899$). Pupils who went to school with pocket money were more likely to practice the STP ($p < 0.001$) but not the TP ($p = 0.842$). Dietary diversity was significantly associated with the TP ($p = 0.035$) but not the STP ($p = 0.074$). For example, most (52.0%) pupils who consumed from at least four food groups had high scores on the STP compared with those who did not (35.0%). Anthropometric status of pupils was not significantly associated with the two diet patterns ($p > 0.05$). However, some other marked differences were obvious. Father's educational level ($p = 0.033$) and employment type ($p = 0.006$) were associated with STP but not the TP ($p > 0.05$). Pupils whose

**Table 2** Dietary patterns of participating pupils

| Food items | Dietary patterns with factor loadings | | Communalities |
|---|---|---|---|
| | Sweet tooth | Traditional | |
| Milk and milk products | *.801* | .087 | .648 |
| Fruits and fruit juice | *.756* | .251 | .635 |
| Meat, poultry, and eggs | *.749* | .153 | .584 |
| Energy and soft drinks | *.684* | .206 | .510 |
| Tubers and plantain | *.636* | .243 | .464 |
| Sugared snacks | *.626* | .293 | .478 |
| Sweets | *.605* | .307 | .460 |
| Fats, oils, and fat-based foods | *.587* | .377 | .486 |
| Tea and coffee | *.574* | .056 | .332 |
| Fish and seafood | − .077 | *.747* | .564 |
| Nuts, seeds, and legumes | .287 | *.740* | .630 |
| Local sugared beverages | *.420* | *.540* | .467 |
| Vegetables | .203 | *.524* | .316 |
| Cereals and grains | *.411* | *.457* | .378 |
| *% of variance explained* | 32.516 | 17.156 | |
| *% of accumulated variance explained* | 49.672 | | |

Extraction method, principal component analysis. Rotation method, varimax with Kaiser normalization. Italic factor loadings are items contributing significantly to each PCA component

fathers had higher education of at least senior high school and worked in civil service had higher scores on the STP. Mothers' educational level and employment type were not significantly associated with both dietary patterns. Household wealth status was associated with the STP ($p < 0.001$) as well as the TP ($p = 0.003$). There was an observed increasing scores with increasing household wealth for both dietary patterns where pupils from the wealthiest households scored higher (Table 3).

Multivariable logistic regression analyses showed that living with parents, going to school with pocket money, and household wealth status was associated with STP. Pupils who lived with their parents had higher odds (2.0) of having a high STP [AOR = 1.95; 95% CI (1.1–3.4); $p = 0.019$]. Those who went to school with pocket money were 4.7 times more likely to have high STP [AOR = 4.7; 95% CI (1.5–15.0); $p = 0.008$]. Compared to pupils who lived in the poorest homes, those who lived in the wealthiest homes were almost 3.4 times more likely to have an STP [AOR = 3.4; 95% CI (1.6–7.5); $p = 0.002$)].

Only household wealth status was associated with the TP in regression analysis. The results show that pupils from the wealthiest homes were 3.5 times more likely to follow TP compared with those from the poorest homes [AOR = 3.5; 95% CI (1.8–7.0); $p < 0.001$) (Table 4).

## Discussion

The present study assessed dietary patterns of adolescents in junior high schools in predominantly urban areas of the Tamale metropolis and factors associated with the patterns. Two distinct dietary patterns were identified among the pupils; sweet tooth pattern (STP) and traditional pattern (TP). The STP was characterized by intake of sugar sweetened snacks, energy and soft drinks, sweets (chewing gums and toffees), tea and coffee, milk and milk products, and fats and high fat-based foods. The TP was characterized by consumption of cereals and grains, local beverages, nuts, seeds and legumes, vegetables, and fish and seafood. STP was associated more with household socio-economic factors including household wealth, pupil having pocket money to school, and living with parents. The TP was also associated with household wealth and dietary diversity.

The dietary patterns identified in this study are similar to those identified among school-age children in a metropolitan area of Southern Ghana by Alangea et al. [32]. Alangea et al. identified four dietary patterns, the first of which had food characteristic of the STP in this study. However, the traditional pattern as identified in this study could be traced to three separate dietary patterns: starchy root staple and vegetables, cereal-grain staples and poultry, and fish and sea foods.

Dietary patterns in the present study were not associated with overweight or obesity among adolescents. Even though overweight or obese adolescents scored relatively higher on the STP while those with lower BMI scored relatively higher on the TP, these were not significant. The sweet tooth pattern which had foods typically of a modern, an affluent, or a westernized nature have been identified in previous studies among children and adolescents including in China [18], Australia [33], The Netherlands [34], UK [35], Germany [36], and in Ghana [32]. Foods in this pattern are largely energy-dense and have previously been linked with overweight or obesity in children and adolescents elsewhere [18, 32, 37]. However, this has not been the same in all studies that assessed dietary patterns of adolescents. A lack of association between an energy-dense pattern and dietary patterns in general and overweight or obesity among adolescents has been reported in the literature. For example, Shi et al. [33] identified a "processed food" pattern characterized by consumption of processed meats, snacks, and sugary foods among Australian children which was not associated with obesity. Cutler et al. [11] could not find intuitive associations between dietary patterns of US adolescents and weight status. An "unhealthy pattern" characterized by snack and puddings intake identified by Craig et al. [35] was not also associated with overweight or obesity

**Table 3** Bivariate analysis of the predictors of dietary patterns of participating pupils

| Predictor | Dietary pattern | | | | | |
|---|---|---|---|---|---|---|
| | Sweet tooth | | | Traditional | | |
| | Low (183) *n* (%) | High (183) *n* (%) | *p* value | Low (183) *n* (%) | High (183) *n* (%) | *p* value |
| Sex | | | 0.210 | | | 0.676 |
| Male | 85 (46.7) | 97 (53.3) | | 89 (48.9) | 93 (51.1) | |
| Female | 98 (53.3) | 86 (46.7) | | 94 (51.1) | 90 (48.9) | |
| Age (years) | | | 0.917 | | | 0.464 |
| ≤ 15 | 88 (50.3) | 87 (49.7) | | 91 (52.0) | 84 (48.0) | |
| > 15 | 95 (49.7) | 96 (50.3) | | 92 (48.2) | 99 (51.8) | |
| Live with parents | | | *0.016* | | | 0.899 |
| Yes | 134 (46.7) | 153 (53.3) | | 144 (50.2) | 143 (49.8) | |
| No | 49 (62.0) | 30 (38.0) | | 39 (49.4) | 40 (50.6) | |
| Pocket money to school | | | *< 0.001* | | | 0.842 |
| Yes | 160 (47.2) | 179 (52.8) | | 170 (50.1) | 169 (49.9) | |
| No | 23 (85.2) | 4 (14.8) | | 13 (48.1) | 14 (51.9) | |
| Dietary diversity (food groups) | | | 0.074 | | | *0.035* |
| < 5 | 27 (62.8) | 16 (37.2) | | 28 (65.1) | 15 (34.9) | |
| ≥ 5 | 156 (48.3) | 167 (51.7) | | 155 (48.0) | 168 (52.0) | |
| Nutritional status | | | 0.320 | | | 0.358 |
| Underweight | 10 (43.5) | 13 (56.5) | | 10 (43.5) | 13 (56.5) | |
| Normal | 165 (51.4) | 156 (48.6) | | 159 (49.5) | 162 (50.5) | |
| Overweight/obese | 8 (36.4) | 14 (63.6) | | 14 (63.6) | 8 (36.4) | |
| Father's educational level | | | *0.033* | | | 0.858 |
| None | 107 (54.9) | 88 (45.1) | | 95 (48.7) | 100 (51.3) | |
| Primary/junior high school | 49 (50.0) | 49 (50.0) | | 51 (52.0) | 47 (48.0) | |
| Senior high/tertiary | 27 (37.0) | 46 (63.0) | | 37 (50.7) | 36 (49.3) | |
| Father's occupation | | | *0.006* | | | 0.392 |
| Agriculture/farming | 66 (55.0) | 54 (45.0) | | 64 (53.3) | 56 (46.7) | |
| Trader | 39 (52.7) | 35 (47.3) | | 32 (43.2) | 42 (56.8) | |
| Civil servant | 7 (21.2) | 26 (78.8) | | 14 (42.4) | 19 (57.6) | |
| Others | 71 (51.1) | 68 (48.9) | | 73 (52.5) | 66 (47.5) | |
| Mother's educational level | | | 0.392 | | | 0.592 |
| None | 134 (52.3) | 122 (47.7) | | 127 (49.6) | 129 (50.4) | |
| Primary/junior high school | 37 (44.6) | 46 (55.4) | | 40 (59.3) | 43 (51.8) | |
| Senior high/tertiary | 12 (44.4) | 15 (55.6) | | 16 (59.3) | 11 (40.7) | |
| Mother's occupation | | | 0.170 | | | 0.859 |
| Agriculture/farming | 23 (65.7) | 12 (34.3) | | 17 (48.6) | 18 (51.4) | |
| Trader | 124 (47.5) | 137 (52.5) | | 131 (50.2) | 130 (49.8) | |
| Civil servant | 2 (33.3) | 4 (66.7) | | 2 (33.3) | 4 (66.7) | |
| Others | 34 (53.1) | 30 (46.9) | | 33 (51.6) | 31 (48.4) | |

**Table 3** Bivariate analysis of the predictors of dietary patterns of participating pupils *(Continued)*

| Predictor | Dietary pattern | | | | | |
|---|---|---|---|---|---|---|
| | Sweet tooth | | | Traditional | | |
| | Low (183) *n* (%) | High (183) *n* (%) | *p* value | Low (183) *n* (%) | High (183) *n* (%) | *p* value |
| Wealth quintile | | | *< 0.001* | | | *0.003* |
| Poorest | 48 (64.9) | 26 (35.1) | | 47 (63.5) | 27 (36.5) | |
| Poor | 48 (63.2) | 28 (36.8) | | 38 (50.0) | 38 (50.0) | |
| Medium | 35 (50.0) | 35 (50.0) | | 38 (54.3) | 32 (45.7) | |
| Wealthy | 32 (43.8) | 41 (56.2) | | 37 (50.7) | 36 (49.3) | |
| Wealthiest | 20 (27.4) | 53 (72.6) | | 23 (31.5) | 50 (68.5) | |

Predictors with *p* values in italics are statistically significant

among Scottish school-age children. Further, no significant associations were found between adolescent dietary patterns and overweight in German adolescents [36]. The lack of association is contrary to our expectation that adolescents who follow the STP would more likely be overweight or obese as they may be taking more energy. The reasons for the lack of association between a diet pattern high in energy and sweets and overweight or obesity among adolescents are unclear. However, few explanations are plausible. In this physiological group, diet might not be the only important determinant of over-nutrition; effects of physical activity may equally be important [38]. In addition, important confounding may exist when overweight adolescents may have consciously attempted to lose weight [39]. In our setting and as with other studies using FFQ, social desirability bias in dietary assessments may be unavoidable [40, 41], resulting in over-reporting of some foods, especially with foods characteristic of the STP which are more likely to be seen as affluent foods among Ghanaians. On the other hand, under-reporting of fatty foods and foods high in energy may be high among the obese [42]. However, the former is more likely among our participants and may have led to misclassification of some adolescents into the dietary patterns. Further, as portion sizes were not estimated in the present study, similar intake frequencies may not necessarily mean similar exposure levels as portions may differ between individuals. Moreover, dietary patterns identified with PCA are rarely entirely made of foods that promote or are harmful to health. The effects of a particular pattern on health will principally depend on the individual foods that make up the pattern and may explain the inconsistencies with studies. The low prevalence of overweight or obesity in this study could also lead to low statistical power to detect a significant association.

The association between the dietary patterns and socio-economic factors are consistent with earlier findings. In our sample, higher socio-economic status was associated with STP similar to a recent review of the literature which concluded that high socio-economic status was associated with unhealthy eating patterns in developing country setting but with healthy eating patterns among adolescents in developed countries [43]. Our findings therefore, do not agree with McNaughton et al. [10] who did not find association between dietary patterns and socio-economic status. Adolescents who live with their parents may have advantages with household food shares including money to school. An earlier study in northern region of Ghana reported disproportionate food shares between children of household heads and other children within the same household [44]. Pupils from high wealth homes may go to school with pocket money and therefore, are able to purchase sweets, snacks, and soft drinks. The association between living with parents and pocket money and the STP is therefore understandable. Following from these, it may be important for adolescents to receive nutrition education and guidance regarding food choices especially while in school where they make independent food choices. Equally important is the need to make the food environment of schools healthier to influence healthy choices.

The high dietary diversity descriptive of the TP in bivariate analysis but not the STP may be explained by the food characteristic of the patterns. Food characteristic of the STP such as sweets, energy and soft drinks, teas, and coffees are typically not included in the calculation of dietary diversity. However, foods characteristic of the TP such as cereals and grains, nuts, seeds and legumes, fruits, vegetables, and fish and sea foods are included in the calculation of dietary diversity [23, 45]. As increased dietary diversity may mean nutrient adequacy among adolescents [46, 47], it may be reasonable to promote a TP way of eating among adolescents.

The interpretation of the findings of this study should be made with some limitations in mind. The present study used a cross-sectional design and hence no causal links can be implied. The use of a qualitative approach to dietary intake assessment may not reveal the actual exposure level. The use of FFQ which

**Table 4** Logistic regression analysis of the determinants of high STP and TP among pupils

| | AOR | *p* value | 95% CI for AOR | |
|---|---|---|---|---|
| | | | Lower | Upper |
| Sweet tooth pattern (STP) | | | | |
| Sex | | | | |
| Male | 1.12 | 0.644 | 0.70 | 1.80 |
| Female | 1 | | | |
| Live with parents? | | | | |
| Yes | 1.95 | *0.019* | 1.11 | 3.40 |
| No | 1 | | | |
| Pocket money to school? | | | | |
| Yes | 4.73 | *0.008* | 1.49 | 14.99 |
| No | 1 | | | |
| Dietary diversity (food groups) | | | | |
| Less than 5 | 0.76 | 0.460 | 0.37 | 1.57 |
| Above 5 | 1 | | | |
| Father's educational level | | 0.803 | | |
| None | 0.85 | 0.650 | 0.42 | 1.72 |
| Primary/junior high school | 0.78 | 0.510 | 0.37 | 1.63 |
| Senior high/tertiary | 1 | | | |
| Mother's occupation | | 0.972 | | |
| Agriculture/farming | 0.84 | 0.728 | 0.32 | 2.23 |
| Trader | 0.97 | 0.925 | 0.53 | 1.77 |
| Civil servant | 0.71 | 0.733 | 0.10 | 5.19 |
| Others | 1 | | | |
| Father's occupation | | 0.173 | | |
| Agriculture/farming | 1.09 | 0.768 | 0.61 | 1.96 |
| Trader | 0.83 | 0.563 | 0.45 | 1.54 |
| Civil servant | 3.04 | *0.044* | 1.03 | 8.98 |
| Others | 1 | | | |
| Household wealth | | 0.004 | | |
| Wealthiest | 3.40 | *0.002* | 1.55 | 7.46 |
| Wealthy | 1.59 | 0.218 | 0.76 | 3.35 |
| Medium | 1.35 | 0.430 | 0.64 | 2.86 |
| Poor | 0.86 | 0.685 | 0.42 | 1.77 |
| Poorest | 1 | | | |
| Traditional pattern (TP) | | | | |
| Household wealth | | 0.008 | | |
| Wealthiest | 3.52 | *< 0.001* | 1.76 | 7.02 |
| Wealthy | 1.62 | 0.156 | 0.83 | 3.14 |
| Medium | 1.38 | 0.348 | 0.70 | 2.71 |
| Poor | 1.68 | 0.120 | 0.87 | 3.25 |
| Poorest | 1 | | | |
| Dietary diversity (food groups) | | | | |
| Less than 5 | 0.57 | 0.103 | 0.29 | 1.12 |
| Above 5 | 1 | | | |

Predictors with *p* values in italics are statistically significant

rely on respondent memory over along exposure period may introduce recall bias which can affect our findings. However, dietary intake assessments using FFQ have been shown to be reliable in revealing usual intake which is important in the present study [40, 41]. In spite of these limitations, our data reveal important dietary patterns and associated factors among urban adolescents in the Tamale metropolis of northern Ghana.

## Conclusion

Schooling Ghanaian adolescents in the present study followed a sweet tooth or traditional diet pattern. Household wealth, living with parents, and going to school with pocket money were associated with the sweet tooth pattern. The traditional pattern was associated with household wealth. Identified patterns were not associated with anthropometric status.

## Additional files

**Additional file 1:** Food groups based on foods in the FFQ and used for PCA. (DOCX 14 kb)

**Additional file 2:** Seven day Food Frequency Questionnaire. (DOCX 16 kb)

### Abbreviations

AOR: Adjusted odds ratio; FFQ: Food Frequency Questionnaire; JHS: Junior high school; PCA: Principal component analysis; STP: Sweet tooth pattern; TP: Traditional pattern

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### Availability of data and materials

The data supporting the conclusions of this article are included within the manuscript. The dataset could be obtained from the corresponding author upon reasonable request.

### Authors' contributions

ARA and ZA conceived and designed the study. ZA was responsible for field data collection and supervision. ARA and ZA analyzed and interpreted the data. ZA wrote first draft of the manuscript and ARA reviewed it critically for important intellectual content. ARA and ZA have the responsibility for the final content. Both authors read and approved the final manuscript.

**Ethics approval and consent to participate**
Permission to carry out this study was sought from the Metropolitan Education Directorate of Northern Region and the headmasters of the schools. The pupils signed an informed consent before participating in the study. Participation was voluntary. The study protocol was also approved by the Scientific Review Committee of the School of Allied Health Sciences, University for Development Studies, Ghana.

**Consent for publication**
Not applicable.

**Competing interests**
The authors declare that they have no competing interests.

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## *Supplementary material for paper 2*

**Additional file 1: Food groups based on foods in the FFQ and used for PCA**

| **Food group** | **Food items** |
|---|---|
| Cereals and grains | Tuo zaafi, banku, kenkey, riceballs, pain rice, bread |
| Tubers and plantain | Fufu, yam, plantain, sweet potato |
| Meat, poultry and eggs | Meats (cow, goat, sheep, rabbit), poultry (chicken, duck, guinea fowl, turkey), eggs |
| Vegetables | Traditional vegetables, exotic vegetables |
| Fruits and fruit juice | Pineapple, watermelon, apple, orange, mango, banana, pear/avocado, pawpaw, shea fruit, date, berries, fruit juice |
| Milk and milk products | Milk, yoghurt, waagashie |
| Fish and seafood | Fish and seafood |
| Sugared snacks | Biscuits, chocolates |
| Tea and coffee | Tea, coffee |
| Sweets | Sweets (chewing gums, toffees), fanmilk, fanchoco |
| Nuts, seeds and legumes | Cow pea, peanut, pigeon pea, Bambara beans, soya beans |
| Local sugared beverages | Mashed kenkey, koko, zimkuom, sobolo, poha, bear |
| Energy and soft drinks | Energy drinks, soft drinks, malts |
| Fats, oils and fat based foods | Fats and oils, jollof, fried rice, masa, palmnut, coconut, |

**Additional file 2: Seven day Food Frequency Questionnaire**

How often have you on average had the following in the past one week? (Please tick)

| Food item | Frequency | | | | | | |
|---|---|---|---|---|---|---|---|
| | > 6 times a week | 5 times a week | 4 times a week | 3 times a week | 2 times a week | once a week | not at all |
| Tuo Zaafi (made from corn/millet flour) | | | | | | | |
| Banku (made from fermented corn and/cassava dough) | | | | | | | |
| Fufu (pounded yams/cassava) | | | | | | | |
| Kenkey (made from fermented corn dough) | | | | | | | |
| Rice and beans | | | | | | | |
| Jollof (boiled rice with stew) | | | | | | | |
| Fried rice | | | | | | | |
| Rice balls | | | | | | | |
| Plain rice | | | | | | | |
| Yam (fried or boiled) | | | | | | | |
| Sweet potato | | | | | | | |
| Plantain | | | | | | | |
| Bread | | | | | | | |
| Biscuits | | | | | | | |
| Mashed kenkey | | | | | | | |
| Maasa (fried corn dough) | | | | | | | |
| Porridge | | | | | | | |
| Fula (made from millet dough) | | | | | | | |
| Zimkuom (local drink made from corn/millet flour) | | | | | | | |
| Sobolo (Roselle drink) | | | | | | | |
| Meat (cow, goat, sheep) | | | | | | | |
| Fish and seafood | | | | | | | |
| Poultry | | | | | | | |
| Egg | | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Milk | | | | | | | |
| Yoghurt | | | | | | | |
| Waagashie (local cheese) | | | | | | | |
| Soya/soy kebab (soya beans) | | | | | | | |
| Chocolate | | | | | | | |
| Pineapple | | | | | | | |
| Watermelon | | | | | | | |
| Apple | | | | | | | |
| Orange | | | | | | | |
| Mango | | | | | | | |
| Banana | | | | | | | |
| Avocado /pear | | | | | | | |
| Pawpaw | | | | | | | |
| Shea fruit | | | | | | | |
| Date (date fruit) | | | | | | | |
| Berries (all kinds) | | | | | | | |
| Soft drinks (coca cola, plastic coloured soft drinks) | | | | | | | |
| Fan milk | | | | | | | |
| Fan choco | | | | | | | |
| Tea | | | | | | | |
| Coffee | | | | | | | |
| Poha (local tamarind drink) | | | | | | | |
| Honey | | | | | | | |
| Energy drink (5 star, Rush etc) | | | | | | | |
| Malts (guinness, Rasta, Magic, etc) | | | | | | | |
| Bear (local pepper drink) | | | | | | | |
| Fruit juice (packed) | | | | | | | |
| Traditional vegetables vegetables (bra leaves (*Hibiscus sabdariffa*), *ayoyo* leaves (*Corchorus olitorius*), *aleefu* (*Amarantus sp*.), tomato, red hot | | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| pepper, onions, baobab leaves (dry), okro (fresh fruits, fruit powder)) | | | | | | | |
| Exotic vegetables (cabbage, lettuce, broccoli, carrots etc) | | | | | | | |
| Sweets (toffee, gum etc) | | | | | | | |
| Peanut (roasted, soup) | | | | | | | |
| Cow pea (koose, boiled) | | | | | | | |
| Adowa (pigeon pea) | | | | | | | |
| Bambara beans | | | | | | | |
| Palm nut | | | | | | | |
| Coconut | | | | | | | |
| Fats and oils (frytol, shea butter etc) | | | | | | | |

**Paper 3:** Socio-economic and food system drivers of nutrition and health transitions in The Gambia from 1990-2017

# RESEARCH PAPER COVER SHEET

**Please note that a cover sheet must be completed <u>for each</u> research paper included within a thesis.**

## SECTION A – Student Details

| | | | |
|---|---|---|---|
| **Student ID Number** | 1800648 | **Title** | Mr |
| **First Name(s)** | Zakari | | |
| **Surname/Family Name** | Ali | | |
| **Thesis Title** | Resilient and healthy food systems in low-income settings | | |
| **Primary Supervisor** | Prof. Andrew Prentice | | |

**If the Research Paper has previously been published please complete Section B, if not please move to Section C.**

### SECTION B – Paper already published

| | | | |
|---|---|---|---|
| Where was the work published? | | | |
| When was the work published? | | | |
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### SECTION C – Prepared for publication, but not yet published

| | |
|---|---|
| Where is the work intended to be published? | Global Food Security |
| Please list the paper's authors in the intended authorship order: | **Zakari Ali**, Pauline F. D. Scheelbeek, Sarah Dalzell, Genevieve Hadida, Alcade C. Segnon, Sulayman M'boob, Andrew M. Prentice, Rosemary Green |
| Stage of publication | **Undergoing revision** |

**SECTION D – Multi-authored work**

| | |
|---|---|
| For multi-authored work, give full details of your role in the research included in the paper and in the preparation of the paper. (Attach a further sheet if necessary) | I first discussed the research idea with Dr Pauline Scheelbeek and Dr Rosemary Green. I identified the relevant databases with the required data with support from my supervisors. I performed the statistical analysis, constructed the tables and graphs, and wrote the first full manuscript draft. I received comments from Dr Pauline Scheelbeek and Dr Rosemary Green on the draft and updated the manuscript using their comments. Prof. Andrew Prentice provided critical comments on the strength of evidence presented in the trend analysis which I used to amend the language for describing the results. All co-authors provided useful comments on the structure of the paper as well as language which I used to produce a final draft of the manuscript for journal submission. I led the journal submission as corresponding author of the paper. I addressed reviewer comments on the manuscript in consultation with my supervisors and other co-authors. |

**SECTION E**

| | |
|---|---|
| **Student Signature** | [redacted] |
| **Date** | 11th October 2022 |

| | |
|---|---|
| **Supervisor Signature** | [redacted] |
| **Date** | 12th October 2022 |

# Global Food Security

## Socio-economic and food system drivers of nutrition and health transitions in The Gambia from 1990-2017

--Manuscript Draft--

| | |
|---|---|
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| | Rosemary Green, PhD |
| **Abstract:** | In common with many nations undergoing a nutrition transition, micronutrient deficiencies, undernutrition and overnutrition coexist in The Gambia. Addressing these challenges simultaneously would require transformational changes in the country's food system. However, the evidence base that would enable informed decision-making in the Gambian food system has been scant, despite several sources of routinely-collected data being available. This descriptive study brings together data from four open-access global databases on food supply, political, economic, and demographic variables, and nutrition and health between 1990 and 2017 to study potential leverage points for improvement in the food system. It compares trends in food supply and nutritional outcomes in The Gambia against regional and global averages, and identifies potential drivers taken from a food systems framework. The data show that, over the past three decades, total energy supply has increased, and obesity is rising quickly, but iron deficiency persists in a proportion of the population. Overall diet composition is poor, with lower availability of fruit and vegetables and higher supply of sugar and oils compared to regional and global averages. Domestic production is low for most food groups and so a high dependence on imports from other countries bridges the gap in terms of energy supply. Measures of economic development, particularly GDP, were positively related with supply of cereals and animal source foods over time, but no such relationship was observed with fruit and vegetable supply. Food system policy to improve nutrition and health outcomes in The Gambia needs to focus on improving the diversity of food supply – especially fruit and vegetables – and maximizing national domestic production to reduce reliance on food imports. The use of open-source global datasets can be effective in exploring food system characteristics and trends at the national level and could be applied in other contexts. |
| **Suggested Reviewers:** | Richmond Aryeetey, PhD<br>Professor, University of Ghana School of Public Health<br>raryeetey@ug.edu.gh<br>Prof. Aryeetey has extensive experience working on food systems in West Africa. |
| | Lydia O'Meara, PhD<br>Natural Resources Institute<br>l.c.omeara@greenwich.ac.uk |

Title Page (with Author Details)

# Socio-economic and food system drivers of nutrition and health transitions in The Gambia from 1990-2017

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**Highlights**

- There is utility in combining large national datasets on food systems to inform nutrition and health policy in LMICs.
- Three decades of food system data show that gross supply of energy is adequate but micronutrient supply is suboptimal in The Gambia.
- Food imports have complemented low domestic production for most food groups in The Gambia.
- Economic development indicators closely tracked availability of cereals and animal source foods over time but not supply of fruit and vegetables.

**Socio-economic and food system drivers of nutrition and health transitions in The Gambia from 1990-2017**

**Abstract**

In common with many nations undergoing a nutrition transition, micronutrient deficiencies, undernutrition and overnutrition coexist in The Gambia. Addressing these challenges simultaneously would require transformational changes in the country's food system. However, the evidence base that would enable informed decision-making in the Gambian food system has been scant, despite several sources of routinely-collected data being available. This descriptive study brings together data from four open-access global databases on food supply, political, economic, and demographic variables, and nutrition and health between 1990 and 2017 to study potential leverage points for improvement in the food system. It compares trends in food supply and nutritional outcomes in The Gambia against regional and global averages, and identifies potential drivers taken from a food systems framework. The data show that, over the past three decades, total energy supply has increased, and obesity is rising quickly, but iron deficiency persists in a proportion of the population. Overall diet composition is poor, with lower availability of fruit and vegetables and higher supply of sugar and oils compared to regional and global averages. Domestic production is low for most food groups and so a high dependence on imports from other countries bridges the gap in terms of energy supply. Measures of economic development, particularly GDP, were positively related with supply of cereals and animal-source foods over time, but no such relationship was observed with fruit and vegetable supply. Food system policy to improve nutrition and health outcomes in The Gambia needs to focus on improving the diversity of food supply – especially fruit and vegetables – and maximizing national domestic production to reduce reliance on food imports. The use of open-source global datasets can be effective in exploring food system characteristics and trends at the national level and could be applied in other contexts.

**Keywords:** Food supply, micronutrient deficiency, overnutrition, under nutrition, urbanization, agriculture, The Gambia

## 1.0 Introduction

Globally, progress is being made in the fight to eliminate undernutrition but for many countries rates of nutritional deficiency, stunting and related mortality remain high (Development Initiatives, 2020). In 2020, Sub-Saharan Africa had the highest per-capita hunger levels in the world according to the Global Hunger Index (Global Hunger Index, 2020), with more than one in five people classified as undernourished. Transformational changes in the food system are urgently needed to deliver adequate and sustainable foods for all, to continue the fight against hunger and to combat the epidemic of nutrition-related chronic disease that has spread from high income to lower income countries. Global studies of food supply have shown that while many food systems have changed radically in recent decades, those in Sub-Saharan Africa have tended to show slight change (Bentham et al., 2020).

The main concern of diets in Sub-Saharan Africa is continued pockets of food insecurity together with high rates of micronutrient deficiency (Beal et al., 2017; FAO et al., 2021). West Africa is no exception to these nutritional challenges (Chadare et al., 2022), with the prevalences of undernourishment, stunting in children <5 years old, and anaemia in women of reproductive age estimated at 19%, 31% and 52% respectively in 2020 (FAO et al., 2021). A further concern is the nutrition transition, characterized by reductions in undernutrition (largely in children) with corresponding rises in overnutrition among adults (Popkin et al., 2012) – such as a reported 3.0 and 6.6 percentage points increase in obesity in adult men and women respectively in 2016 as compared to 2000 (Development Initiatives, 2020). With these trends, the region is currently at increased risk of facing the “double burden” of malnutrition (Ahinkorah et al., 2021; Prentice, 2018) with countries having to deal with the two extremes of nutritional challenges. In countries such as Ghana and The Gambia, this is already noticeable in national statistics. Approximately 1 in 5 children are stunted in both countries and nearly half the women of reproductive age suffer from anaemia. Furthermore, prevalence of overweight is ~40% for adult women in both countries – coexisting with anaemia (Development Initiatives, 2021b; Petry et al., 2019).

While it is important to continue efforts to reduce undernutrition in the region, the prevention of overweight and obesity also needs urgent attention. Therefore, efforts to tackle food system related problems will require a shift in paradigm: rather than feeding the population (i.e. providing sufficient calories per person), food system policies should focus on “nourishing” the population (Searchinger et al., 2019) – with an emphasis on healthy and sufficient food for all from food systems.

A food system framework presents pathways in which a set of complex drivers of change affect the food system including unforeseen consequences acting together and feeding into the system to shape its outcomes (Béné et al., 2019). Data on different components of the food system framework (HLPE, 2020), including on political and economic drivers, innovation, technology and infrastructure, demographic drivers and food supply can help in understanding the specific interrelationships that act together to shape food system outcomes but are currently underutilized. The continuous collection of reliable (national) data on a large spectrum of food system indicators is crucial for evidence-based decision-making aimed at improving nutritional health in Sub-Saharan Africa (Annan, 2018). However, the availability of reliable country-level data on the state of food systems to inform policy has been a consistent challenge in West Africa – partly related to limited resources (Annan, 2018). Recent initiatives, including the Food Systems Dashboard (Fanzo et al., 2020), the Global Dietary Database (Global Dietary Database, 2021), and the Global Nutrition Report (Development Initiatives, 2021a) could provide a suitable alternative to access national level data on food system drivers and outcomes. These are useful initiatives but often operate more at a global level and a single “one size fits all” solution is unlikely to apply well in different country-specific contexts. For example, the Food Systems Dashboard currently provides a set of policies and actions for food systems at global level. More tailored analyses focusing on national level statistics have added advantages – allowing for the inclusion of context specific food system drivers. Country-specific analyses are also a means to test the local applicability of indicators included in global databases.

Therefore, this descriptive study sought to bring together data from different open-access global databases on political and economic drivers, demographic drivers, supply chains and nutrition and health outcomes between 1990 and 2017 to study potential leverage points for improvement in the Gambian food system. It compares trends in food supply and nutritional outcomes in The Gambia against West Africa and global averages, and identifies potential drivers based on a food system framework. We demonstrate how useful this kind of analysis could be to identify key priorities for food system transformations using The Gambia as a case-study.

## 2.0 Methods

## 2.1 Assessment of food system components

In this national food system analysis, we used different open-source databases which provide data on key components of the food systems framework (HLPE, 2017, 2020) for the period between 1990 and 2017. The High Level Panel of Experts (HLPE) on Food Security and Nutrition proposed five key categories of food system drivers that interrelate to influence nutrition and diets (HLPE, 2017). Due to data limitations, our analysis includes data on three drivers: political and economic drivers, innovation, technology and infrastructural drivers, and demographic drivers of food systems change. Other related components of the food systems framework were also analyzed including food supply chains, diets, and nutrition and health outcomes. **Table 1** presents the set of food system drivers, intermediaries and outcomes analyzed for The Gambia. We have presented a simple overview of the potential interrelationships among these factors in shaping food system outcomes (specifically: iron deficiency, vitamin A deficiency, and obesity) in The Gambia guided by a Directed Acyclic Graph (DAG) (Greenland et al., 1999) (Supplementary **Figure S1**). For example, a possible link between food supply and vitamin A deficiency is likely mediated proximally through the amount of vitamin A rich food supplied from both imports and domestic production (crop yields) (Low et al., 2017). In addition, vitamin A deficiency can also, more distally be a result of increased food purchasing power, for example through employment in agriculture, remittances, and GDP. Similarly, living in urban settlements may increase the access of consumers to calorie dense street food – this combined with other urban behaviour, such as sedentariness could form important drivers of high obesity prevalence (Bloem and de Pee, 2017) (Supplementary **Figure S1**).

Insert Table 1

## 2.2 Databases and cleaning

We obtained data from four open-source global databases that provide data on drivers and outcomes of food system change relevant to The Gambia: i) United Nations Food and Agriculture Organization (FAO) Food Balance Sheet (FBS) database (FAO, 2021), ii) World Bank's World Development Indicators database (World Bank, 2021) iii) Global Burden of Disease (GBD) database (Global Burden of Disease Collaborative Network, 2020), and iv) the Non-communicable Diseases (NCD) Risk factor collaboration database (NCD-RisC, 2021).

First, we obtained food supply data from United Nations Food and Agriculture Organization (FAO) Food Balance Sheets (FBS) for the period between 1990 -2017 (FAO, 2021). These are country level estimates of the amount of food available for human consumption per person per day. FAO Food Balance Sheets data are compiled from a combination of official (government sources such as industrial output surveys, food consumption and expenditure surveys) and unofficial (imputed data) data sources plus its own estimates and data corrections. Details on the methodology behind the compilation of the FAO Food Balance Sheets are given elsewhere (FAO, 2021). Food supply data (average kcal and gram/capita/day) were retrieved for The Gambia, West Africa and globally in order to make comparisons of temporal trends and identify potential related factors. The estimated quantity of food supply for each food item represents the amount available for domestic human consumption by a country's resident population at retail level: comprising production and imports adjusted for exports, stock variation, food losses, food used for seed and animal feed. Food supply data for 97 FAO defined food items were used in the current analysis. These were grouped into six food group aggregates based on shared nutrient content (Willett et al., 2019): (i) cereals and roots, (ii) oils, (iii) animal-source foods, (iv) pulses and nuts, (v) fruit and vegetables, and (vi) sugar and sweets. Supplementary **Table S2** provides details of the specific food items that make up the food groups. We assessed the adequacy of total energy and food group supply (in grams per person per day) by comparing with the EAT-Lancet recommendations for healthy and sustainable diets (Willett et al., 2019) that have been shown to reflect micronutrient adequacy of diets in low- and middle-income settings (Hanley-Cook et al., 2021).

Furthermore, we obtained annual cereal and vegetable yields from the FAO database for the period 1990-2017. In addition, food production data from the same FAO database, comprising imports and exports of the 97 food items for The Gambia, West Africa and globally between 1990 and 2017 were retrieved. Import dependency ratios (IDRs) by food group for each country were calculated using the following formula (FAO, 2011):

$$IDR = \frac{Import}{Production + Import - Export}$$

Second, we used the World Bank's World Development Indicators database (WDI) (World Bank, 2021) to retrieve country level and global data on annual proportion of people living in urban areas, employment in agriculture, and gross domestic product (GDP) – corrected for country level purchasing power parity for the period 1990 to 2017. Data on total remittances inflow per year were obtained from the World Bank's KNOMAD (https://www.knomad.org/data/remittances). We computed per capita remittances using United Nations population data (FAO, 2019). Remittances per capita were further corrected for variations in purchasing power in different countries by applying World Bank's Purchasing Power Parities (PPP) conversion factors (World Bank, 2021).

Third, age-standardized prevalence data for two nutritional outcomes were obtained from the Global Burden of Disease (GBD) database (Global Burden of Disease Collaborative Network, 2020). Data on age-standardized prevalence of dietary iron deficiency and vitamin A deficiency for country level, regional and globally for the years 1990-2017 (Global Burden of Disease Collaborative Network, 2020) were extracted for this study. Dietary iron and vitamin A deficiency are associated with increased burden of disease and disability in The Gambia and globally (Global Burden of Disease Collaborative Network, 2020) and are more likely driven by food system factors hence their selection as outcomes for the Gambian food system (Beal et al., 2017; National Nutrition Agency-Gambia et al., 2019). Detailed explanations of how these estimates are derived are provided elsewhere by the GBD (James et al., 2018).

Finally, we used data from the Non-communicable Diseases (NCD) Risk factor collaboration database (NCD-RisC: https://ncdrisc.org/index.html) to derive the age-standardized prevalence of an additional food system outcome variable that is of increasing concern for causing death and disability in The Gambia and globally: high body mass index (obesity) (Murray et al., 2020).

### 2.3 Statistical analysis

We have explored relationships among variables in this study using graphical methods to display and compare trends in different food system indicators due to the aggregate nature of the data. While some databases covered a few more recent years, at the time of data compilation the FAO database reported up to 2017, and hence this was taken as final year of all analyses. Data on remittance inflows were available starting in 2002 for The Gambia and so this was used as the starting point for analysis involving remittances.

We have presented 3-year rolling averages for most estimates to overcome potential reporting inaccuracies associated with reporting yearly data and to account for potential time lags between food supply and outcomes. Nutritional outcome variables were selected based on country-specific prevalence and associated disease burden and include: iron deficiency, vitamin A deficiency (Beal et al., 2017; National Nutrition Agency-Gambia et al., 2019) and obesity (Cham et al., 2020; Murray et al., 2020). We performed pairwise correlations, with Bonferroni corrections to explore interrelationships between the economic and demographic factors (GDP, remittances, urbanization, and employment in agriculture) and also their association with the selected outcomes. We also graphically analyzed intermediate relationships between the economic and demographic factors and the supply of total energy and specific food groups. Finally, we present graphical relationships between food groups supply the selected outcomes in The Gambia.

## 3.0 Results

### 3.1 Trends in GDP, remittances, urbanization, and employment in agriculture in The Gambia

The Gambia's GDP has increased only slightly since 1990. Urbanization has increased rapidly such that over 60% of the population now live in urban areas. Remittances from overseas have more than doubled, while employment in agriculture has decreased (**Figure 1**).

Compared with the wider West African region, per capita remittances rose slowly in The Gambia until 2015 when they rose higher than both West African and global averages. However, remittances had significantly lower purchasing value in The Gambia than in other West African countries when corrected for country level parities in purchasing power (Supplementary **Figure S2**). Therefore, an equal amount of remittances received in The Gambia can purchase less goods and services than it would do elsewhere in West Africa. Rates of urbanization in The Gambia are higher than in West Africa on average and employment in agriculture is lower. Employment in agriculture in The Gambia is broadly similar to the global average but substantially lower than other West African countries and still decreasing (**Figure 1**).

Insert Figure 1

### 3.2 Changes in food supply

Since 2005 the average daily supply of energy per person has been higher than the 2503 kcal (Supplementary **Figure S3)** specified by EAT-Lancet dietary recommendations.

In terms of dietary composition however, average diets in The Gambia appear to have low diversity, with cereals and roots making up the largest part of the diet (54% in 1990 and 56% in 2017; Figure 2). This has not significantly improved over the past decades. Furthermore, fruit and vegetable availability is extremely low (with a steady declining trend over time from 89 to 68g/person/d between 1990 and 2017), while supply of animal-source foods has – on average – been stable (~16% of the diet). The supply of sugars and sweets also declined steadily (from 15% in 1990 to 9% 2017) (**Figure 2**).

Compared to the EAT-Lancet diet recommendations, amounts of cereals available in The Gambia are comparable to the upper limit of the recommended amounts for consumption by the EAT-Lancet (EAT-Lancet recommendation:464g; average per capita supply in The Gambia: 495g in 2017) compared to very high per capita supply of cereals in both West Africa (839g in 2017) and globally (649g in 2017). Fruit and vegetable supply in The Gambia is lower than the West African average and is currently estimated at 68g/person/d in 2017 compared to 276g/person/d in the region, both being below the 500g/person/day EAT-Lancet recommendation – but globally, the supply of fruit and vegetables were higher (592g/person/d in 2017).

The supply of animal-source foods is below the EAT-Lancet maximum recommendation of 334g/person/d (meat, poultry, fish, dairy, and eggs) for The Gambia (164g/person/d in 2017) and West Africa (151g/person/d in 2017), in contrast to the global average which is well above this recommendation at 428g/person/d in 2017. The supply of pulses and nuts was particularly low in The Gambia (9g/person/d in 1990 to 4g/person/d in 2017) compared to West Africa (22g in 1990 to 30g in 2017) and the global average (20g/person/d in 1990 to 25g/person/d in 2017) and well below the EAT-Lancet recommendation of 125g per person per day (Supplementary **Table S3**).

In contrast, the supply of oils and sugars is higher in The Gambia compared to both West African and global averages (**Figure 2** and Supplementary **Table S3**). Supply of sugar in The Gambia is higher than the 31g/person/day maximum intake level recommended by the EAT-Lancet diet despite being reduced from 128g/person/d in 1990 to 82g/person/d in 2017. Comparatively, the supply of sugar in West Africa and the global average were 40g/person/d and 72g/person/d respectively in 2017. The average supply of oils and fats in The Gambia is also higher (77g/person/d in 2017) than the West African average (52g/person/d) and the global average (51g/person/d in 2017) but are all within the EAT-Lancet recommendation of no more than 92g/person/d (Figure 2 and Supplementary **Table S3**).

Insert Figure 2

### 3.3 Trends in food production and trade

To further explore driving factors that may be associated with low availability of some foods in The Gambia, we investigated trends in yields and imports for both the cereal crops providing the bulk of dietary energy and nutritionally important fruits and vegetables (**Figure 3**).

Yields of both cereals and vegetables in The Gambia are low compared to the global mean, averaging below 2 metric tonnes per hectare for cereals and around 5 metric tonnes per hectare for vegetables (Estimate excludes fruit yields) between 1990 and 2017. Dependence on imports of fruit and vegetables (>60%) and cereals (>50%) from other countries is high compared to West African averages. In some years, the proportion of fruit and vegetables imported in The Gambia has reached 80%, indicating very low levels of domestic production. Increasing cereal and vegetable yields were related to the dependence on imports over time. For example, in 2011, there was an inverse relationship where imports start declining and local production increases (Supplementary **Figure S4**).

Insert Figure 3

### 3.4 Changes in nutrition and health outcomes in The Gambia

Over the past decades, iron deficiency rates in The Gambia have been substantially higher than the West African average (**Figure 4**). Between 1990 and 2017, the age-adjusted prevalence of iron deficiency increased from 24.4% to 26.5%. The age-adjusted prevalence of vitamin A deficiency has been low with a current downward trend but remains higher than the West African average. The reported prevalence of vitamin A deficiency of 2.0% in 1990 had halved (1.0%) in 2017.

At the same time an increase is noticeable in the proportion of adults classified as obese (10.7% in 2016 from 2.8% in 1990). At a global scale, the prevalence in Gambia is still relatively low, as the global obesity prevalence is currently 13.5%, but in the past 20 years prevalence in The Gambia has increased to be greater than the West African average (**Figure 4**).

Insert Figure 4

### 3.5 Trends in food supply and nutrition and health outcomes in The Gambia

Exploratory correlation analysis of interrelationships among the political and economic as well as demographic drivers, and nutritional outcomes showed that greater employment in agriculture was associated with lower levels of obesity but was also associated with high levels of vitamin A deficiency (Supplementary **Table S3**).

Greater levels of urbanization were associated with reduced employment in agriculture and higher levels of obesity but did not show a significant relationship with other nutritional outcomes.

Receipt of remittances was significantly correlated with a few other drivers: increased remittances were associated with greater urbanization and reduced employment in agriculture, and with increased prevalence of obesity. However, they were also associated with lower prevalence of vitamin A deficiency. Growth in GDP, conversely, showed no significant correlations with other drivers or with nutritional outcomes.

In terms of crop yields, higher cereal yields were related to greater employment in agriculture but were also associated with higher levels of vitamin A deficiency, while higher vegetable yields were associated with lower vitamin A deficiency. Crop yields were not significantly related to levels of iron deficiency (Supplementary **Table S4**).

Graphical exploration indicated that over time in The Gambia (notwithstanding the fact that these relations cannot be assumed to be causal), increases in both GDP and urbanization both tended to pre-date increases in the supply of cereals, animal-source food, oils, and total food. Remittances did not appear related to the availability of specific food groups directly. Food import was a key factor for the availability of all food groups in The Gambia with over 50% of total supply coming from food import. Importantly, economic factors did not appear related to increased availability of fruit and vegetables (**Figure 5** and supplementary **Figure S5**).

Finally, we explore graphical associations between availability of specific food groups (and energy) and nutrition and health outcomes[1]. An increase in the supply of animal-source foods tended to pre-date a decrease in iron deficiency, and an increase in the availability of oils also tended to pre-date changes in vitamin A deficiency while an increase in the overall food availability appeared to pre-date reductions in both iron and vitamin A deficiency. Obesity related only weakly with supply of oils and total food availability in the country (Supplementary **Figure S6**).

Insert Figure 5

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Only a selection of food groups with a plausible nutritional link with outcome variables were explored.

# 4.0 Discussion

## 4.1 Main findings

Large, open-source routinely-collected datasets are a useful tool to explore current national food systems, their trends, and their comparison in regional and global contexts, especially in settings with limited availability of country specific data. Our analyses show that, over the past three decades in The Gambia, supply of specific food groups and total energy have increased (even though iron deficiency is still a problem) and overall diet composition is poor with less fruit and vegetables, and more sugar and oils compared to neighbouring countries and global supply averages. Obesity prevalence is rising quickly possibly related to increased urbanization and less engagement in agricultural work. Furthermore, domestic production is low throughout all food groups. High imports of cereals, animal-source foods and sugar from other countries seem to bridge the gap in terms of energy supply, but low imports of fruit and vegetables in combination with low domestic supply overall may be leading to micronutrient deficiencies. GDP and urbanization appear to predict the supply of specific food groups in The Gambia, but there is a lack of relationship with employment in agriculture which may reflect the country's persisting low levels of domestic production and crop yields. With ongoing urbanization rates outstripping regional and global levels along with continually declining crop yields and levels of agricultural employment, the trends in food supply may worsen in the future without extensive reliance on imports.

## 4.2 Research in context

The greater reduction in agricultural employment in The Gambia compared to other West African countries may indicate a more prevalent diversification of livelihoods from agriculture in The Gambia and may also be linked with burgeoning tourism in the country in recent years (Mitchell and Faal, 2007). The lower crop yields may indicate significant production inefficiency in the Gambian agriculture sector and shows the potential for increased domestic supply despite the small numbers employed in the sector. Employment in agriculture did not appear to relate to changes in availability of any food groups even though it was strongly related to crop yields, which may reflect the high degree of dependence on imports in the Gambian food system. For instance, increasing cereal and vegetable yields were related to the dependence on imports over time. This implies that increasing domestic production efficiency would have potential to cut the reliance on imports in the country. Further, we show that selected political and economic drivers and demographic drivers did not appear related to the availability of nutritionally important fruit and vegetables. This may mean that without targeted efforts to increase their supply, usual economic growth is unlikely to lead to an increase in the availability of fruit and vegetables.

The increasing supply of energy which reached adequate levels (compared to EAT-Lancet targets) in 2005 could mean sufficient food energy and may partly explain the corresponding decline in prevalence of undernourishment (FAO et al., 2021). Given that inequitable food distributions are highly likely, and that the data do not account for food wastage, the small margin above the recommended intake level may also indicate food insecurity for parts of the population (Mangan, 2021). In contrast, rising obesity also shows that sections of the population still have excess energy supply, presenting a problem with its own associated health and economic burdens (Chu et al., 2018).

There is growing realisation of the importance of national level transitions such as urbanization and economic growth on obesity (Ruel et al., 2017). In The Gambia, urban settlement has traditionally been high and has continued to increase (World Bank, 2021). Hence, the rather recent steep rises in obesity rates can only be partly explained by continuing urbanization and highlighting the role of energy dense food groups such as vegetable oil and sugar. Rising obesity levels in low-and middle-income countries are thought to play through both globalization (the flooding of low-income country markets with inexpensive and high caloric foods) and modernization which recognizes domestic factors (such as an increase in intake of unhealthy foods in response to rising income, automation of processes and increased retail outlets which reduce distance to markets) (Fox et al., 2019). The latter is the most likely culprit, but both concepts have likely played a role in The Gambia's obesity epidemic (Cham et al., 2020; Webb and Prentice, 2006).

Growing urbanization and declines in crop yields over time may be due to movement to urban areas and neglect of crop production in rural areas. This can also be due to loss of incentives for farm work following income from remittances coupled with a lack of profit from declining crop yields. The yield gap in The Gambia is the result of a combination of factors including low soil fertility from low fertilizer use, poor cultivation practices and climate uncertainties (drought, irregular rainfall pattern and salt intrusion of crop land) (FAO et al., 2018). Availability of cheap imported cereals (mainly rice, maize and wheat flour) and consecutive crop production failures (Bagagnan et al., 2019; Sonko et al., 2020) have also led to a reliance on imported food rather than investment in domestic production. The relationship between GDP growth and cereal supply could therefore be explained by increased food importation rather than boosting domestic production through the provision of farm inputs and mechanization.

International food trade including bilateral donations of food can be an efficient way to complement domestic supply insufficiency (Kummu et al., 2020). But over reliance on food imports or aid, especially if such crops are the main staple food, can increase the vulnerability of food supply in consuming countries to shocks such as climate change and crop failure in food producing countries. Food imports and food donations have, so far, successfully bridged the gap in domestic production for most food groups, particularly: cereals, animal-sources, oils, and sugar. Reliance on rice as a main staple food seems to drive the overall dependence on cereal imports in the country. This is similar to neighbouring countries such as Niger and Senegal where rice is a major staple (Fontan Sers and Mughal, 2020). In these rice dominated countries, there is low domestic production due in part to consumer preference for polished imported rice (Demont et al., 2017). In contrast, in less rice reliant countries with a diverse number of staple foods, dependency on cereal imports is far lower. For instance, in Nigeria and Ghana (the two most populated countries in the region) where maize, cassava and yams are major national staples (Ekpa et al., 2018; Haleegoah et al., 2015; Olayiwola et al., 2012) (mainly produced and processed locally), the dependency on cereal imports is below 10%.

Unlike cereals and other food groups, the gap in domestic supply of fruit and vegetables has not been met through imports and hence there is low overall supply. While this is a consistent trend with regional supply levels, actual amounts available per person in The Gambia are far lower and are inadequate when compared with amounts set by WHO to meet health needs (WHO, 2003) and the sustainable diet target by EAT-Lancet (Willett et al., 2019). The low supply of fruit and vegetables is consistent with evidence from a national survey which showed that only 7% of adults aged 25-64 years consumed five servings of fruit and vegetables per day in The Gambia (Government of Gambia and WHO, 2010). Most of the agricultural workforce in The Gambia is engaged in horticultural production (65% of all employed in agriculture) (United Purpose and IFAD, 2018). Despite this, domestic production meets only 18% of national demand. A significant proportion of this amount goes into hotel and restaurant chains and is consumed by tourists and wealthy residents, further reducing the amounts available for the wider public (United Purpose and IFAD, 2018). With similar trends in vegetable yields compared to regional averages, the low domestic supply is possibly due to high post harvest losses or less cultivated land. There are also large seasonal fluctuations in availability of fruit and vegetables in the country with gluts of mangoes, oranges and watermelons concentrated within short periods (Bates et al., 1982; United Purpose and IFAD, 2018). These are associated with major fluctuations in vitamin C status for instance (Bates et al., 1982). Therefore, without proper irrigation farming (currently underutilized) (Segnon et al., 2021), improved storage facilities and control of post-harvest losses, dependence on imports from other countries seems to be a more suitable way to ensure consistent supply of fruit and vegetables throughout the year.

### 4.3 Strengths and limitations

This study has demonstrated the utility of combining food system and economic development data to understand a country's food system situation with reference to regional and global contexts. It brings further use to routinely collected and often expensive data by governments and development partners which individual surveys will be unable to achieve independently.

However, this study has several limitations worth noting when interpreting the meanings of these results. Chiefly, the data used for the analysis are ecological in nature and therefore causality cannot be determined, only inferred from the kinds of graphical relationships presented here showing the onset of different trends over time. We were also unable to explore differences among population groups in The Gambia in terms of food consumption or income levels etc. and could only rely on national averages. These kinds of national data should be supplemented by additional sources such as national household or dietary surveys to give a more complete picture of individual food systems. Our analysis of food supply did not also account for bioavailability, enhancers, and inhibitors as well as fortification of specific foods which can affect deficiency dynamics independent of food supply levels. For example, the relationship between supply of oils and vitamin A deficiency is likely the result of fortification of vegetable oil with vitamin A. The use of EAT-Lancet dietary guidelines was also limited to adult diets and not children, pregnant and lactating women who have heightened nutrient needs and are very vulnerable to nutrient deficiency in this population (National Nutrition Agency-Gambia et al., 2019).

Reliance on data from secondary sources also implies that the trends presented are only as accurate as the original surveys or any further data processing performed by database holders. Of note is the FAO Food Balance Sheet data that have been criticised for not reflecting actual consumption with major overestimations for high income countries while underestimating consumption in low-income settings (Del Gobbo et al., 2015). For example, onions are the largest produced vegetables in The Gambia (United Purpose and IFAD, 2018), yet these are not included in FAO's calculation of vegetable supply for The Gambia (FAO, 2021) leading to an underestimation of overall availability of vegetables in the country. The trends in supply of vegetables over time may however be important as the set of included vegetables is reported consistently. Further, the FAO food supply data do not account for small-scale production and wild crops that are likely to constitute a significant part of rural diets. This may imply that our analysis of food supply is likely more relevant to urban populations than rural dwellers even though availability of imported foods such as rice, wheat (flour and bread), sugar, oils, tomato paste etc (included in FAO statistics) are high in rural areas (Gambia Bureau of Statistics, 2016). The limitations of data and sampling methods of the other databases used in this study are detailed elsewhere (James et al., 2018; NCD-RisC, 2021; World Bank, 2014).

### 4.4 Recommendations

From the 2008 global economic crisis that impacted heavily on prices of imported food and ongoing impacts of climate change (Epule et al., 2014), the government of Gambia's current agricultural policy aims to increase domestic production and achieve self-sufficiency by 2026 (Government of Gambia, 2019). While this is commendable, there should be consideration of the realistic proportion of food that can be produced domestically given the resources available. A recent global analysis showed that stability in national dietary diversity can be improved through crop diversification with strong contributions from imported food (Nicholson et al., 2021). Therefore, a certain level of food import will be important to ensure improved national diet diversity and supply sufficiency. This should be done through comprehensive evidence mapping of the economic and environmental trade offs that come with increasing domestic production and import sources. Diversification in cereals used as main staple food should be considered to reduce reliance on rice. Promoting the production and consumption of biofortified crops such as pearl millet, maize, and cassava as alternative staple foods in the country could be a viable strategy for diversification and combat micronutrient deficiency, as availability and consumption of these is increasing (FAO-Gambia, 2020). The diversification of food import sources could also be a strategy to reduce supply vulnerability such that disruptions in one producing country will not impact heavily on the food supply.

To meet fruit and vegetable supply deficits, substantial increases in current amounts from both domestic supply and imports are needed. This can be done by taking advantage of the large labour force working in horticultural production in the country – including in urban areas (CTA, 1991). The promotion of small-urban vegetable production may have additional benefits to effectively complement rural production through shorter supply chains (FAO, 2007). It may lead to less sedentary lifestyles (Cham et al., 2020) and serve as a 'double duty' intervention to address both vegetable supply problems and increase physical activity. Increasing urbanization rates may also release large pieces of land in rural areas which could be harnessed for large scale mechanized and sustainable intensification agriculture that is shown to improve domestic food supply sufficiency (Wang et al., 2021). There is also the need to improve assessment of fruit and vegetable production in the country by making them a major component of routine national surveys such as the National Agricultural Survey (NAS). This will improve understanding of actual supply and improve the quality of data hosted in global databases including FAOSTAT, Food System Dashboard and the Global Dietary Database.

The variables considered in this analysis constitute a small aspect of the food system, as many different components of the food system framework that interrelate to shape food system outcomes such as biophysical and environmental drivers, technology and innovation, food environments and socio-cultural factors (HLPE, 2020) as well as different dynamics of food security such as food access and utilization were not included. These should be considered in future studies of food system analysis for a more holistic understanding of food system outcomes.

## Conclusion

Open-source routinely collected global data is a useful tool for food system analyses, especially in settings with limited data collection and availability at national level, such as The Gambia. We can conclude that measures of development, particularly GDP, were positively related to supply of cereals and animal-source foods over time, but no such relationship was observed for fruit and vegetable supply. Food system policy to improve nutrition and health outcomes in The Gambia needs to focus on improving the diversity of food supply and imports – especially fruit and vegetables – and maximize domestic production to reduce reliance on food import.

### 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.

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## Tables

**Table 1**: Distribution of selected factors among components of the food system framework

| **Drivers of food systems change** | **Relevant factor(s) analyzed** |
|---|---|
| Political and economic | Gross domestic product, remittances, trade/ food importation |
| Demographic | Urbanization, employment in agriculture |
| Innovation, technology and infrastructure | Crop yields* |
| Biophysical and environmental drivers | Not included (NI) |
| Socio-cultural drivers | NI |
| **Other components of the food systems framework** | |
| Food supply chains | Domestic food production, imported food |
| Diets | Supply of individual food groups |
| Nutrition and health outcomes | Iron deficiency, vitamin A deficiency, obesity |
| Consumer behavior | NI |
| Food environments | NI |

*Used as an outcome of this driver.
NI: Variables not included due to lack of data.
Food Systems frame

# Figures

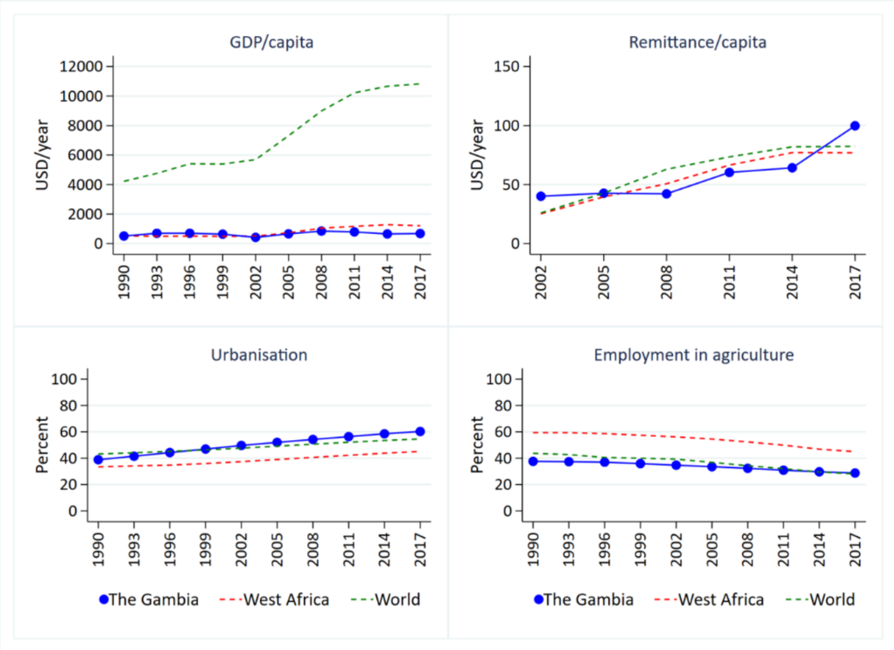


**Figure 1:** GDP, remittances, urbanization and agriculture employment transitions in The Gambia, West Africa and globally 1990 to 2017

**[Intended for color production]**

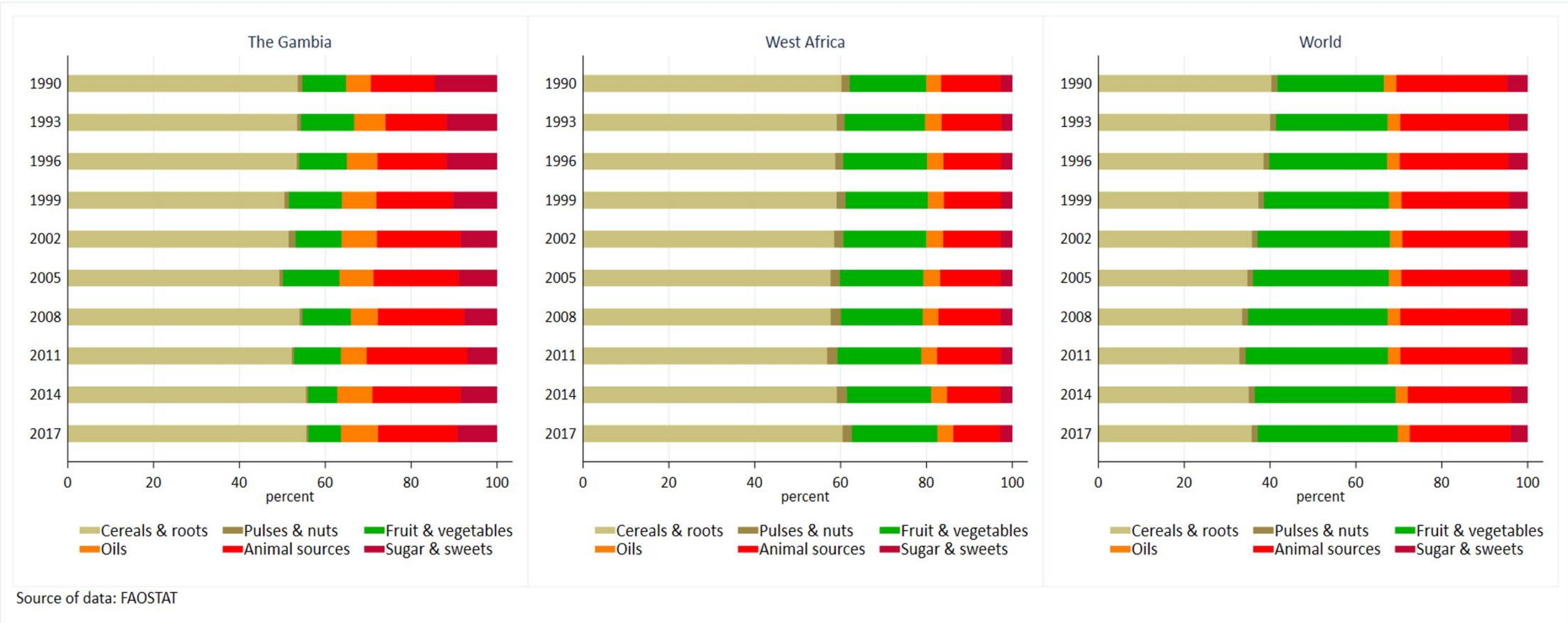


**Figure 2:** Transitions in food supply in The Gambia, West Africa and globally 1990 to 2017 [Food supply is in gram/capita/day]

**[Intended for color production]**

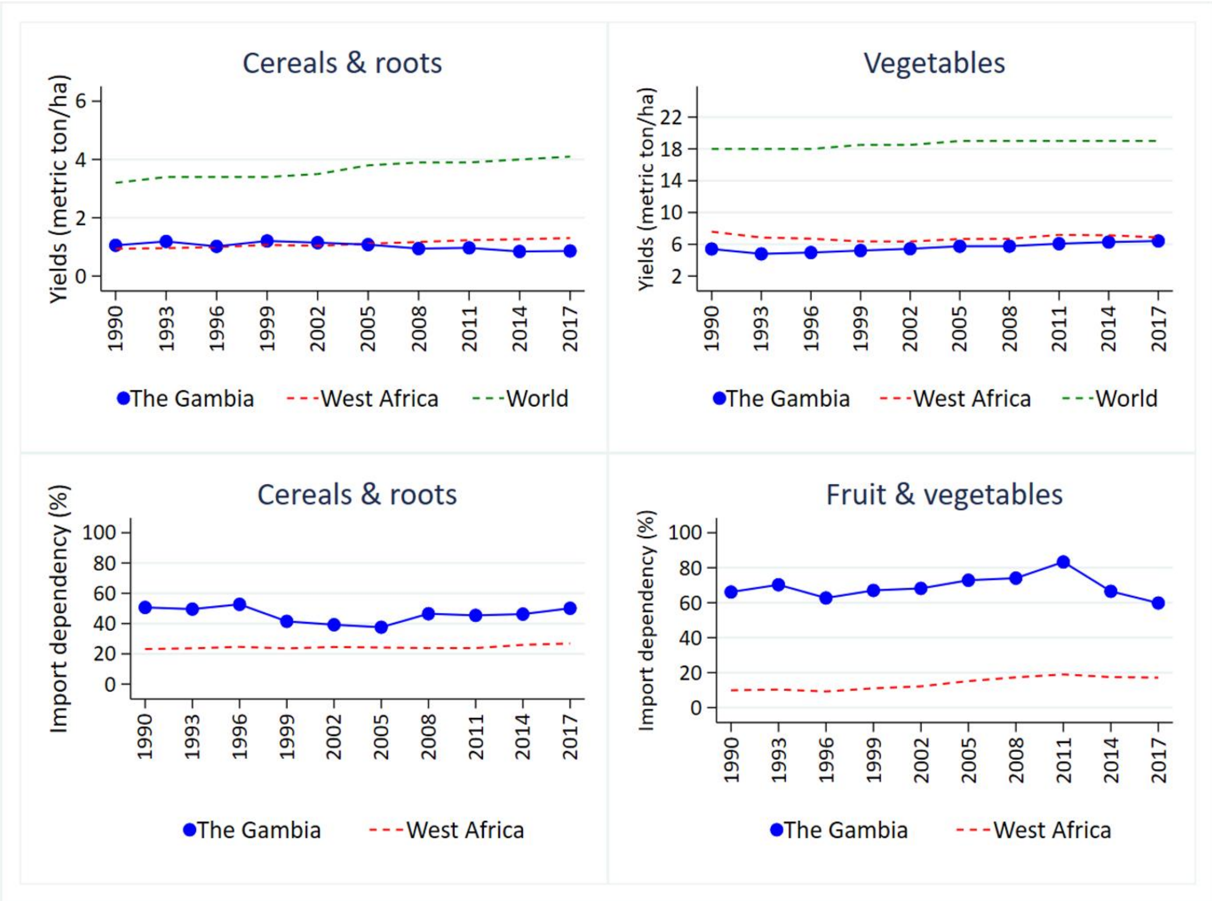


**Figure 3:** Yields and imports of cereals and vegetables in The Gambia, West Africa and globally 1990 to 2017

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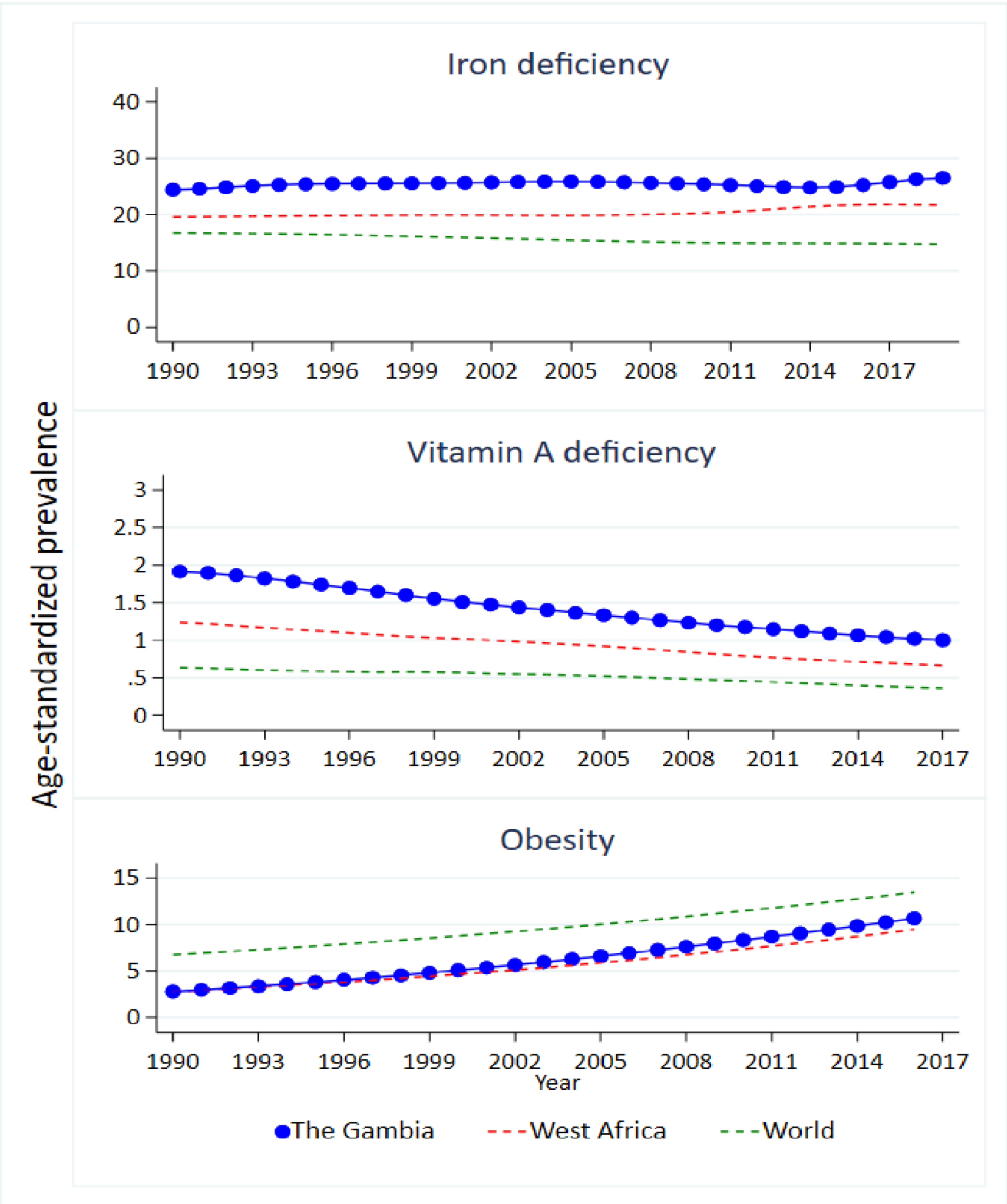


**Figure 4:** Nutrition and health transitions in The Gambia, West Africa and globally 1990 to 2017

**[Intended for color production]**


Agric employment
Cereals
GDP
Cereals
Urbanisation
Cereals
Import dependence
Cereal import
Cereals
Agric employment
Fruit & veg
GDP
Fruit & veg
Urbanisation
Fruit & veg
Import dependence
Fruit & veg
Agric employment
Animal sources
GDP
Animal sources
Urbanisation
Animal sources
Import dependence
Animal sources
Agric employment
Oil & sweets
Oil & sweet
GDP
Oil & sweets
Oil & sweet
Urbanisation
Oil & sweets
Oil & sweet
Import dependence
Oil & sweets
Oil & sweet
Agric employment
Total supply
GDP
Total supply
Urbanisation
Total supply
Import dependence
Total supply
1990 1993 1996 1999 2002 2005 2008 2011 2014 2017

**Figure 5:** Potential predictors of food supply in The Gambia (1990-2017) [The specific food groups are in g/person/day; total supply is in kcal/person/day; GDP is in USD/year; employment in agriculture is in percent of total employment/year; urbanization is in percent/year; import dependence is in percent/year]

**[Intended for color production]**

***Supplementary material for paper 3***

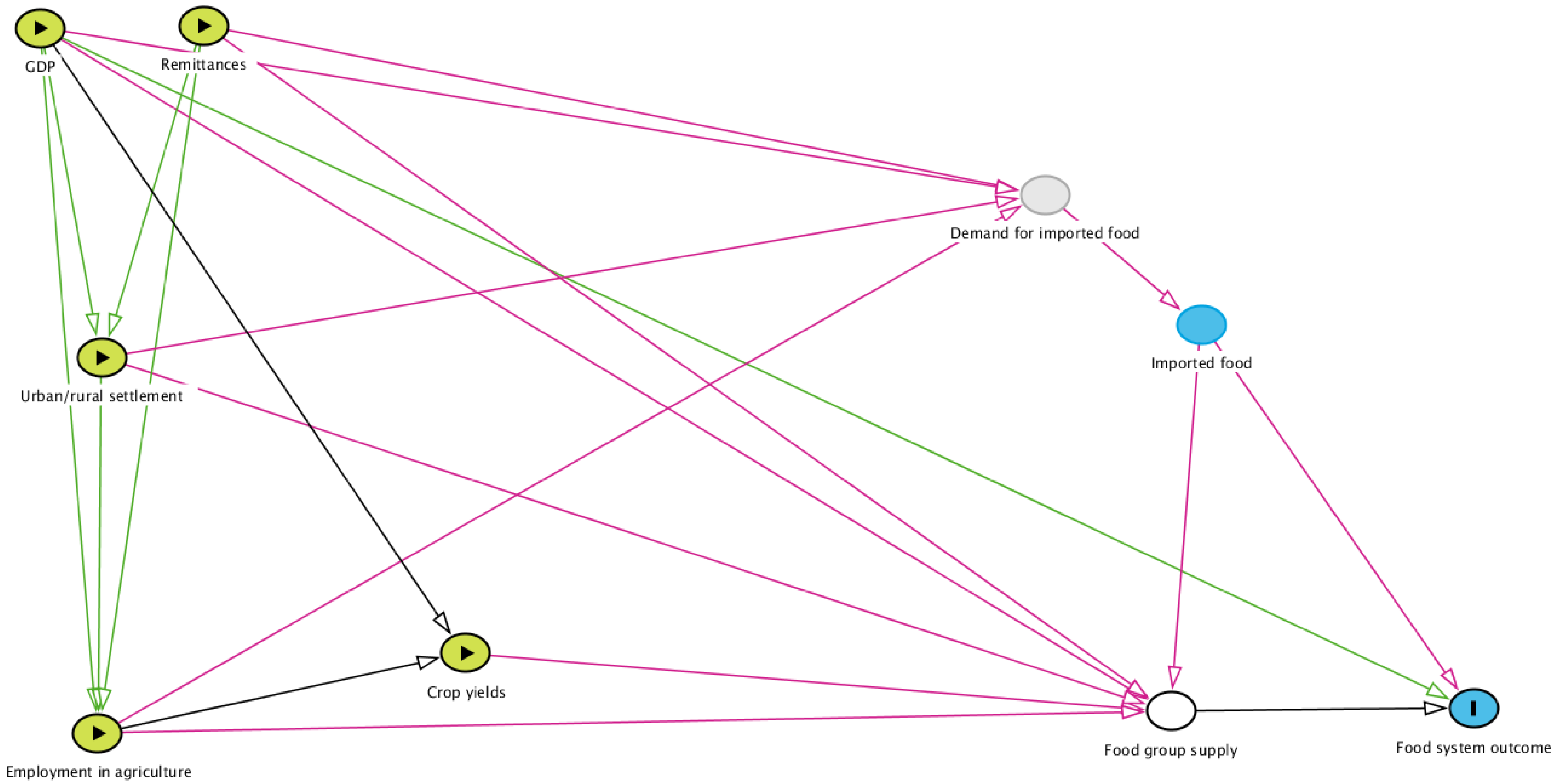


**Figure S1**: Theorized pathways of the structural determinants of nutrition and health outcomes in The Gambi

**Table S1**: Food groups and constituent food items

| Food groups* | Cereals and roots | Oils | Animal-sources | Pulses and nuts | Fruit and vegetables | Sweets and sugar |
|---|---|---|---|---|---|---|
| Constituent food items | Wheat, rice, barley, maize, rye, oats, millet, sorghum, other cereal, potato, cassava, sweet potato, other root, yam | Fish liver oil, fish body oil, cream, butter, raw animal fat, other oil, maize germ oil, rice bran oil, olive oil, sesame seed oil, coconut oil, palm oil, palm kernel oil, cotton seed oil, mustard/rapeseed oil, sunflower oil, groundnut oil, soyabean oil | Bovine meat, mutton, pig meat, poultry, other meat, edible offal, eggs, fresh water fish, demersal fish, pelagic fish, other marine fish, crustaceans, cephalopods, molluscs, aquatic mammal, other aquatic animal, milk. | Beans, peas, other pulse, nuts, soyabean, groundnuts, sunflower seed, rapeseed/mustard, cotton seed, coconut, sesame seed, palm kernel, other oil crop, cocoa beans and products. | Tomatoes, onions, other vegetable, orange/mandarins, lemon/lime, grape fruit, other citrus, banana, plantain, apple, pineapple, dates, grape product, other fruit, pepper, pimento, cloves | sugar cane, sugar beet, non-centrifugal sugar, raw sugar, honey, other sweetener |
| Total | 14 | 18 | 17 | 14 | 17 | 6 |

Food constituents follow FAO official groupings and where other is stated, constituents are often a cluster of many more food items defined by FAO. For example, other vegetables contain: Cabbages and other brassicas, Artichokes, Asparagus, Lettuce and chicory, Spinach, Cassava leaves, Cauliflowers and broccoli, Pumpkins, squash and gourds, Cucumbers and gherkins, Eggplants (aubergines), Chillies and peppers, green, Onions, shallots, green, Garlic, Leeks, other alliaceous vegetables, Beans, green, Peas, green, Vegetables, leguminous nes, String beans, Carrots and turnips, Okra, Maize, green, Sweet corn frozen, Sweet corn prep or preserved, Mushrooms and truffles, Mushrooms, dried, Mushrooms, canned, Chicory roots, Carobs, Vegetables, fresh nes, Vegetables, dried nes, Vegetables, canned nes, Juice, vegetables nes, Vegetables, dehydrated, Vegetables in vinegar, Vegetables, preserved nes, Vegetables, frozen, Vegetables, temporarily preserved, Vegetables, preserved, frozen, Vegetables, homogenized preparations, Watermelons, Melons, other (inc.cantaloupes), Coffee, substitutes containing coffee

**Table S2**: EAT-Lancet diet recommendations and food group supply

| EAT-Lancet food group | Target intake (range in grams) | Functional category used in analysis | The Gambia* | | West Africa* | | World* | |
|---|---|---|---|---|---|---|---|---|
| | | | 1990 | 2017 | 1990 | 2017 | 1990 | 2017 |
| Vegetables | 300 (200-600) | Fruit and vegetables | 89.49 | 67.56 | 201.55 | 276.47 | 347.73 | 592.34 |
| Fruits | 200 (100-300) | | | | | | | |
| Beans, lentils, peas | 75 (0-150) | Pulses and nuts | 9.32 | 4.12 | 21.63 | 29.56 | 19.77 | 25.39 |
| Peanuts and tree nuts | 50 (0-100) | | | | | | | |
| Cereals and grains | 232 (0-464) | Cereals and roots | 472.74 | 495.38 | 679.31 | 839.16 | 564.97 | 648.98 |
| Potatoes and cassava | 50 (0-100) | | | | | | | |
| Unsaturated oils | 40 (20-80) | Oils | 51.31 | 77.23 | 39.36 | 51.79 | 40.56 | 50.83 |
| Palm oil | 6.8 (0-6.8) | | | | | | | |
| Lard or tallow | 5 (0-5) | | | | | | | |
| Added sugar | 31 (0-31) | Sugars and sweets | 127.67 | 82.08 | 30.59 | 39.51 | 66.32 | 71.90 |
| Fish | 28 (0-100) | Animal-source foods | 131.04 | 164.29 | 156.01 | 150.50 | 361.61 | 426.08 |
| Beef and lamb | 7 (0-14) | | | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Pork | 7 (0-14) | | | | | | | |
| Poultry | 29 (0-58) | | | | | | | |
| Dairy | 250 (0-500) | | | | | | | |
| Eggs | 13 (0-25) | | | | | | | |

*Food group supply is in gram per capita per day.

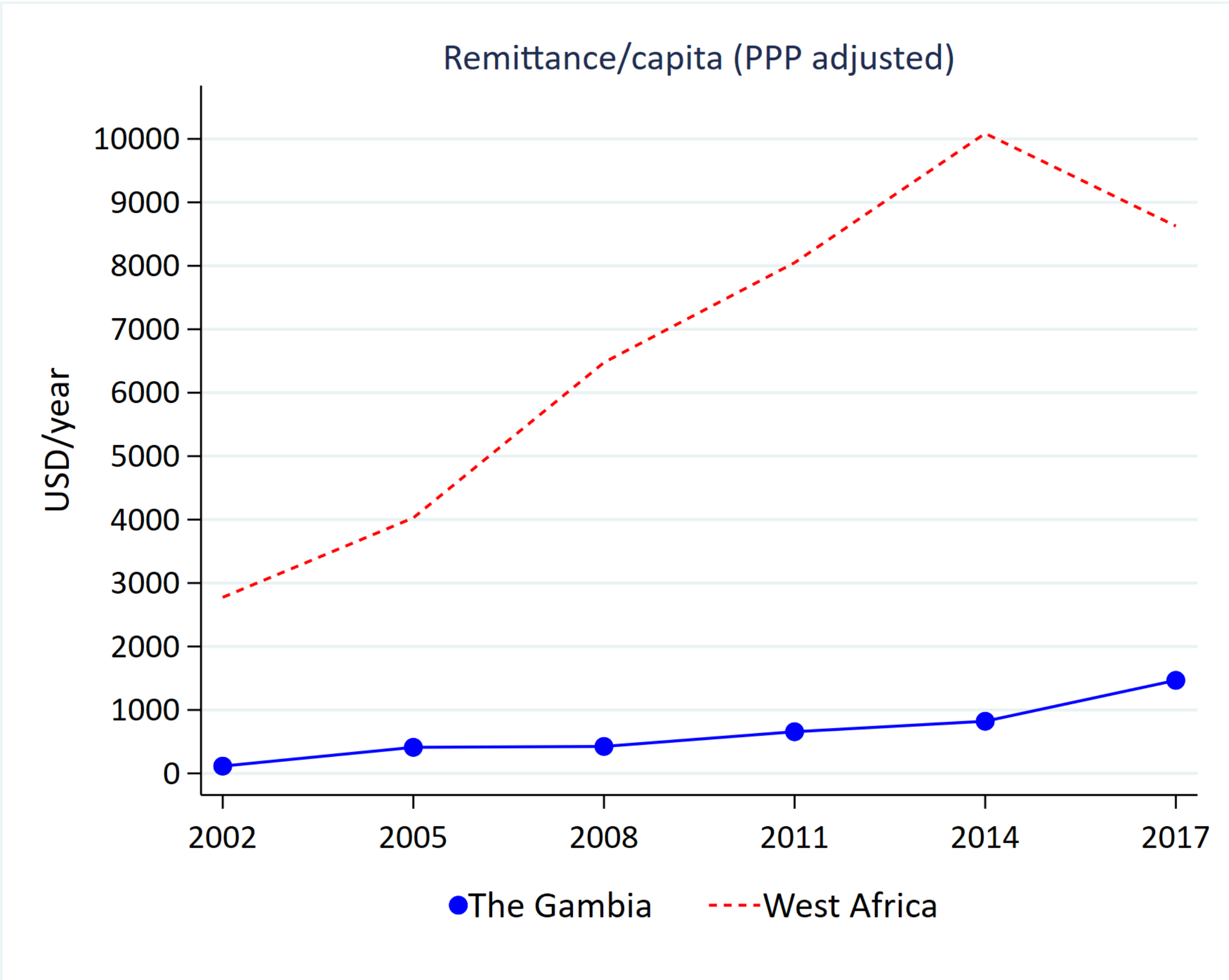


**Figure S2**: Trends in remittances adjusted for country-level purchasing power parities (PPP)

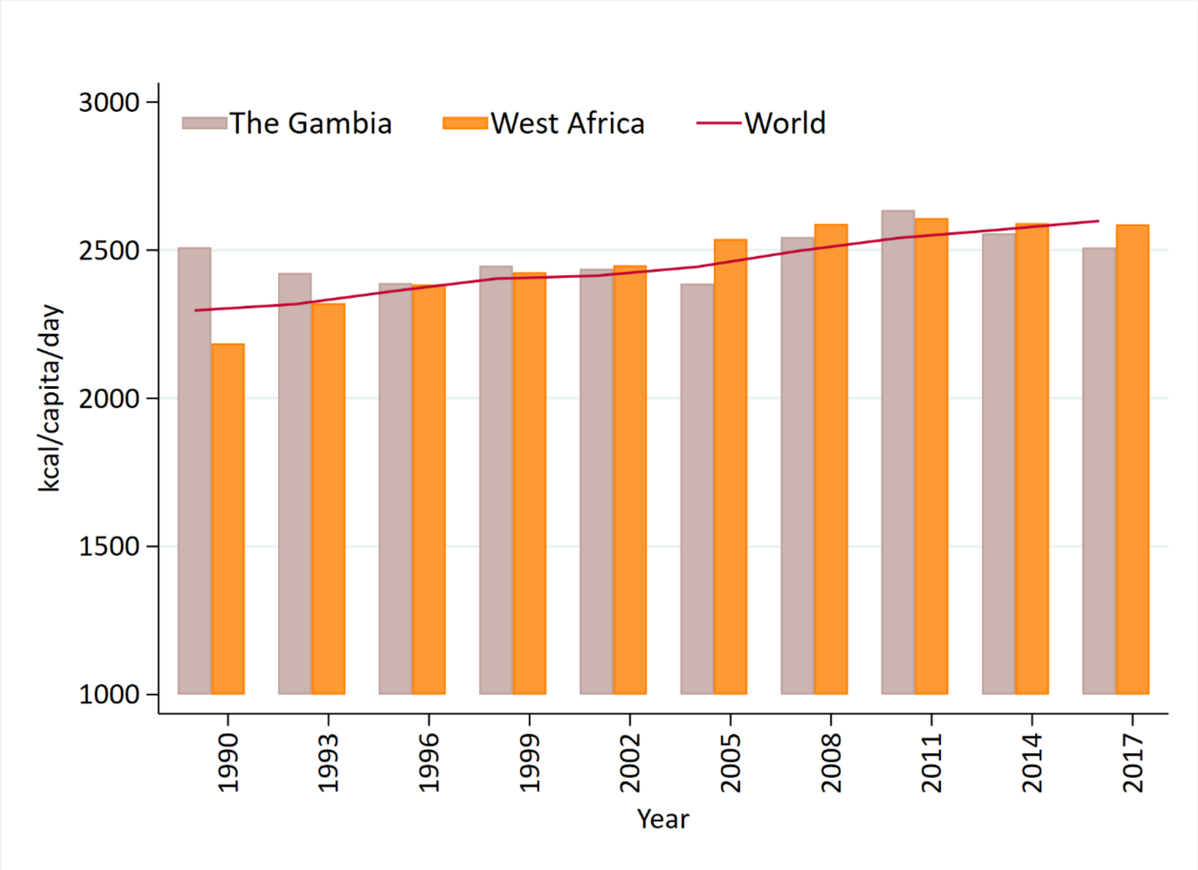


**Figure S3:** Supply of total calories in The Gambia, West Africa and globally (1990-2017)

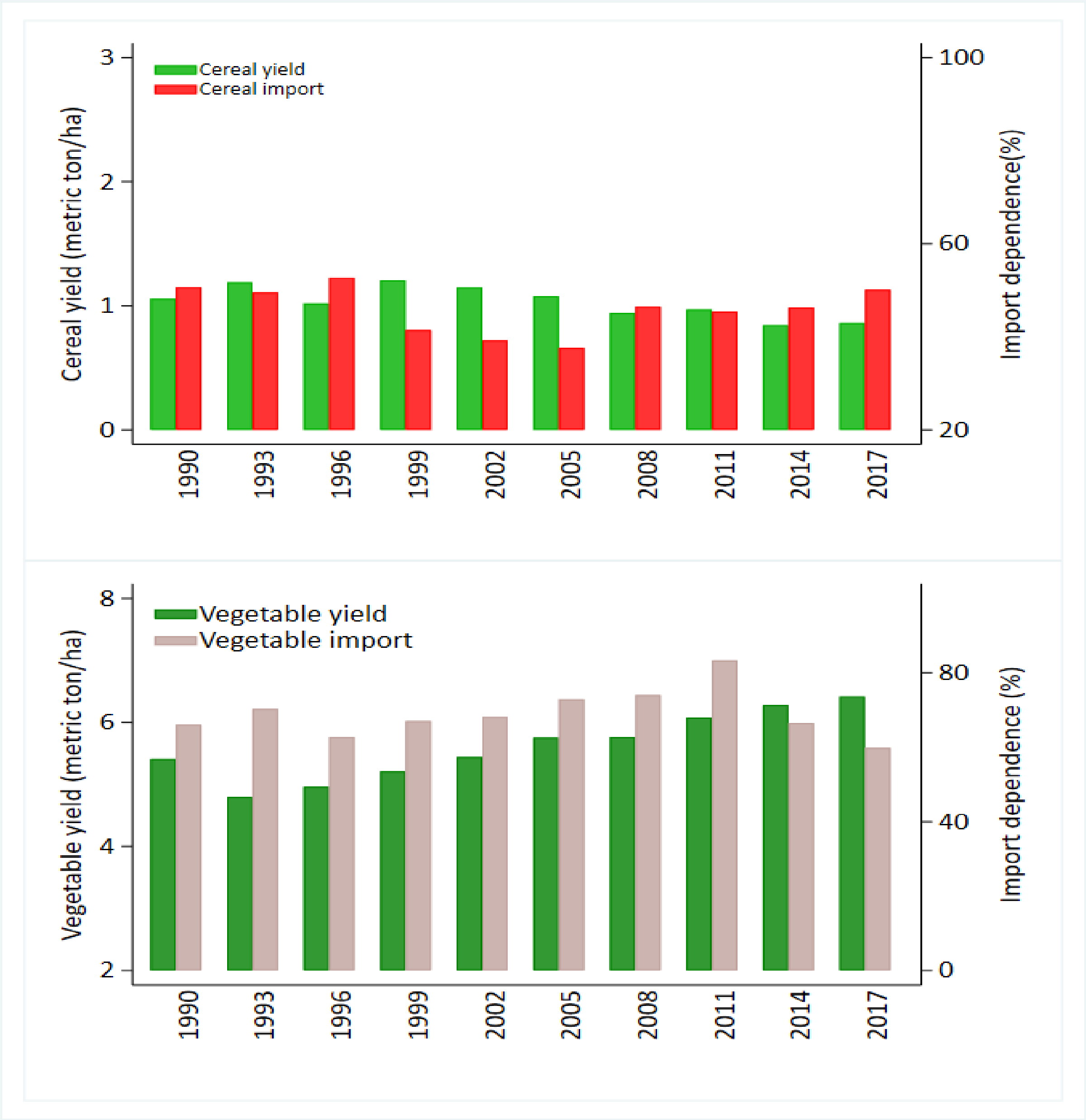


**Figure S4:** Relationship between crop yield and import dependency in The Gambia (1990-2017)

**Table S3:** Pairwise correlations of interrelationships between food system components in The Gambia

| | Vegetable yields | Cereal yields | Employment in agriculture | GDP growth | Remittance | Urbanization | Iron deficiency | Vitamin A deficiency | Obesity |
|---|---|---|---|---|---|---|---|---|---|
| Vegetable yields | 1 | | | | | | | | |
| Cereal yields | **NS** | 1 | | | | | | | |
| Employment in agriculture | **-0.983(<0.001)** | **0.646(0.004)** | 1 | | | | | | |
| GDP growth | 0.025(0.999) | -0.191(0.999) | -0.195(0.999) | 1 | | | | | |
| Remittances | NS | NS | **-0.867((<0.001)** | 0.007(0.999) | 1 | | | | |
| Urbanization | NS | NS | **-0.984(<0.001)** | 0.286(0.999) | **0.858(<0.001)** | 1 | | | |
| Iron deficiency | -0.054 (0.999) | 0.176 (0.999) | 0.048 (0.999) | 0.071 (0.999) | -0.365 (0.999) | 0.241 (0.999) | 1 | | |
| Vitamin A deficiency | **-0.852 (<0.001)** | **0.580 (0.034)** | **0.978 (<0.001)** | -0.276 (0.999) | **-0.832 (0.003)** | -0.998**(<0.001)** | NS | 1 | |
| Obesity | NS | NS | **-0.996 (<0.001)** | 0.298 (0.999) | **0.851 (0.003)** | **0.982(<0.001)** | NS | NS | 1 |

Co-efficient (p-value)
P-values are Bonferroni corrected for multiple testing.
Bolded values indicate coefficients with p<0.05.
NS: Not supported by theorized pathway analysis.


**Figure S5**: Remittances and food supply in The Gambia (1990-2017) [The specific food groups are in g/person/day; total supply is in kcal/person/day; remittance is in USD/person/year; GDP is in USD/year]


**Figure S6**: Supply of selected food groups (and energy) with nutrition and health outcomes in The Gambia (1990-2017) [Iron deficiency, vitamin A deficiency and obesity values are age-standardised prevalence estimates; the specific food groups are in g/person/day; total supply is in kcal/person/day].

**Paper 4:** Characteristics of distinct dietary patterns in rural Bangladesh: Nutrient adequacy and vulnerability to shocks

# RESEARCH PAPER COVER SHEET

**Please note that a cover sheet must be completed <u>for each</u> research paper included within a thesis.**

## SECTION A – Student Details

| | | | |
|---|---|---|---|
| **Student ID Number** | 1800648 | **Title** | Mr |
| **First Name(s)** | Zakari | | |
| **Surname/Family Name** | Ali | | |
| **Thesis Title** | Resilient and healthy food systems in low-income settings | | |
| **Primary Supervisor** | Prof. Andrew Prentice | | |

**If the Research Paper has previously been published please complete Section B, if not please move to Section C.**

**<u>SECTION B – Paper already published</u>**

| | | | |
|---|---|---|---|
| Where was the work published? | Nutrients | | |
| When was the work published? | 15th June 2021 | | |
| If the work was published prior to registration for your research degree, give a brief rationale for its inclusion | | | |
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## SECTION D – Multi-authored work

| | |
|---|---|
| For multi-authored work, give full details of your role in the research included in the paper and in the preparation of the paper. (Attach a further sheet if necessary) | I proposed the study idea in discussion with Dr Rosemary Green who had already identified the dataset. I performed data management and cleaning on the dataset. I conducted the nutrient and dietary analysis. Dr Rosemary Green provided technical assistance on defining dietary patterns in MPlus. I defined the objectives, performed all statistical modelling, and constructed the tables, graphs and results interpretations. After writing the first manuscript draft, I invited Dr Timothy Thomas who was part of the team that conducted the original survey to contribute. Dr Pauline Scheelbeek helped to invite Prof. Tahmeed Ahmed and Dr Kazi Istiaque Sanin who provided additional country-level knowledge and expertise on diets to also contributed to the manuscript revisions. All co-authors commented on the first draft which I used to produce an updated manuscript. I led the journal submission of the paper as corresponding author and addressed reviewer comments in consultation with my supervisors and co-authors. |

## SECTION E

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| **Student Signature** | [redacted] |
| **Date** | 2nd August 2022 |

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| **Supervisor Signature** | [redacted] |
| **Date** | 12th October 2022 |

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MDPI

*Article*

# Characteristics of Distinct Dietary Patterns in Rural Bangladesh: Nutrient Adequacy and Vulnerability to Shocks

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**Abstract:** Food security in Bangladesh has improved in recent years, but the country is now facing a double burden of malnutrition while also being highly vulnerable to climate change. Little is known about how this may affect food supply to different sectors of the population. To inform this, we used a national dietary survey of 800 rural households to define dietary patterns using latent class analysis. Nutrient adequacy of dietary patterns and their potential vulnerability to climate shocks (based on diversity of calorie sources) were assessed. We fitted mixed effects logistic regression models to identify factors associated with dietary patterns. Four dietary patterns were identified: rice and low diversity; wheat and high diversity; pulses and vegetables; meat and fish. The wheat and high diversity and meat and fish patterns tended to be consumed by households with higher levels of wealth and education, while the rice and low diversity pattern was consumed by households with lower levels of wealth and education. The pulses and vegetables pattern was consumed by households of intermediate socio-economic status. While energy intake was high, fat and protein intake were suboptimal for all patterns except for the wheat and high diversity pattern. All patterns had fruit and vegetable intake below the WHO recommendation. The wheat and high diversity pattern was least vulnerable to shocks, while the rice and low diversity pattern was the most vulnerable, relying mainly on single cereal staples. The diets showed "double vulnerability" where the nutrient inadequate patterns were also those most vulnerable to shocks.

**Keywords:** staples; dietary pattern; latent class analysis; farm production; diet vulnerability; nutrition transition



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## 1. Introduction

Bangladesh is one of the most populous countries in the world and will be home to a significant proportion of the world's population in the near future despite declines in population growth rates over the last decade [1]. The country has undergone one of the most rapid declines in poverty in the world in the last 30 years, and this has been accompanied by major improvements in food security. However, this progress has not occurred equally across all population groups, and large sections of the population are still vulnerable to food insecurity [2]. The country is, thus, currently facing a double burden of malnutrition where both over- and under-nutrition persist in the same society [3,4]. Recent estimates show that 31% of children under five years are stunted [5], yet overweight and obesity prevalence is above 18% in adults and has tripled in adolescents between the years 2000 and 2016 [6].

Given the diversity of diets and nutritional health within the country, the requirements and needs for nutritional improvement vary greatly [7]. Thirteen per cent of the population have insufficient habitual food consumption, and 32% experience moderate or severe food insecurity [8]. In addition, Bangladesh is classified as being highly vulnerable to climate change [9] and has widespread subsistence agriculture [10], which adds further pressure to food production, supply and food prices. Due to the substantial inequalities in access to an adequate and diverse supply of foods, some diets may be more vulnerable than others to shocks such as price fluctuations induced by climate change, disease outbreaks or other events.

In order to take evidence-based decisions aiming at improving nutritional health and resilience to shocks at the sub-national level, it is important to identify hotspots of poor nutrition (both over and under-nutrition) and study the exact composition and socio-economic determinants of such diets. Identification of dietary patterns allows for a broader understanding of population diets than looking at individual foods or nutrients alone [11,12]. Analysis of single nutrients or foods also fails to account for the fact that people eat meals that include many foods and nutrients that interact in different ways. This makes dietary advice based on these analyses less useful and more difficult to implement. As a result, population-wide dietary pattern analysis has been proposed as an alternative method of assessing the way people eat and its relationship with health [13]. The identification of dietary patterns over space and time can be a solid first step in identifying what needs there are at sub-national levels, so as to guide key decision makers to develop tailored responses. Patterns can identify which food groups are inadequate or overly abundant in diets and identify priority populations at risk of poor nutrition. This can inform the planning of agriculture and food production to improve diets.

In this analysis, we have determined dietary patterns, identified associated factors and assessed both nutrient adequacy and vulnerability of the diet to potential shocks (based on the diversity of calorie sources) in order to inform appropriate diet shifts towards resilient and nutrient-adequate diets in Bangladesh.

## 2. Materials and Methods

### *2.1. Study Design and Participants*

This study is a secondary analysis of cross-sectional data from the Bangladesh Climate Change Adaptation Survey (BCCAS) Round I [14]. The survey involved 800 farming households, which were selected to be representative of the seven broad agroecological zones of Bangladesh and collected in the same season. It was administered by the International Food Policy Research Institute (IFPRI) and Data Analysis and Technical Assistance Limited (DATA) from December 2010 to February 2011. The database contains data on demographic characteristics, crop and livestock production, food consumption, land tenure, incidence of climatic shocks in the last five years and adaptation options. The present analysis is based on the food consumption, crop and livestock production and household characteristics data.

### *2.2. Food Consumption and Socio-Demographic Data*

Participants reported through interview, the quantities of household consumption of 127 different food items over a 14-day recall period. Women responsible for food preparation and distribution were interviewed on behalf of household members with assistance from other household members. They were asked to estimate the amounts in grams or kilograms of foods household members had consumed over the last 14 days preceding the survey. Total household level intakes of each raw food item in grams were linked with the Bangladesh food composition tables (FCT) [15] to determine total energy and amounts of carbohydrate, fat and protein. Subsequent calculations of energy from carbohydrate, fat and protein were done by multiplying total amounts in grams of each macronutrient by the general Atwater factors: 4, 9 and 4 kcal/g, respectively.

We obtained proxy-individual level daily intakes of energy and macronutrients by dividing daily household intakes by a weighted sum of the household size, which accounted for age and sex differences in energy intake. We used proxy-individual requirements that are relevant to South Asia and previously used by the Indian National Sample Survey [16] and recently by Aleksandrowicz et al. [17] to convert daily household level intakes into approximate individual intakes. This approach has been demonstrated to be a useful measure, which approximates well the individual intakes from household level data [18].

The adequacy of energy intake from macronutrients was calculated following World Health Organization (WHO) guidelines on the appropriate daily range of proportions of energy from macronutrients to total energy intake [19]. We calculated the proportion of energy each macronutrient contributed to the total daily energy intake and compared it with the WHO guideline. Participants whose proportion of intake of a macronutrient fell within the WHO recommended range for that nutrient were regarded as having adequate energy intake for that nutrient.

Other covariates selected based on previous literature were household size and age, educational level and religion of the head of household. Variables representing characteristics of the head of household were chosen on the basis that they would act as a proxy for general household characteristics. Household wealth status was determined using household possession of 29 durable items in principal component analysis [20,21].

Farm or home production diversity was assessed as the total number of types of crops and livestock produced by households over the last 12 months preceding the survey [22]. We classified farm production diversity into $\leq$5, 6–10 and >10. Grouping of categorical variables was done to ensure a reasonable spread of participants in each category in order to avoid the problem of data sparsity in statistical modelling.

### *2.3. Vulnerability of Dietary Patterns*

The vulnerability of household dietary patterns was assessed based on extent of dependency on major calorie sources of the diets [23]—an indication of dietary vulnerability to crop failure or price fluctuations. Vulnerability scores were calculated by determining calorie concentration proportions of staples to total consumption in the diets. Dietary patterns with the highest proportion of calories from single staples were considered to be more vulnerable than those dependent on many major sources of energy.

### *2.4. Statistical Analysis*

Thirty-two food groups were created from the 127 food items based on shared nutritional content. For example, different types of large fish and small fish were combined to form the large and small fish food groups; similarly, different types of green leafy vegetables were combined to form the green leafy vegetables group. Details on the food groupings are provided in the Supplementary Materials (Table S1). Average household level energy intakes were categorized into zero, low, medium and high proportions of total calories by each food group (i.e., zero intake and tertiles of energy from that food group as a proportion of total dietary energy consumption). The categorical variables were used to define separate dietary patterns of the data using finite mixture modelling. All dietary predictor variables were considered to be uncorrelated with one another and were entered into the latent class analysis (LCA) models (see Supplementary Materials). The LCA method of dietary pattern analysis allows membership of dietary patterns to be mutually exclusive, hence each household was assigned to a single dietary pattern based on probability. We described each pattern by looking at the mean consumption of the different food groups by households assigned to that pattern.

The main explanatory variables were wealth status, age, religion, marital status and educational level of the head of household, plus household size and farm production diversity of households. Dietary patterns were the outcomes of interest.

Due to likely clustering in the data within both households and districts, we fitted mixed effects logistic regression models to enable us to account for the correlations in dietary intake. Therefore, we specified households nested in districts as random effects and included the explanatory variables as fixed effects utilizing the *melogit* command in Stata. Further details on the modelling strategy, tests for interactions and multicollinearity are provided in the Supplementary Materials (Table S2).

LCA was conducted in Mplus (version 7.5). Descriptive statistics and mixed effects logistic regression modelling were performed using Stata (version 16.1).

## 3. Results

### 3.1. Dietary Patterns in Bangladesh

The study sample included 800 households in predominantly rural areas of Bangladesh. The mean age of household heads was 45 ± 14 years who mostly practiced Islam (88.9%), and nearly half (47.6%) had no formal education. The average household size was 5 ± 2 members, and 40% were classified as poor households. Most households across dietary patterns had farm production diversity between six and 10 different crops or livestock (48.5%). All geographical regions of Bangladesh were reasonably equally represented (Table 1).

**Table 1.** Distribution of socio-demographic characteristics of households by dietary pattern in Bangladesh.

| Characteristic | Rice and Low Diversity *n* (%) | Wheat and High Diversity *n* (%) | Pulses and Vegetables *n* (%) | Meat and Fish *n* (%) | Total *n* (%) |
|---|---|---|---|---|---|
| Total | 263 (32.9) | 262 (32.8) | 259 (32.4) | 16 (2.0) | 800 (100.0) |
| Age group [a] (years) | | | | | |
| ≤35 | 53 (20.2) | 99 (37.8) | 68 (26.3) | 3 (18.8) | 223 (27.9) |
| 36–45 | 95 (36.1) | 62 (23.7) | 64 (24.7) | 4 (25.0) | 225 (28.1) |
| 46–55 | 55 (20.9) | 55 (21.0) | 65 (25.1) | 6 (37.5) | 181 (22.6) |
| >55 | 60 (22.8) | 46 (17.6) | 62 (23.9) | 3 (18.8) | 171 (21.4) |
| Religion [a] | | | | | |
| Muslim | 247 (93.9) | 223 (85.1) | 230 (88.8) | 11 (68.8) | 711 (88.9) |
| Hindu/other | 16 (6.1) | 39 (14.9) | 29 (11.2) | 5 (31.3) | 89 (11.1) |
| Educational level [a] | | | | | |
| None | 156 (59.3) | 102 (38.9) | 119 (45.9) | 4 (25.0) | 381 (47.6) |
| Primary school | 96 (36.5) | 123 (46.9) | 113 (43.7) | 7 (43.7) | 339 (42.4) |
| Secondary/Tertiary | 11 (4.2) | 37 (14.1) | 27 (10.4) | 5 (31.3) | 80 (10.0) |
| Household size | | | | | |
| 1–4 | 89 (33.8) | 159 (60.7) | 119 (46.0) | 7 (43.8) | 374 (46.8) |
| 5–7 | 136 (51.7) | 86 (32.8) | 116 (44.8) | 8 (50.0) | 346 (43.2) |
| >7 | 38 (14.6) | 17 (6.5) | 24 (9.3) | 1 (6.3) | 80 (10.0) |
| Farm production | | | | | |
| ≤5 | 97 (36.9) | 72 (27.5) | 86 (33.2) | 3 (18.7) | 258 (32.2) |
| 6–10 | 125 (47.5) | 129 (49.2) | 124 (47.9) | 10 (62.5) | 388 (48.5) |
| >10 | 41 (15.6) | 61 (23.3) | 49 (18.9) | 3 (18.8) | 154 (19.3) |
| Household wealth | | | | | |
| Poor | 146 (55.5) | 69 (26.3) | 101 (39.0) | 4 (25.0) | 320 (40.0) |
| Medium | 39 (14.8) | 6.1 (23.3) | 58 (22.4) | 2 (12.5) | 160 (20.0) |
| Rich | 78 (29.7) | 132 (50.4) | 100 (38.6) | 10 (62.5) | 320 (40.0) |
| Region of residence | | | | | |
| Northern | 83 (31.6) | 50 (19.1) | 59 (22.8) | 8 (50.0) | 200 (25.0) |
| Eastern | 100 (38.0) | 99 (37.8) | 97 (37.4) | 4 (25.0) | 300 (37.5) |
| Central | 39 (14.8) | 50 (19.1) | 49 (18.9) | 2 (12.5) | 140 (17.5) |
| Southern | 41 (15.6) | 63 (24.0) | 54 (20.8) | 2 (12.5) | 160 (20.0) |

[a] Characteristic of household head.

Four dietary patterns were identified in the best-fitting latent class analysis model. We named these patterns rice and low diversity (263 households or 33% of the sample); wheat and high diversity (262 households or 33% of the sample); pulses and vegetables (259 households or 32% of the sample); meat and fish (16 households or 2% of the sample), based on the major food groups consumed in each pattern.

### *3.2. Energy and Nutrient Intakes of Dietary Patterns*

There were notable differences in the intake of staple cereals between dietary patterns: all patterns were highly based on rice, but rice consumption was highest among participants who followed the rice and low diversity and the meat and fish pattern, while those who followed the wheat and high diversity pattern consumed around 500 kcal less rice per day, accompanied by a higher consumption of wheat, pulses and oils (Figure 1).

Fruit and vegetable consumption was low in the rice and low diversity pattern at around 100 kcal per day and highest in the wheat and high diversity pattern at around 180 kcal per day. Meat and fish represented a significant amount of daily energy for followers of the meat and fish and the wheat and high diversity patterns but were much more rarely consumed in the other two patterns (Figure 1). Dairy products were hardly ever consumed in all sampled households (Supplementary Table S2). Further details of food groups that describe the patterns are provided in Supplementary Table S3.

The average daily energy intake was 2934 kcal/capita/day. Energy intakes were highest among followers of the wheat and high diversity pattern (3055 kcal/capita/day) and lowest in the rice and low diversity pattern (2813 kcal/capita/day) (Table 2). Average diets across the sample were high in carbohydrates and did not meet WHO recommendations for the proportion of energy from fat or protein (Table 2). However, consumers of the wheat and high diversity pattern did meet these requirements on average, and consumers of the meat and fish pattern just met the recommendation on protein intake. In the rice and low diversity pattern, only 3% of individuals met the requirement on fat intake, and 10% met the requirement on protein intake. Even though participants in the wheat and high diversity pattern had the highest daily fruit and vegetable intake (381 g), this was still below the WHO recommendation of 400 g per day. Only 18.4% of the total sample met the recommendation for fruit and vegetables—lowest in the rice and low diversity pattern (3.4%) and highest in the wheat and high diversity pattern (37.0%) (Table 2). The distribution of proportions of participants meeting the WHO recommendations for carbohydrates, fat, protein and fruit and vegetables by other household characteristics are presented in the Supplementary Materials (Table S4).

**Table 2.** Adequacy of macro-nutrient intake and fruit and vegetable intake by dietary pattern in Bangladesh.

| | WHO Recommendation | Rice and Low Diversity (*n* = 263) | Wheat and High Diversity (*n* = 262) | Pulses and Vegetables (*n* = 259) | Meat and Fish (*n* = 16) | Total (*n* = 800) |
|---|---|---|---|---|---|---|
| Total energy (kcal/capita/day) mean (95% CI) | | 2812.86 (27310.8–2893.3) | 3054.7 (2956.6–3152.8) | 2918.7 (2839.1–2998.3) | 3225.1 (2750.9–3699.3) | 2933.5 (2883.5–2983.5) |
| Macro-nutrient (mean % of total energy) | | | | | | |
| Carbohydrate | 55–75 | **78.9** | 70.6 | **76.1** | **75.2** | **75.2** |
| Fat | 15–30 | **9.1** | 16.2 | **11.4** | **12.5** | **12.2** |
| Protein | 10–15 | **9.0** | 11.0 | **9.7** | 10.1 | **9.9** |
| Fruit and vegetables (mean in grams) | 400 | **218.9** | **380.7** | **284.4** | **248.6** | **293.7** |
| Met WHO recommendation (%) | | | | | | |
| Carbohydrate | | 100.0 | 97.7 | 100.0 | 100.0 | 99.2 |
| Fat | | 3.0 | 48.1 | 8.5 | 25.0 | 20.0 |
| Protein | | 10.0 | 37.0 | 29.0 | 37.5 | 25.4 |
| Fruit and vegetables | | 3.4 | 36.6 | 15.4 | 12.5 | 18.4 |

Bolded values indicate inadequacy.

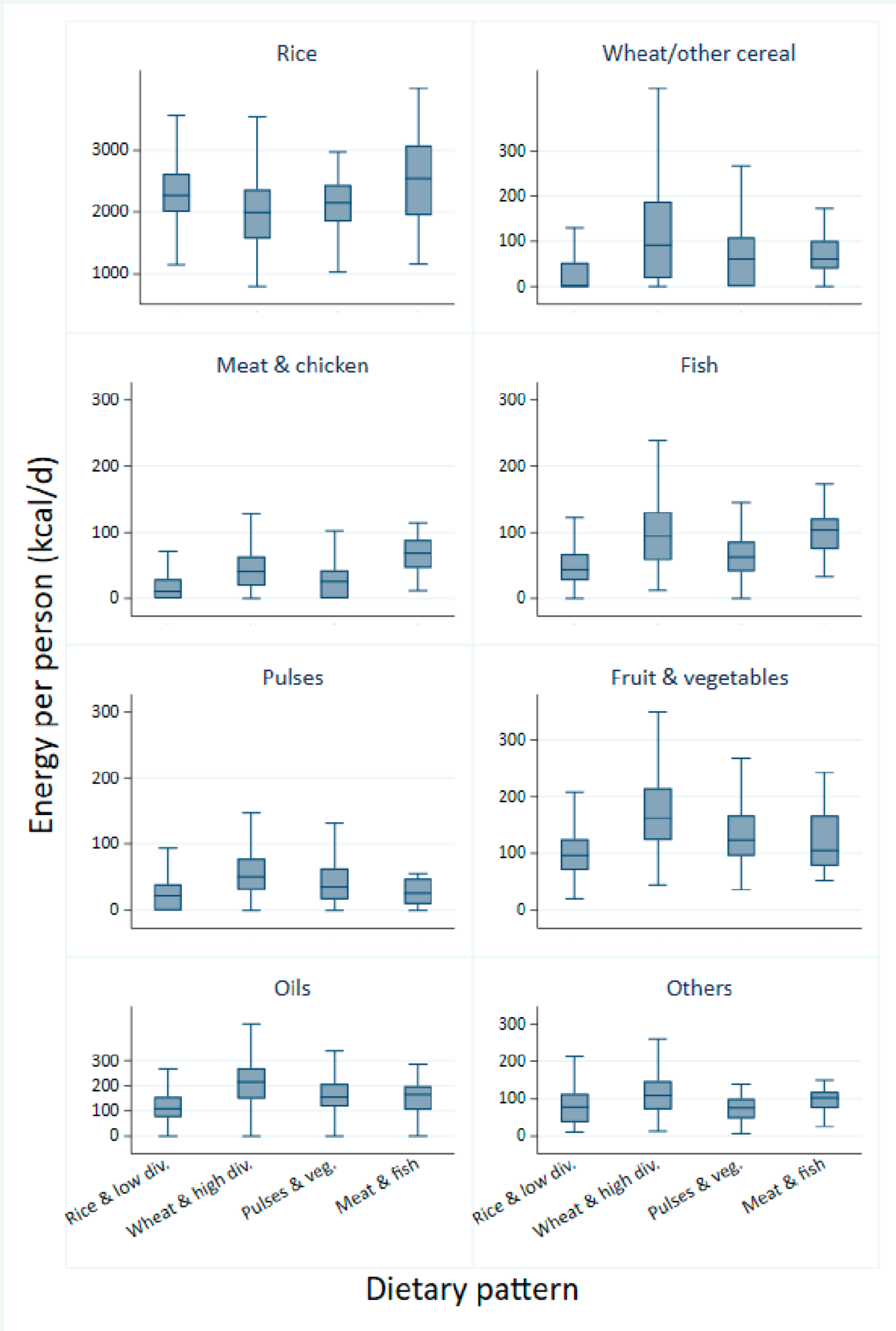


**Figure 1.** Mean energy from consumption of food groups by dietary pattern.

### *3.3. Predictors of Dietary Patterns in Bangladesh*

Wealth and education levels both varied according to the dietary patterns: the rice and low diversity pattern tended to be consumed by poorer households and those with lower levels of education, while the meat and fish and wheat and high diversity patterns were consumed by households with higher levels of education and wealth (Table 1 and Supplementary Table S5). The pulses and vegetables pattern tended to be consumed by households of intermediate status. There was also some evidence of differences in dietary patterns according to region. In particular, the rice and low diversity pattern was more likely to be consumed in the north and less in the central and southern regions, as was the meat and fish pattern, although the sample size for this diet was low. The wheat and high diversity pattern was less likely to be consumed in the north and more common in the southern and central regions. Few other differences between household characteristics and dietary patterns were observed (Table 1).

In a mixed effects regression model adjusting for other potential predictor variables including household wealth, age of household head, religion, education, household size, farm production diversity and region of residence (Table 3), the most important predictors of consumption of the rice and low diversity pattern were lower household wealth (OR 0.41 (95% CI: 0.27–0.61) of following this pattern for the wealthiest households compared to the least wealthy), lower educational attainment (OR 0.37 (95% CI: 0.18–0.77) for heads of households with at least secondary education compared to none), larger household size (OR 4.15 (95% CI: 2.28–7.58 for largest households compared to smallest) and residence in the northern region (OR 2.43 (95% CI: 1.46–4.03) compared to those in the south) (Table 3).

**Table 3.** Predictors of dietary pattern in Bangladesh (mixed effects logistic regression).

| Predictor | Rice and Low Diversity ($n$ = 263) | | Wheat and High Diversity ($n$ = 262) | | Pulses and Vegetables ($n$ = 259) | | Meat and Fish ($n$ = 16) | |
|---|---|---|---|---|---|---|---|---|
| | AOR † (95% CI) | $p$-Value | AOR † (95% CI) | $p$-Value | AOR † (95% CI) | $p$-Value | UOR ¶ (95% CI) | $p$-Value |
| Household wealth | | | | | | | | |
| Poor | 1 | <0.001 | 1 | <0.001 | 1 | 0.49 | 1 | 0.19 |
| Medium | 0.46 (0.29–0.73) | | 1.94 (1.23–3.06) | | 1.21 (0.58–2.53) | | 1.00 (0.18–5.52) | |
| Rich | 0.41 (0.27–0.61) | | 2.66 (1.77–4.02) | | 0.91 (0.54–1.51) | | 2.55 (0.79–8.21) | |
| Age group (years) | | | | | | | | |
| ≤35 | 1 | 0.04 | 1 | 0.10 | 1 | 0.16 | 1 | 0.57 |
| 36–45 | 1.75 (1.11–2.74) | | 0.63 (0.41–0.97) | | 0.87 (0.47–1.63) | | 1.32 (0.29–6.00) | |
| 46–55 | 1.00 (0.61–1.64) | | 0.66 (0.42–1.04) | | 1.36 (0.51–3.66) | | 2.51 (0.62–10.20) | |
| >55 | 1.17 (0.71–1.92) | | 0.60 (0.37–0.98) | | 1.42 (0.47–4.31) | | 1.31 (0.26–6.57) | |
| Religion | | | | | | | | |
| Muslim | 1 | 0.02 | 1 | 0.25 | 1 | 0.84 | 1 | 0.03 |
| Other | 0.49 (0.27–0.91) | | 1.35 (0.81–2.25) | | 1.06 (0.58–1.93) | | 3.79 (1.28–11.17) | |
| Educational status | | | | | | | | |
| None | 1 | 0.002 | 1 | 0.74 | 1 | 0.74 | 1 | 0.01 |
| Primary school | 0.71 (0.50–1.01) | | 1.10 (0.77–1.57) | | 1.21 (0.63–2.31) | | 1.99 (0.58–6.80) | |
| Secondary/Tertiary | 0.37 (0.18–0.77) | | 1.23 (0.71–2.15) | | 1.31 (0.48–3.63) | | 1.28 (1.65–23.95) | |
| Household size | | | | | | | | |
| 1–4 | 1 | <0.001 | 1 | <0.001 | 1 | 0.80 | 1 | 0.93 |
| 5–7 | 2.30 (1.59–3.32) | | 0.43 (0.30–0.62) | | 1.06 (0.70–1.62) | | 1.24 (0.45–3.46) | |
| >7 | 4.15 (2.28–7.58) | | 0.28 (0.15–0.54) | | 0.87 (0.41–1.83) | | 0.66 (0.08–5.47) | |
| Farm production | | | | | | | | |
| <5 | 1 | 0.35 | 1 | 0.22 | 1 | 0.93 | 1 | 0.51 |
| 6–10 | 0.81 (0.56–1.18) | | 1.22 (0.83–1.80) | | 0.94 (0.61–1.44) | | 2.07 (0.56–7.60) | |
| >10 | 0.70 (0.42–1.17) | | 1.54 (0.94–2.52) | | 0.91 (0.50–1.64) | | 1.56 (0.31–7.81) | |
| Region of residence | | | | | | | | |
| Northern | 2.43 (1.46–4.03) | <0.001 | 0.43 (0.26–0.70) | 0.005 | 0.87 (0.45–1.69) | 0.74 | 3.29 (0.69–15.72) | 0.20 |
| Eastern | 1.32 (0.81–2.17) | | 0.79 (0.50–1.25) | | 1.02 (0.61–1.70) | | 1.07 (0.19–5.89) | |
| Central | 1.20 (0.68–2.12) | | 0.74 (0.44–1.25) | | 1.18 (0.56–2.48) | | 1.14 (0.16–8.24) | |
| Southern | 1 | | 1 | | 1 | | 1 | |

† Adjusted for all other variables in the model (mixed effects model). ¶ Unadjusted odds ratio from univariate logistic regression.

By contrast, higher household wealth (OR 2.66 (95% CI: 1.77–4.02) for the wealthiest households compared to the least wealthy), smaller household size (OR 0.28 (95% CI: 0.15–0.54) for the largest households compared to the smallest) and residence in the southern region (OR 0.43 (95% CI: 0.26–0.70) for households in the north compared to the south) were the strongest predictors of the wheat and high diversity pattern.

There was no significant association between any household characteristics and households following the pulses and vegetables dietary pattern, which appeared to be broadly spread across all categories of households.

For predictors of the meat and fish dietary pattern, due to data sparsity problems in multivariable models, we present only univariate logistic regression tests of associations between explanatory variables and this dietary pattern. Non-Muslim-headed households were more likely to have this pattern of eating compared with Muslim-headed households

(OR 3.79 (95% CI 1.28–11.17)), and having at least secondary education showed some evidence of an association (OR 1.28 (95% CI: 1.65–23.95)). However, results for this pattern should be interpreted with caution due to the small sample size.

In general, age of household head tended to be only weakly associated with dietary pattern, and we found no significant associations between levels of farm production diversity and dietary pattern.

### *3.4. Vulnerability of Dietary Patterns to Potential Shocks*

The test of vulnerability of the diets to possible price fluctuations and crop failure showed that diets in the sample tended to be highly vulnerable with an overall 75% of total household calories contributed by a single staple crop (rice). The rice and low diversity pattern was the most vulnerable with 84.2% of total calories contributed by a single staple crop; the wheat and high diversity pattern was the least vulnerable, with a little above half of total calories (63%) derived from a single staple. The pulses and vegetables and meat and fish patterns were the second and third most vulnerable diets, respectively (Table 4).

**Table 4.** Vulnerability scores of household dietary patterns.

| Pattern | $V_1$ | $V_2$ | $V_3$ | Vulnerability Rank |
|---|---|---|---|---|
| Rice and low diversity | 84.16 | 85.19 | 85.20 | 1 * |
| Wheat and high diversity | 63.00 | 69.45 | 69.54 | 4 |
| Pulses and vegetables | 76.40 | 79.04 | 79.06 | 2 |
| Meat and fish | 75.50 | 78.81 | 78.81 | 3 |
| Overall | 74.55 | 77.92 | 77.95 | |

$V_i$ = proportion of total calories consumed from staple food accounted for by *i* most important staple crops. * Most vulnerable diet.

## 4. Discussion

### *4.1. Summary of Main Results*

Our analysis of dietary patterns among households in Bangladesh identified four distinct dietary patterns: we characterized these as being based on rice and low diversity, wheat and high diversity, pulses and vegetables and meat and fish. The most important factors predicting dietary pattern of households were wealth and education, with family size, age and religion also showing some associations. Farm production diversity was not associated with dietary pattern after adjustment for other factors. All patterns attained by far the majority of their energy supply from carbohydrates and tended to have inadequate consumption of the other macronutrients and fruit and vegetables. Households following the rice and low diversity pattern had the lowest proportion of members with adequate fat, protein and fruit and vegetable intake. Those following other patterns had a higher proportion of members with adequate intakes. The rice and low diversity and meat and fish patterns were the most vulnerable diets to external shocks, while the wheat and high diversity and pulses and vegetables patterns were less vulnerable to potential shocks and potentially more nutritionally adequate, as indicated by higher intakes of fruit and vegetables.

### *4.2. Comparison with Previous Studies*

Previous studies reporting dietary patterns in Bangladesh have found varying numbers of patterns. Two studies found three patterns using principal component analysis [24,25]. Seven patterns were identified by Waid et al. using principal component analysis [26]. The basic components of identified patterns are, however, similar and include intake of foods such as rice, vegetables, pulses, meats and oils, which are similar to the foods that make up the patterns identified in the present analysis. For instance, the three patterns described by Chen et al. [24] were a "balanced pattern" characterized by rice, fish, meat, fruits and vegetable consumption; an "animal protein diet" and a "gourd and root vegetable diet". These patterns could be traced to the wheat and high diversity, meat and fish and the pulses and vegetables patterns identified in the present study.

The high wealth and education associated with the wheat and high diversity and the meat and fish patterns make them characteristic of diets that might represent a nutrition transition. Even though these patterns were generally associated with high energy from fats and proteins, the wheat and high diversity pattern may be a healthier pattern than the meat and fish pattern because it had higher intakes of fruit and vegetables. Previous studies have found evidence of a positive association between production diversity and dietary diversity [22,27]. This was not the case in the present study, although for the two patterns more associated with higher social status, there was some evidence of a positive trend with increased production diversity. However, in this study, at least it appears clear that wealth and education levels were much more clearly associated with dietary diversity than diversity of production. There is evidence that as wealth increases, consumption of less expensive staples such as rice decreases with a shift towards intake of prestigious cereals such as polished rice or processed wheat, meat, oils, sugar and high diet diversity [28,29]. The characteristic high education and wealth of these two patterns is indicative of this idea. These findings are consistent with a recent global analysis, which showed that household wealth and higher female education are strongly related to nutrition and health outcomes [30].

Low membership of the meat and fish pattern may suggest that it is an emerging dietary pattern in the country. It has characteristics typical of a nutrition transition diet: high meat, oils, rice and sugar [31]. In addition, low membership could be because the sample was drawn from predominantly rural farming areas of Bangladesh, and most of this pattern's components are less likely to be available to or affordable by many rural households.

The high proportion of total energy from carbohydrates in all patterns is consistent with the results of previous national data, where 70% of total energy of Bangladeshi diets was from cereals [32]. Even though increased energy intake from carbohydrates has been linked with good health and delayed onset of chronic diseases [33], having more than the recommendation could mean a substitution for other essential energy sources that are important to health. The low proportion of households with adequate intakes of fats, proteins and fruit and vegetables is indicative of nutrient substitution.

### *4.3. Strengths and Limitations*

This study has some important strengths. Data were collected on a wide range of household variables across population groups in Bangladesh, which allowed for a better understanding of diet and associated characteristics. Another strength is the availability of food quantities, which enabled energy calculations for use in LCA, improving the interpretations of results compared to using food frequencies to define dietary patterns [34]. An additional strength is the ability to estimate macro-nutrient adequacy of the diets, which many studies reporting dietary patterns are not able to do, either due to limitations in statistical methods or underlying data limitations. Our assessment of the relative vulnerability of the diets to external shocks is an added strength not usually assessed in similar studies.

The study also has some limitations that are worth noting. We cannot rule out data validity and reliability problems associated with use of recalled dietary intake data. However, the longer recall period could mean that the dietary data reflect the usual intake of households, hence dietary patterns resulting from them are more likely to reflect people's regular food intake. The United Nation's Food and Agriculture Organization food balance sheet data show an increasing trend of total energy per person per day in Bangladesh. However, these have remained ~2500 kcal/person/day between 2008 and 2013 [35], which could indicate some level of over-reporting of energy intakes in this study where average intakes were ~3000 kcal per person per day. As the estimation of dietary patterns relies largely on comparing proportions of different foods consumed rather than absolute amounts, over-reporting is likely to have had a minimal effect on the findings of the study. Despite the likely high over-reporting of intakes, fats, proteins and fruit and vegetables consumption were still suboptimal, implying that actual intakes could even be lower than what we have reported. There is also a possibility that the results obtained from the survey were seasonally biased, since data collection took place only in the months of December to February. Other dietary patterns may, therefore, exist among this population in other seasons that were not captured in the present analysis.

In addition, the data used in defining dietary patterns did not include foods eaten out of home. It is possible the foods people eat out of home are different from what they will eat in the home. This may constitute an important part of the pattern that people eat and could affect the validity of our results. While this may be a limitation of the data, it can be difficult to obtain accurate estimates of out of home food intake at the household level, and attempts to do this may increase errors associated with recalled data. There are also not many reasons to suggest that out of home eating had much effect on our results, because households were from mostly rural areas and foods eaten away from home are less likely to be very different from what they will normally eat at home.

Further, individual-level energy and macro-nutrient intakes were derived from household level estimates using proxy nutrient requirements of individuals. Even though this approach is shown to closely approximate individual intakes in comparison with self-reported data [18] and has also permitted the use of household food expenditure and food consumption data in making useful individual level inference, some limitations may persist. For instance, household food may not be equitably distributed among all members [36], but the approach is unable to account for this potential intra-household food distribution problem. Therefore, our estimates of energy intake and macro-nutrient adequacies need to be interpreted with caution. To avoid over-interpretation of results, we did not estimate micro-nutrient adequacy of the diets; rather, we assessed the adequacy of fruit and vegetable intake, a good proxy for micro-nutrient intake. However, because of the limited nutritional variables used in the analysis, we were unable to adequately measure over-consumption of particular nutrients such as sugar or salt, which may have shed further light on the double burden of malnutrition in Bangladesh.

When defining the vulnerability of dietary patterns to shocks, we used the proportion of energy that came from single staples as the defining factor. This measure is, therefore, based heavily on diversity of the diet and does not take into account potential vulnerability of individual crops to particular shocks. Some dietary patterns may, therefore, be more vulnerable in particular ways that are not documented in this analysis.

Another limitation is the size and representativeness of the dataset. The data are representative across regions, but there was likely under representation of urban and some socio-economic groups because households were sampled from largely rural farming areas. The sample size proved adequate for the analysis of three of the four dietary patterns identified, but there were too few households assigned to the meat and fish pattern to produce a robust analysis. Finally, the data were collected between 2010 and 2011, so diets may have changed quite substantially since this time.

### *4.4. Implications Including Policy Recommendations*

Our findings suggest that energy deprivation is not a major problem among rural farming households in Bangladesh. Public health nutrition efforts should focus on improving other diet quality indicators: fruit and vegetable intake, fats and protein adequacy.

We also find that household wealth and education were more strongly related to diets than farm production diversity. Those who are doing the farm production might prefer selling their products over consumption, as they perceive it as an income generating source. Public health nutrition interventions aiming to improve diets should target the consumption of one's own produce among less wealthy and less educated households.

Further, the dietary patterns showed characteristics of an emerging nutrition transition. The patterns represent a mixture of both healthy and potentially less healthy diets. They appear to indicate a transition from a more staple-based diet composed of less diversity through a mixture of staples and high diversity towards diets high in meats, fats and refined foods (potentially represented by the emerging meat and fish pattern, although this diet was only consumed by small numbers of households at the time of data collection). These results are suggestive of an emerging transition of Bangladeshi diets towards potentially less healthy patterns as people get wealthier [37], although in our analyses, we found no evidence that fat intake was above the recommended levels in any of the dietary patterns.

Finally, our data show evidence of a double vulnerability of diets [38], whereby the dietary patterns most associated with nutritional inadequacy (rice and low diversity and pulses and vegetables) were also those most vulnerable to shocks including those that may occur as a result of food price fluctuations and future climate change. As Bangladesh is already highly vulnerable to climate change, crop failure and food price instability, especially in rice, it will have a greater impact on diets. In the spectrum of the transitioning diets, the pulses and vegetables diet could be an achievable short-term goal towards a lower vulnerability and increased nutritional adequacy for households currently consuming the rice and low diversity diet, due to its greater diversity and likely higher micronutrient content. While diet diversification of major staples will make diets less vulnerable to shocks from crop failure and price instability, switching to other staples such as wheat or maize could come with additional costs in the short term, which can hinder their uptake and sustainability. In spite of this possible initial setback, our analysis shows that some households such as those following the wheat and high diversity pattern are already deriving a substantial amount of dietary energy from alternative sources such as wheat, which can be considered for a national scale-up. While existing Government of Bangladesh price stabilization plans for rice remain a major guard against diet vulnerabilities, potential future declines in rice yields due to climate change and resulting increases in price may become unbearable in the long term. Therefore, it is important to promote and subsidize alternative staples such as wheat and maize to ensure that major shocks affecting rice will have minimal impacts on overall diets in Bangladesh.

## 5. Conclusions

Our findings show clear evidence of vulnerability to shocks among all diets in the sampled rural Bangladeshi households, due to their reliance on single staple foods. The identified dietary patterns consist of a mixture of healthy and potentially less healthy patterns, with some patterns showing evidence of greater dietary diversity but only among wealthier population groups. The diets also showed "double vulnerability" where the nutrient-inadequate patterns were also those most vulnerable to potential shocks. National food policies should aim to increase the availability of other staples and fruits and vegetables to reduce over reliance on single staples such as rice to minimize dietary vulnerability and improve nutrient adequacy of diets.

**Supplementary Materials:** The following are available online at https://www.mdpi.com/article/10.3390/nu13062049/s1, Table S1: 32 food groups from 127 foods data, S1: Latent class analysis modelling, Table S2: Latent class model fit statistics, S2: Statistical modelling strategy, Table S3: 32 food groups and mean individual daily consumption (in kcal) by identified dietary patterns, Table S4: Distribution of proportions meeting WHO recommendations by selected sample characteristics, Table S5: Univariable predictors of dietary patterns in Bangladesh.

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**Institutional Review Board Statement:** The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Institutional Review Board (or Ethics Committee) of the London School of Hygiene and Tropical Medicine (Ref. 17414, approved: 2019).

**Informed Consent Statement:** Written informed consent has been obtained from the patient(s) to publish this paper.

**Data Availability Statement:** The data used in this analysis have been made completely anonymized and available for free download by the International Food Policy Research Institute (IFPRI) through the following web address: https://doi.org/10.7910/DVN/27704, accessed on 10 June 2019. IFPRI obtained informed consent from all subjects involved in the study.

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## *Supplementary material for paper 4*

**Table S1: 32 food groups from 127 foods data**

| No. | Food group | Component foods |
|---|---|---|
| 1. | Cereal-rice | Rice, fine rice, rice flour, suji |
| 2. | Cereal-wheat | Wheat, chira, atta/moida, |
| 3. | Cereal-other | Noodles, semai, other cereal |
| 4. | Pulse-lentil | Lentil |
| 5. | Pulse-blackgram | Black gram |
| 6. | Pulse-other | Khesari, Mashkalai, mung, chick pea, other pulse |
| 7. | Vegetable-oil | Soyabean/palm oil, mustard/sesame oil, ghee, other |
| 8. | Vegetable-egg plant | Egg plant |
| 9. | Vegetable-tomato | Tomato |
| 10. | Vegetable-gourd | Ash gourd, sweet gourd, jhinga, bitter gourd |
| 11. | Vegetable-cabbage | Cabbage, cauliflower |
| 12. | Vegetable-bean | Long bean, soybean bori |
| 13. | Vegetable-onion | Onion, garlic |
| 14. | Vegetable-radish | Radish |
| 15. | Vegetable-other | Patal, cucumber, okra, drumstick, green banana, papaya, katchu, danta, carrot, green chilli, jhinga, other vegetable |
| 16. | Potato | Potato |
| 17. | Leafy vegetable-pui | Pui |
| 18. | Leafy vegetable-other | Kalmi, lal shak, bathua, lau shak, kachu, blackgram leaves, mustard leaves, radish leaves, onion/garlic stalk, pat shak, mixed leafy vegetables, tea leaf, other leafy vegetable |
| 19. | Chicken | Chicken |
| 20. | Beef | Beef |
| 21. | Meat-other | Mutton/goat, pork |
| 22. | Egg | Eggs |
| 23. | Fruit-jujube | Jujube/olive |
| 24. | Fruit-banana | Banana |
| 25. | Fruit-orange | Orange |
| 26. | Fruit-apple | Apple, bell/wood apple |
| 27. | Fruit-other | Tamarind, jaamrul, chalta, ata, guava, papaya, dalim, grapes, coconut, lemon, other fruit |
| 28. | Fish-large | Hilsa, grass carp, boal, should, tilapia, singi, kalibaus, baim, tortoise, dry fish, other big fish |
| 29. | Fish-small | Puti, moa, pabda, koi, tatkeni, prawn, other small fish |
| 30. | Dairy | Cow/goat/sheep milk, condensed milk, powder milk |
| 31. | Sweets | Sugar, sweets/curd, biscuits/cookies, prepared tea, soft drink/coke, pack juice |
| 32. | Spices | Dried chilli, tejpata, turmeric, corianda, jira, elachi, panchforan, ginger, salt, other spice |

**S1: Latent class analysis modelling**

We ran latent class models for both continuous and categorical variables and chose outputs with better model fit characteristics and showed more local relevance. With increasing number of classes from one to seven, we identified the best class solution for the data. Random iteration starts were specified at 50 to 2000 increasing with increasing number of classes specified in LCA. We stopped at a maximum of seven classes because there was no improvement in model fit statistics and convergence problems emerged despite increasing the number of random starts. Goodness of fit statistics of the models considered for choosing the best class solution for the data were Akaike information criterion (AIC), Bayesian information criterion (BIC) and entropy of class membership[a]. Models with the lowest AIC and BIC, and a high entropy had best fit to the data and were selected for the regression modelling. In addition to model fit statistics, we considered interpretability of the solutions in choosing the final class solution for the data.

**Table S2: Latent class model fit statistics**

| **Number of classes** | **AIC** | **BIC** | **Entropy** | **Probability of membership** |
|---|---|---|---|---|
| 1 | 68850.72 | 69150.54 | 1 | 1:0 |
| 2 | 67319.96 | 67774.37 | 1 | 0.30:0.70 |
| 3 | 65768.14 | 66377.14 | 1 | 0.030:0.68:0.29 |
| **4** | **64261.56** | **65025.15** | **1** | **0.33:0.33:0.32:0.02** |
| 5 | 63498.16 | 64416.34 | 1 | 0.02:0.33:0.32:0.30:0.03 |
| 6 | 62999.22 | 64072 | 0.939 | 0.02:040:0.15:0.32:0.08:0.03 |
| 7 | 62354.91 | 63582.28 | 0.945 | 0.02:0.39:0.32:0.15:0.02:0.07:0.03 |

[a] Patterson BH, Dayton CM, Graubard BI. Latent class analysis of complex sample survey data: application to dietary data. Journal of the American Statistical Association. 2002;97(459):721-41.

**S2: Statistical modelling Strategy**

We used the likelihood ratio test to assess the suitability of a 3-level model which includes both households and districts as random effects or a 2-level model which includes only households as random effects as best fit for the data. The most suitable model level was chosen for the data.

The decision to include a covariate in the multivariable models was based on theorised causal relationships between variables and informed by best model fit statistics using the likelihood ratio test. We first tested for bivariate associations between explanatory variables and the outcomes using chi-squared tests. All explanatory variables were either binary or categorical in nature. We performed tests of departures from linearity to assess the suitability to use either a linear or categorical form of explanatory variables in the models which also used the likelihood ratio test. Reference categories for explanatory binary/categorical variables in our models were those with more participants. Where this rule made interpretation difficult, we chose a reference group that improved interpretation of the results. We assessed the possibility of multi-collinearity among the fixed effects in our models by checking changes in standard errors when other variables were added to the models. Interactions among explanatory variables in the models were also checked by fitting interaction terms between covariates of interest.

Dietary patterns with fewer observations faced data sparsity problems in mixed effects models. This meant that the models did not have enough outcome data to estimate multiple odds ratios. For this reason, mixed effects models were not fitted. Instead, we used univariate logistic regression to explore unadjusted associations between explanatory variables.

**Table S3: 32 food groups and mean individual daily consumption (in kcal) by identified dietary patterns**

| No. | Food group | Rice & low diversity (mean) | Wheat & high diversity (mean) | Pulses & vegetables (mean) | Meat & fish (mean) |
|---|---|---|---|---|---|
| 1. | Cereal-rice | 2403.08 | 1968.38 | 2248.05 | 2533.96 |
| 2. | Cereal-wheat | 32.06 | 208.64 | 77.64 | 108.92 |
| 3. | Cereal-other | 0.23 | 3.09 | 0.57 | 0.10 |
| 4. | Pulse-lentil | 13.20 | 32.40 | 18.35 | 48.12 |
| 5. | Pulse-blackgram | 8.06 | 16.18 | 14.61 | 0.10 |
| 6. | Pulse-other | 6.31 | 21.12 | 11.15 | 0.31 |
| 7. | Vegetable-oil | 118.39 | 239.66 | 164.43 | 170.85 |
| 8. | Vegetable-egg plant | 7.67 | 12.10 | 9.71 | 10.18 |
| 9. | Vegetable-tomato | 1.36 | 2.96 | 1.88 | 1.89 |
| 10. | Vegetable-gourd | 0.95 | 2.50 | 1.43 | 0.81 |
| 11. | Vegetable-cabbage | 12.05 | 18.52 | 14.30 | 13.96 |
| 12. | Vegetable-bean | 12.48 | 28.79 | 19.58 | 23.41 |
| 13. | Vegetable-onion | 12.01 | 21.34 | 15.73 | 15.61 |
| 14. | Vegetable-radish | 4.65 | 5.20 | 5.24 | 1.88 |
| 15. | Vegetable-other | 31.25 | 45.67 | 37.81 | 30.14 |
| 16. | Potato | 50.18 | 77.31 | 67.78 | 67.17 |
| 17. | Leafy vegetable-pui | 2.29 | 4.81 | 2.77 | 4.44 |
| 18. | Leafy vegetable-other | 11.19 | 19.19 | 15.77 | 10.26 |
| 19. | Chicken | 15.08 | 3.95 | 24.82 | 24.99 |
| 20. | Beef | 1.96 | 6.93 | 3.42 | 4.18 |
| 21. | Meat-other | 0.14 | 0.16 | 0.22 | 38.11 |
| 22. | Egg | 0.47 | 1.10 | 0.84 | 0.733 |
| 23. | Fruit-jujube | 8.32 | 21.79 | 14.77 | 5.50 |
| 24. | Fruit-banana | 0.25 | 0.59 | 0.34 | 0.33 |
| 25. | Fruit-orange | 0.10 | 0.99 | 0.58 | 0.56 |
| 26. | Fruit-apple | 1.05 | 5.18 | 1.60 | 4.64 |
| **27.** | Fruit-other | 1.98 | 4.92 | 2.03 | 2.89 |
| 28. | Fish-large | 37.50 | 96.76 | 57.58 | 79.03 |
| 29. | Fish-small | 12.50 | 25.65 | 17.71 | 18.50 |
| 30. | Dairy | 2.29 | 16.80 | 3.67 | 13.28 |
| 31. | Sweets | 34.23 | 103.92 | 66.95 | 82.30 |
| 32. | Spices | 16.64 | 30.96 | 21.73 | 24.55 |

## 33. Table S4: Distribution of proportions meeting WHO recommendations by selected sample characteristics

| Characteristic | Proportion meeting WHO recommendations | | | |
|---|---|---|---|---|
| | Carbohydrate (%) | Fat (%) | Protein (%) | Fruit and vegetables (%) |
| **Household wealth** | | | | |
| Poor | 100.0 | 15.0 | 21.3 | 17.2 |
| Medium | 97.5 | 20.6 | 28.1 | 17.5 |
| Rich | 99.4 | 24.7 | 28.1 | 20.0 |
| **Educational level[a]** | | | | |
| None | 99.7 | 16.3 | 23.1 | 15.0 |
| Primary school | 98.5 | 20.9 | 25.7 | 19.5 |
| Secondary/Tertiary | 100.0 | 33.8 | 35.0 | 30.0 |
| **Household size** | | | | |
| 1-4 | 98.9 | 30.8 | 25.7 | 27.0 |
| 5-7 | 99.7 | 11.8 | 25.4 | 11.0 |
| >7 | 98.7 | 5.0 | 23.7 | 10.0 |
| **Region of residence** | | | | |
| Northern | 99.0 | 23.5 | 15.0 | 17.5 |
| Eastern | 99.3 | 18.0 | 31.7 | 19.0 |
| Central | 99.3 | 16.4 | 25.0 | 24.3 |
| Southern | 99.4 | 22.5 | 26.9 | 13.1 |

[a] Characteristic of household head

**34. Table S5: Univariable predictors of dietary pattern in Bangladesh**

| Predictor | Rice & low diversity (n=263) | | Wheat & high diversity (n=262) | | Pulses & vegetables (n=259) | |
|---|---|---|---|---|---|---|
| | OR (95%CI) | p-value | OR (95%CI) | p-value | AOR† (95%CI) | p-value |
| **Household wealth** | | | | | | |
| Poor | 1 | <0.001 | 1 | <0.001 | 1 | 0.50 |
| Medium | 0.38 (0.25-0.59) | | 2.24 (1.48-3.40) | | 1.23 (0.83-1.84) | |
| Rich | 0.38 (0.27-0.53) | | 2.55 (1.80-3.61) | | 0.99 (0.71-1.38) | |
| **Age group (years)** | | | | | | |
| ≤35 | 1 | <0.001 | 1 | <0.001 | 1 | 0.24 |
| 36-45 | 2.34 (1.56-3.51) | | 0.48 (0.32-0.71) | | 0.91 (0.60-1.36) | |
| 46-55 | 1.40 (0.90-2.18) | | 0.55 (0.36-0.82) | | 1.28 (0.84-1.94) | |
| >55 | 1.73 (1.12-2.69) | | 0.46 (0.30-0.71) | | 1.30 (0.85-1.98) | |
| **Religion** | | | | | | |
| Muslim | 1 | 0.002 | 1 | 0.02 | 1 | 0.96 |
| Other | 0.41 (0.23-0.72) | | 1.71 (1.1-2.67) | | 1.01 (0.63-1.62) | |
| **Educational status** | | | | | | |
| None | 1 | <0.001 | 1 | <0.001 | 1 | 0.80 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Primary school | 0.57 (0.42-0.78) | | 1.56 (1.13-2.14) | | 1.10 (0.80-1.51) | |
| Secondary/Tertiary | 0.23 (0.11-0.45) | | 2.35 (1.43-3.86) | | 1.12 (0.67-1.87) | |
| **Household size** | | | | | | |
| 1-4 | 1 | <0.001 | 1 | <0.001 | 1 | 0.79 |
| 5-7 | 2.07 (1.50-2.86) | | 0.45 (0.33-0.62) | | 1.08 (0.79-1.48) | |
| >7 | 2.90 (1.78-4.77) | | 0.36 (0.21-0.65) | | 0.92 (0.54-1.55) | |
| **Farm production** | | | | | | |
| <5 | 1 | 0.03 | 1 | 0.03 | 1 | 0.97 |
| 6-10 | 0.74 (0.531.04) | | 1.35 (0.95-1.93) | | 0.96 (0.68-1.36) | |
| >10 | 0.56(0.36-0.88) | | 1.78 (1.16-2.74) | | 0.96 (0.62-1.48) | |
| **Region of residence** | | | | | | |
| Northern | 2.05 (1.31-3.24) | 0.007 | 0.51 (0.33-0.80) | 0.03 | 0.82 (0.53-1.28) | 0.72 |
| Eastern | 1.45 (0.94-2.22) | | 0.76 (0.51-1.13) | | 0.94 (0.62-1.40) | |
| Central | 1.12 (0.687-1.87) | | 0.86 (0.53-1.37) | | 1.06 (0.66-1.70) | |
| Southern | 1 | | 1 | | 1 | |

**Paper 5:** Adherence to EAT-Lancet dietary recommendations for health and sustainability in The Gambia

# RESEARCH PAPER COVER SHEET

**Please note that a cover sheet must be completed for each research paper included within a thesis.**

## SECTION A – Student Details

| | | | |
|---|---|---|---|
| **Student ID Number** | 1800648 | **Title** | Mr |
| **First Name(s)** | Zakari | | |
| **Surname/Family Name** | Ali | | |
| **Thesis Title** | Resilient and healthy food systems in low-income settings | | |
| **Primary Supervisor** | Prof. Andrew Prentice | | |

**If the Research Paper has previously been published please complete Section B, if not please move to Section C.**

### SECTION B – Paper already published

| | | | |
|---|---|---|---|
| Where was the work published? | Environmental Research Letters | | |
| When was the work published? | 6th October 2022 | | |
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## SECTION D – Multi-authored work

| | |
|---|---|
| For multi-authored work, give full details of your role in the research included in the paper and in the preparation of the paper. (Attach a further sheet if necessary) | I proposed the study idea in discussion with my supervisors: Prof. Andrew Prentice and Dr Pauline Scheelbeek. I identified and obtained the dataset and performed data cleaning and management. I led the collection of additional data on market quantities which I used to convert non-metric dietary data into metric units which enabled the dietary intake estimates. I defined the study objectives, performed the dietary analysis, and performed the statistical modelling. I constructed the tables and designed the illustrations. I wrote the first manuscript draft and received initial comments from Dr Pauline Scheelbeek, Dr Rosemary Green and Prof. Andrew Prentice which I used to shape the analysis and produced an updated manuscript. All co-authors provided valuable comments which were used for drafting a final manuscript for journal submission. I led the journal submission of the paper and addressed reviewer comments in consultation with my supervisors and co-authors. |

**SECTION E**

| | |
|---|---|
| **Student Signature** | [redacted] |
| **Date** | 11th October 2022 |

| | |
|---|---|
| **Supervisor Signature** | [redacted] |
| **Date** | 12th October 2022 |

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LETTER

# Adherence to EAT-Lancet dietary recommendations for health and sustainability in the Gambia

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Supplementary material for this article is available online

## Abstract

Facilitating dietary change is pivotal to improving population health, increasing food system resilience, and minimizing adverse impacts on the environment, but assessment of the current 'status-quo' and identification of bottlenecks for improvement has been lacking to date. We assessed deviation of the Gambian diet from the EAT-Lancet guidelines for healthy and sustainable diets and identified leverage points to improve nutritional and planetary health. We analysed the 2015/16 Gambian Integrated Household Survey dataset comprising food consumption data from 12 713 households. Consumption of different food groups was compared against the EAT-Lancet reference diet targets to assess deviation from the guidelines. We computed a 'sustainable and healthy diet index (SHDI)' based on deviation of different food groups from the EAT-Lancet recommendations and modelled the socio-economic and geographic determinants of households that achieved higher scores on this index, using multivariable mixed effects regression. The average Gambian diet had very low adherence to EAT-Lancet recommendations. The diet was dominated by refined grains and added sugars which exceeded the recommendations. SHDI scores for nutritionally important food groups such as fruits, vegetables, nuts, dairy, poultry, and beef and lamb were low. Household characteristics associated with higher SHDI scores included: being a female-headed household, having a relatively small household size, having a schooled head of the household, having a high wealth index, and residing in an urban settlement. Furthermore, diets reported in the dry season and households with high crop production diversity showed increased adherence to the targets. While average Gambian diets include lower amounts of food groups with harmful environmental footprint, they are also inadequate in healthy food groups and are high in sugar. There are opportunities to improve diets without increasing their environmental footprint by focusing on the substitution of refined grains by wholegrains, reducing sugar and increasing fruit and vegetables consumption.

## 1. Introduction

Globally, over 40% of all men and women are overweight or obese, 195 million children under five years suffer from stunted growth or wasting [1] and micronutrient deficiencies affect over 2 billion people [2]. Furthermore, over the last decade, slow progress has been made in meeting global targets on maternal and child nutrition; and no country is currently on course to meet global diet-related non-communicable disease (NCD) targets related to reducing adult obesity and salt intake [1]. Sub-optimal diets, resulting from low consumption of nutritious food and high consumption of harmful foods, are leading risk factors for morbidity and mortality around the world [3, 4]. Additionally, existing food production systems threaten the health of the planet and require urgent transformation [5]. The agriculture sector alone is responsible for 70% of global fresh water use, 23% of greenhouse gas emissions, and significant soil degradation and biodiversity loss [6].

Food system inequalities are being exacerbated by climate change [7]. Low-and middle-income countries have a reduced capacity to adapt to climate change and will face the harshest impacts from low crop yields, high food prices and compromised food utilisation arising from disruptions in household drinking water and increased infectious disease burden [8, 9].

The Gambia, situated on the lower edge of the Sahel, is highly vulnerable to climate change [10]. It experiences irregular rainfall patterns and flooding, together with longer periods of drought, and extreme heat that affect food production and livelihoods [11, 12]. Consequently, domestic food production is lower than national demand for many food items including rice, the national staple, and fruits and vegetables—so food supply is heavily supported through importation from other countries [13, 14]. Ongoing economic and demographic changes such as increased income and high urbanisation rates have also shifted diets away from traditional foods that are high in wholegrain and vegetables towards more processed foods high in refined grains, oils and sugar [15, 16]. These changes have compounded health implications—increasing overweight and obesity and diet related chronic diseases (hypertension and diabetes) in adults [17, 18], and also reduce the resilience of diets by increasing dependence on food trade with associated high water [19] and carbon footprints [20]. Improving the food system to deliver healthy diets could therefore be a means to improve health and increase environmental sustainability [21]. But this will require realignment of the current food systems and consumption patterns—supported by strong political will [22].

Drawing from the best available evidence, the EAT-Lancet Commission in 2019 proposed a universal reference 'diet for the Anthropocene' to deliver optimal human health whilst maintaining environmental sustainability [23]. The diet is estimated to sustainably feed the future population and prevent a substantial number of deaths from diet related NCDs [23]. The diet is largely plant-based and emphasises consumption of vegetables, fruits, wholegrains, legumes and nuts, and unsaturated oils. The EAT-Lancet diet recommends low consumption of red and processed meat, added sugar, refined grains and starchy foods. While advocating for a 'Great Food Transformation', the Commission recognised that the required changes in diets will have to differ by region and from country to country [23]. Therefore, adoption of the reference diet needs to be carefully tailored to context-specific needs to limit unintended health and environmental impacts [24]. Furthermore, in countries such as The Gambia which has co-existing undernutrition and overnutrition, the required dietary changes might need to vary among different population groups. For example, despite progress over the years in reducing undernutrition, one in five children under five years still suffer from stunting and three in five are anaemic. Increased provision of animal source foods could be important sources of essential nutrients to combat these conditions [25, 26]. At the same time, over 40% of adults are overweight implying excess provision of calories and a need for moderation [27].

Given these problems and existing government efforts to improve on undernutrition [28], diet-related chronic diseases and the environment [29], it is important and timely to examine national dietary patterns and identify major leverage points and opportunities to achieve multiple co-benefits of changing diets among different population groups. Therefore, we assessed deviation of the average Gambian diet from the EAT-Lancet dietary guidelines for healthy and sustainable diets and identified leverage points to simultaneously improve nutritional and planetary health.

## 2. Methods

### 2.1. Study design and survey details

This study analysed the Integrated Household Survey (IHS2015/16) of The Gambia conducted between May 2015 and April 2016 [30, 31], The IHS2015/16 was a comprehensive nationally representative cross-sectional survey with dietary data collected year-round to reflect seasonal changes in diets. The survey was designed to enable comparison of average diets at national and district level and to explore rural-urban differences. It covered data collection on demographic and economic household characteristics. Details of the sampling procedure used by the IHS2015/16 are provided elsewhere [30]. Briefly, the survey used a two-stage probability proportional to size procedure with stratified random sampling. The Gambia Bureau of Statistics defined enumeration areas (EAs) across the eight local government areas (LGAs) (including two municipalities) and districts were selected at the first stage. Each EA was classified as either rural or urban. The next stage involved selection of an equal number of households with equal probability of selection from the household listing in each EA. Overall, 622 EAs and 13 340 households were selected with a response rate of 99.4% (13 281 households interviewed).

### 2.2. Dietary data and processing

The IHS2015/16 collected quantitative household food consumption data using a 7 d recall questionnaire [31]. The questionnaire included 145 food items organised into broad food groups: cereals and products; poultry and products; meat; fish; milk and products; oils and fats; fruits; nuts; starchy roots and tubers; vegetables; sugar, honey and confectionary; and spices and condiments [30]. Our analysis includes consumption of 92 food items excluding spices and condiments (supplementary table S1). Quantities of consumption were reported in both metric units and household measures (e.g. one cup of rice) which were converted into grams of average household intake per person per day by dividing equally by number of people in households. Where household measures were reported without metric unit equivalent estimation, we estimated the gram equivalents using market determined quantities (supplementary material S1).

We calculated total energy intake by linking food intake data with the United Nations Food and Agriculture Organization (FAO) food composition tables for West Africa [32]. The US Department of Agriculture's food composition data [33] and Gambia specific tables [34] were used where food items were not contained in the West African tables.

### 2.3. Covariates

Most covariates were at household level unless specified otherwise. The covariates considered for multivariable regression modelling were: household wealth; remittances per capita; seasonality; crop production diversity; total energy; sex of household head; ethnicity; education of household head; household size; and urbanisation status (supplementary material S2).

### 2.4. The sustainable and healthy diet index (SHDI) score

The EAT-Lancet reference diet corresponds to 2500 kcal per day energy needs for a 30-year-old woman weighing 60 kg with moderate to high physical activity level. It sets serving averages and suitable ranges (in grams per person per day) for each food group to reflect diets associated with greater health and environmental sustainability [23]. To measure adherence to, or deviations from, the proposed diet, we developed an EAT-Lancet diet index (the 'sustainable and healthy diet index (SHDI)') by combining two previous scoring methods [35, 36] (Method 1 and Method 2 respectively) to reflect The Gambian food system, nutritional needs and eating patterns. Method 1 scores consumption of food groups to reflect on micronutrient adequacy [35]. The method assigns one point for intakes within the EAT-Lancet range for each food group and zero points for consumption outside of the range. The method does not assign positive scores for zero intakes of essential food groups. The ranges of intake recommended by EAT-Lancet often include zero intake values (e.g. 0–14 grams for beef and lamb and 0–14 grams for pork) to allow for interchangeability and replacement between closely related food groups [23]. However, in many food insecure or minimally food secure areas, such as The Gambia, there is low availability of alternatives to replace non-consumed food groups. Consequently, assigning positive scores for non-consumption of these foods could be a proxy for inadequate intake of micronutrients [35]. In these instances, the mean of the target range is taken as the lower bound instead of zero [35]. We adopted this approach by Method 1 to ensure greater micronutrient adequacy of the resulting index.

The scoring approach used by Method 2 reflects risk of NCD and associated mortality [36] by assigning scores 0–3 depending on different levels of consumption of food groups. The method assigns higher scores for greater consumption of 'emphasised' food groups for which high consumption is good for health (vegetables, fruits, unsaturated oils, legumes, nuts, wholegrains, and fish) while points are taken away for higher consumption of 'limited' food groups for which overconsumption is bad for health (beef and lamb, pork, poultry, eggs, dairy, potatoes, and added sugar) [36]. Method 2 does not make micronutrient adequacy considerations for nutrient-rich food groups including meat and dairy which may lead to diets rich in these food groups being penalised under this scoring system.

In our combined EAT-Lancet index (SHDI), we used the points distribution system similar to Method 2 (0–3 points) and applied micronutrient adequacy considerations for nutrient-rich food groups similar to Method 1. Therefore, in food groups where the EAT-Lancet range includes zero intake as the lower bound such as beef and lamb (0–14 grams) we used the mean of the target range to represent the lower bound instead of zero (i.e. 7–14grams) (Method 1). We then assigned the scores (0–3 points) according to consumption within or outside this new range avoiding positive points for zero intake (table 1 and supplementary material S3). This avoids assigning a positive score for non-consumption of these food groups as would result from applying Method 2.

Overall, 16 food groups (based on EAT-Lancet recommendations with some modifications) were defined in this study with each having a maximum score of three points depending on intake level—resulting in a total maximum score of 48 for the composite SHDI. Further details about the scoring criteria

**Table 1.** Scoring system used to generate the SHDI.

| EAT-Lancet food group | EAT-Lancet target intake (range in grams $d^{-1}$) | Intake range with minimum intake values (g $d^{-1}$)[a] | Score[b] | | | |
|---|---|---|---|---|---|---|
| | | | 3 | 2 | 1 | 0 |
| All vegetables | 300 (200–600) | 200–600 | >300 | 200–300 | 100–200 | <100 |
| All fruits | 200 (100–300) | 100–300 | >200 | 100–200 | 50–100 | <50 |
| Unsaturated oils | 40 (20–80) | 20–80 | >40 | 20–40 | 10–20 | <10 |
| Beans, lentils and peas[c] | 75 (0–150) | 75–150 | >75 | 37.5–75 | 18.75–37.5 | <18.75 |
| Peanuts and tree nuts | 50 (0–100) | 50–100 | >50 | 25–50 | 12.5–25 | <12.5 |
| Wholegrains[c] | 116 (0–232) | 116–232 | >116 | 58–116 | 29–58 | <29 |
| Potatoes and cassava | 50 (0–100) | 50–100 | >50 | 25–50 | 12.5–25 | <12.5 |
| Fish | 28 (0–100) | 28–100 | >28 | 14–28 | 7–14 | <7 |
| Palm oil | 6.8 (0–6.8) | ⩽6.8 | <1.7 | 1.7–3.4 | 3.4–6.8 | >6.8 |
| Added sugar | 31 (0–31) | 15.5–31 | <7.75 | 7.75–15.5 | 15.5–31 | >31 |
| Refined grains[c] | 116 (0–232) | 116–232 | <116 | 58–116 | 116–232 | >232 |
| Beef and lamb | 7 (0–14) | 7–14 | 7–14 | 3.5–7 | 1.75–3.5 | <1.75 or >14 |
| Pork | 7 (0–14) | 7–14 | 7–14 | 3.5–7 | 1.75–3.5 | <1.75 or >14 |
| Poultry | 29 (0–58) | 29–58 | 29–58 | 14.5–29 | 7.25–14.5 | <7.25 or >58 |
| Dairy | 250 (0–500) | 250–500 | 250–500 | 125–250 | 62.5–125 | <62.5 or >500 |
| Eggs | 13 (0–25) | 13–25 | 13–25 | 6.5–13 | 3.25–6.5 | <3.25 or >25 |

[a] Based on Method 1 [35] except for refined grains and palm oil where we allowed positive scoring for non-consumption. Our approach treats beef & lamb and pork as two groups and splits grains into wholegrains and refined grains.
[b] Scores were assigned based on Method 2 [36] with exceptions to: wholegrains, beef and lamb, pork, poultry, dairy, and potatoes and cassava where we used different criteria and avoided awarding points for non-consumption. We awarded points differently for added sugar intake by taking points away for intakes above the upper limit while Method 2 assigned positive scores for intakes up to 200% of the upper limit.
[c] Grains (whole and refined), beans, lentils and peas are dry, raw and includes soy foods consistent with EAT-Lancet recommendations. EAT-Lancet recommendations for grains are combined with target 232 g (0–464 g). These were split in this report to reflect local availability and consumption patterns.

used for each food group and specific modifications applied to the SHDI are shown in table 1 and supplementary material S3.

### 2.5. Statistical analyses

Scores obtained for each food group were summed to form a composite SHDI. The proportion of total index scores over the total expected scores was used as an indicator of the level of adherence to the EAT-Lancet recommendations. We used both graphical methods and descriptive statistics to explore and summarise the data and to elicit patterns.

We fitted multivariable mixed effects regression models specifying 'region' as a random effect and other covariates as fixed effects using maximum-likelihood estimation to assess factors associated with a 1-unit increase or decrease in the SHDI. Potential multicollinearity among variables was assessed using the variance inflation factor by including the variables of the fully adjusted model in a normal least squares regression. All statistical analyses were performed using Stata version 16.1 (StataCorp, USA).

## 3. Results

From an initial sample of 13 281, the current analysis includes 12 713 households after data processing to exclude households reporting extreme energy intakes (supplementary table S2). Proportional to the population distribution, the majority of the households in the sample were based in the Central River region (24.5%) and the West Coast region (22.2%), with the smallest number of households reporting from Banjul (5.6%). More than two thirds of the households were in rural areas (75.6%), 84.8% were headed by a male family member, and 76.1 of the households had a head without schooling. More than seven in ten households reported to grow at least one crop (77.4%) and approximately two in five households received remittances during the last year (37.7%) (supplementary table S3).

### 3.1. Mean consumption of energy and food groups

Average daily energy intake per capita was 2536 kcal with wide regional variation. The lowest energy intake was recorded in West Coast region (2011.0 kcal $day^{-1}$) while those in Central River and Upper River regions had the highest energy intake of 2912.9 kcal per person per day compared to the 2500 kcal person $day^{-1}$ recommended by EAT-Lancet. Households in rural areas (2616.9 kcal person $day^{-1}$) consumed more energy than their counterparts in urban areas (2284.3 kcal person $day^{-1}$). There was 100 kcal more energy intake on average in the rainy season than in the dry season (2512.6 kcal person $day^{-1}$). Households headed by men also had higher energy intakes over female headed households (table 2 and supplementary table S4). Consumption of different food groups differed by household and geographic characteristics. For example, consumption of fruit and vegetables was high among household members in urban areas

**Table 2.** Background characteristics of sampled households, energy, and food group consumption.

| EAT-Lancet food group | Percent of households consuming each food group per day (national) % (95% CI) | Mean consumption of food groups (national) g day$^{-1}$ | Type of settlement mean (95% CI) g day$^{-1}$ | | Season mean (95% CI) g day$^{-1}$ | | Household head mean (95% CI) g day$^{-1}$ | |
|---|---|---|---|---|---|---|---|---|
| | | | Urban | Rural | Rainy | Dry | Male | Female |
| Total energy | | 2536.2 (2514.3–2558.2) | 2284.3 (2247.3–2321.2) | 2616.9 (2590.6–2643.2) | 2616.1 (2568.4–2663.9) | 2512.6 (2487.9–2537.3) | 2545.6 (2521.4–2569.8) | 2483.6 (2431.7–2535.5) |
| All vegetables | 96.6 (96.0–97.0) | 153.9 (151.5–156.3) | 206.2 (200.7–211.7) | 137.2 (134.7–139.7) | 145.6 (140.7–150.6) | 156.4 (153.7–159.1) | 144.4 (141.9–146.8) | 207.4 (200.2–214.5) |
| All fruits | 37.2 (36.3–38.0) | 53.1 (50.7–55.6) | 77.8 (72.0–83.6) | 45.2 (42.7–47.7) | 22.6 (20.3–24.9) | 62.1 (59.2–65.1) | 50.9 (48.4–53.4) | 65.3 (58.3–72.4) |
| Unsaturated oils | 87.2 (86.6–87.7) | 21.8 (21.4–22.1) | 24.0 (23.2–24.7) | 21.1 (20.7 (21.4) | 21.6 (20.9–22.4) | 21.8 (21.4–22.2) | 20.9 (20.6–21.3) | 26.6 (25.6–27.6) |
| Beans, lentils and peas | 26.5 (25.7–27.2) | 8.6 (8.2–9.0) | 5.1 (4.5–5.6) | 9.7 (9.3–10.2) | 8.8 (8.0–9.6) | 8.5 (8.1–8.9) | 8.9 (8.5–9.3) | 6.7 (5.8–7.6) |
| Peanuts and tree nuts | 67.3 (66.5–68.1) | 19.1 (18.4–19.7) | 15.3 (14.1–16.6) | 20.2 (19.5–20.9) | 18.9 (17.5–20.3) | 19.1 (18.4–19.8) | 19.2 (18.6–19.9) | 17.9 (16.3–19.5) |
| Wholegrain | 19.8 (19.1–20.5) | 41.7 (39.7–43.8) | 6.7 (5.1–8.2) | 53.0 (50.3–55.6) | 51.1 (46.4–55.9) | 39.0 (36.7–41.3) | 47.0 (44.6–49.4) | 12.4 (9.6–15.2) |
| Potatoes and cassava | 48.4 (47.5–49.5) | 18.8 (18.3–19.4) | 34.9 (33.3–36.4) | 13.7 (13.2–14.3) | 18.0 (16.8–19.3) | 19.1 (18.4–19.7) | 17.6 (17.0–18.2) | 25.5 (23.8–27.3) |
| Fish | 93.8 (93.4–94.2) | 81.1 (79.9–82.3) | 93.5 (90.7–96.4) | 77.1 (75.8–78.5) | 79.9 (77.3–82.6) | 81.4 (80.0–82.8) | 76.3 (75.1–77.6) | 107.8 (103.9–111.6) |
| Palm oil | 68.8 (68.0–69.6) | 7.6 (7.4–7.7) | 9.1 (8.7–9.4) | 7.1 (6.9–7.3) | 8.1 (7.7–8.4) | 7.4 (7.3–7.6) | 7.2 (7.1–7.4) | 9.6 (9.1–10.1) |
| Added sugar | 96.4 (96.1–96.7) | 66.5 (65.6–67.5) | 76.7 (74.4–79.0) | 63.3 (62.3–64.3) | 65.4 (63.4–67.4) | 66.9 (65.8–67.9) | 65.8 (64.8–66.8) | 70.7 (68.2–73.2) |
| Refined grains | 98.8 (98.6–99.0) | 411.6 (407.0–416.1) | 352.5 (345.8–359.3) | 430.4 (424.9–436.0) | 429.6 (419.9–439.4) | 406.2 (401.1–411.3) | 415.7 (410.7–420.8) | 388.1 (378.3–397.9) |
| Beef and lamb | 28.4 (27.7–29.2) | 12.4 (11.8–12.9) | 17.5 (16.1–18.8) | 10.7 (10.2–11.2) | 12.5 (11.4–13.6) | 12.3 (11.7–12.9) | 12.2 (11.6–12.8) | 13.2 (11.9–14.5) |
| Poultry | 26.8 (26.0–27.6) | 12.3 (11.8–12.8) | 18.6 (17.2–19.9) | 10.3 (9.8–10.8) | 12.3 (11.3–13.3) | 12.3 (11.7–12.9) | 11.5 (11.0–12.0) | 17.0 (15.3–18.7) |
| Dairy | 44.0 (43.2–44.9) | 26.6 (25.5–27.7) | 21.8 (20.0–23.6) | 28.1 (26.8–29.4) | 27.6 (25.3–29.9) | 26.3 (25.0–27.5) | 27.1 (25.9–28.4) | 23.5 (20.9–26.0) |
| Eggs | 13.8 (13.2–14.4) | 1.3 (1.2–1.4) | 3.2 (2.9–3.5) | 0.7 (0.6–0.8) | 1.4 (1.2–1.6) | 1.3 (1.2–1.4 | 1.2 (1.1–1.3) | 1.6 (1.4–1.9) |

Pork is excluded from table as consumption $\leqslant$0.5 g day$^{-1}$. CI: Confidence Interval compared to rural areas, but households in urban areas also consumed relatively higher amounts of sugar, and beef and lamb. In contrast, total grain intake was higher among rural households than urban households. Furthermore, the intake of fruits, vegetables, and grains (whole and refined) varied more by season than other food groups. While fruit and vegetable consumption was higher in the dry season compared to the rainy season, the reverse was true for consumption of grains (table 2 and supplementary table S4).

### 3.2. Household food consumption and adherence to EAT-Lancet diet recommendations

Comparing mean intakes to the EAT-Lancet targets, only a small proportion of household members had intakes falling within the recommended range (figure 1). Food groups with a relatively high proportion of households consuming within the EAT-Lancet target include: fish (50.5%) and unsaturated oils (40.8%)—all other food groups had a quarter or less of households with consumption falling within the EAT-Lancet range. The majority of household members had mean intakes above the upper limit recommended by EAT-Lancet for added sugar (77.5%), refined grains (76.1%), and palm oil (43.9%). For all other food groups (fruits, vegetables, pork, beef and lamb, eggs, dairy, poultry, potatoes and cassava, wholegrains and peanuts and tree nuts), most households consumed below the lower range (figure 1). However, more than 20% of households were also consuming above the upper range for beef and lamb and fish. Consumption above the recommendation for beef and lamb and fish was higher among the wealthiest households and those residing in urban areas (supplementary table S5).

Consequently, the overall score on the SHDI was very low, with a mean composite index of 10.1/48 (SD = 3.7) and a highest reported score of 28.0/48 (supplementary figure S1). The distribution of SHDI scores obtained by households for each food group is presented in figure 2. Note that failure to meet targets for any individual category does not imply an overall failure because substitutions are permitted.

Considering adherence by individual food groups and consistent with figure 1, most households (79%) scored three points for fish intake. The proportion of households scoring three points for other food groups was lower than 50%. For refined grains, most households (76%) scored zero points due to over consumption, but most households (84%) scored zero points on wholegrain intake due to extreme under consumption. Many households (>70%) also reported very low or no consumption of fruits, beans, lentils and peas, beef and lamb, dairy, pork, eggs, and chicken, resulting in scoring zero points in these food groups (figure 2). Overall, 66.8% of households scored three points in one or two food groups (comprising mainly fish and palm oil) and only 10% scored three points in four or more food groups (these were mainly fish, palm oil, vegetables, and unsaturated oils) (figure 3 and supplementary table S6). However, households that scored three points on only one food group also scored two points on a number of other food groups for which consumption did not reach a three score (supplementary table S6).

### 3.3. Determinants of increased sustainable and healthy diet index (SHDI) score

The adjusted mixed effects model (accounting for per capita energy intake and receipt of remittances) showed that diets of female headed households scored 0.32 points higher on the SHDI than diets of male headed households (95% CI: 0.14–0.50, $P < 0.001$). Similarly, diets of households in urban areas scored 0.61 points higher compared to those in rural areas (95% CI: 0.41–0.81, $P < 0.001$). There was a positive association between household wealth index and the SHDI ($\beta = 0.37$; 95% CI: 0.32–0.43, $P < 0.001$). Furthermore, in households where the head had no schooling, there was a lower mean dietary index score ($\beta = -0.41$; 95% CI: $-0.57$-($-0.26$), $P < 0.001$) compared to households where the head received some schooling. There was evidence of a strong relationship between ethnic group and dietary index score: compared to Mandinkas, other ethnicities (Fula, Jola and Serahulleh) showed lower index scores, except the Wollof who scored higher (table 3). Diets in the dry season scored on average 0.47 points higher on the index than those in the rainy season (95% CI: 0.32–0.61, $P < 0.001$). Crop production diversity was also positively associated with the SHDI ($\beta = 0.14$; 95% CI: 0.10–0.19, $P < 0.001$) while each additional family member was associated with a marginal decrease in dietary score of 0.02 points ($-0.04$-($-0.01$), $P < 0.001$) (table 3).

## 4. Discussion

### 4.1. Main findings

In this study, we have demonstrated that average Gambian diets typically show strong deviations from the healthy and sustainable dietary guidelines as proposed by the EAT-Lancet Commission. The diet was dominated by consumption of less-healthy options such as refined grains and added sugars which exceeded the recommendations, whilst intake of nutritionally important food groups such as fruits, vegetables, dairy, and poultry were much lower than the EAT-Lancet targets. Less than a third of the population consumed beef and lamb, with many non- or very low consumers with low wealth indices and living in rural areas while there were some over-consumers of these foods in the wealthiest and urban households. Relatively high meat intake among urban dwellers is consistent with the wider sub-Saharan Africa region [37]. Importantly, we show that, consistent with similar low-and middle-income settings


**Figure 1.** Comparison of mean household food group consumption with EAT-Lancet ranges [Recommended ranges are according to Method 1 with minimum values as described in the 'intake range' column of table 1].

[38], the diet does not fulfil nutritional requirements but consumption is often within recommended levels for food components known to impact heavily on the environment (such as livestock products) [21]. We also identified important socioeconomic characteristics that could serve as leverage points for improving healthiness whilst not impacting on the sustainability of diets in The Gambia.

### 4.2. Research in context

Diets in The Gambia typically show low dietary diversity [39], which partly explains the low levels of alignment with the healthy and sustainable dietary guidelines by the EAT-Lancet Commission. A less diverse diet implies that a few food groups are over consumed (e.g. polished white rice, bread, oils, and added sugar) while others are under consumed; both cases result in deviations from the EAT-Lancet targets.

The higher scores on the SHDI in the dry season compared to the rainy season are consistent with results from Kenya and Vietnam [35]. As other food groups remained relatively unchanged throughout the year, higher availability of fruit and vegetables during the dry season as compared to the rainy season explains much of the difference in scores. High SHDI scores among those with better wealth, schooling and urban settlement also seem to be driven by availability and consumption of fruits and vegetables. Furthermore, female-headed households have been shown by past studies to spend a higher proportion

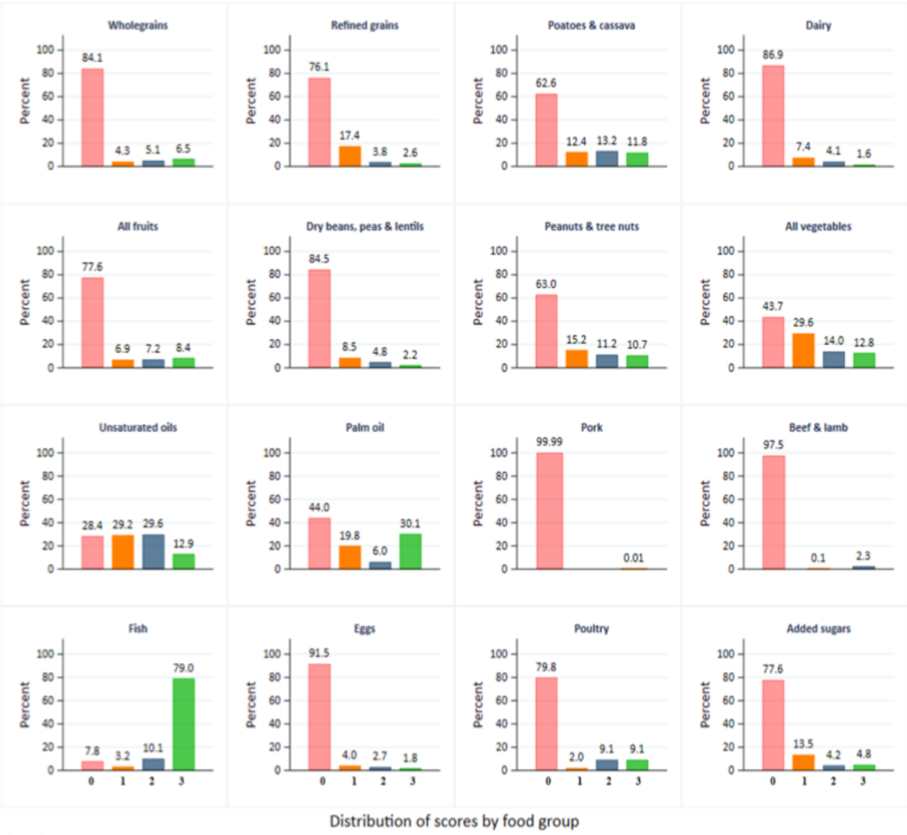


**Figure 2.** Distribution of scores obtained on each of the 16 food groups [Scores 1, 2 and 3 generally refer to consumption within acceptable limits of a food group. A 0 score generally means consumption outside acceptable limits for a food group (details in table 1). Scores 0, 1, 2 & 3 are shown by light shades of red, orange, blue and green respectively. Scores with 0% households are not shown].

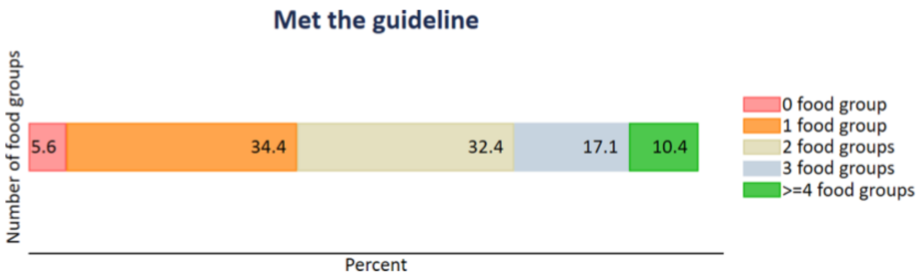


**Figure 3.** Percent of households meeting the EAT-Lancet guidelines by number of food groups [Total number of food groups = 16. Meeting guidelines here is defined by obtaining a score of 3 in each food group].

of income towards household food and nutrition (in this case, on more vegetables) than males [40]. This underscores the overarching importance of fruit and vegetables in improving diets and meeting healthy and sustainable diet targets in The Gambia. Previous evidence shows that increased production diversity is associated with diet diversity [41], which may explain the positive association between SHDI and home agricultural production found in this study. Contrary to a recent meta-regression that found higher vegetables intake in rural areas as compared to urban areas [37], urban residence could be a good proxy for better access to food markets and income than in rural areas and may explain the higher SHDI scores

**Table 3.** Mixed effects regression analysis of the determinants of EAT-Lancet diet index in The Gambia.

| | EAT-Lancet index score ($\beta$) (95% confidence interval)[a] | P-value |
|---|---|---|
| Household head | | <0.001 |
| Male | 0 (base) | |
| Female | 0.32 (0.14–0.50) | |
| Area of residence | | <0.001 |
| Rural | 0 (base) | |
| Urban | 0.61 (0.42–0.81) | |
| Wealth quintile | 0.37 (0.32–0.43) | <0.001 |
| Ethnicity/tribe | | <0.001 |
| Mandinka/Jahanka | 0 (base) | |
| Fula/Tubular/Lorobo | −0.31 (−0.47– (−0.15)) | |
| Wolof | 0.37 (0.17–0.58) | |
| Jola/Karoninka | −0.02 (−0.29–0.25) | |
| Serahulleh | −0.01 (−0.30–0.28) | |
| Other | −0.07 (−0.36–0.22) | |
| Household head ever attended school | | <0.001 |
| Yes | 0 (base) | |
| No | −0.41 (−0.57– (−0.26)) | |
| Season | | <0.001 |
| Rainy | 0 (base) | |
| Dry | 0.48 (0.32–0.61) | |
| Crop diversity score | 0.14 (0.10–0.19) | <0.001 |
| Remittances (per capita) | $9.17 \times 10^{-6}$ ($1.58 \times 10^{-6}$–$1.67 \times 10^{-5}$)[b] | 0.02 |
| Household size | −0.02 (−0.04-(−0.01)) | 0.001 |
| Total energy | $9.24 \times 10^{-4}$ ($8.71 \times 10^{-4}$–$9.77 \times 10^{-4}$)[b] | <0.001 |

[a] Coefficients are adjusted for all other variables in the model.

[b] e = x10 exponentiation.

associated with urban settlement in this study [42]. Finally, while remittances are a key source of household income in The Gambia [43] and linked with improvement in food and nutrition security in sub-Saharan Africa [44], they were only weakly associated with the sustainable diet index in this study. This could be due to using income from remittances to buy less healthy food groups (such as refined grains and sugar) or for purchases of non-food household items.

### 4.3. Implications including policy recommendations

If The Gambia was to successfully promote healthy and sustainable dietary guidelines, such as those proposed by the EAT-Lancet commission, it would require substantial shifts in current food supply and consumption patterns. Chiefly, it would involve increasing the supply and intake of fruits, vegetables and wholegrains as well as ensuring that they are available in all parts of the country throughout the year. This would have to go along with cutting down on refined grains (polished white rice and bread) and added sugar. Also, the current low amounts of livestock products with a dominant aquatic source of protein (mainly fish) would need to be maintained to remain within health and sustainability limits. The national average intake of dairy products lies far below the 250 g EAT-Lancet target and needs to increase to improve the nutrient content of the diet. These changes would involve a careful consideration of the food supply and demand side dynamics. Improving food choice and demand can drive food supply under favorable structural factors that enable adequate supply from both domestic production and import sources [45]. However, a variety of other factors that influence food choice would need to be tackled—including the affordability of food groups that are currently under-consumed, nutrition education about the importance of dietary diversity, food preferences, and marketing practices [46].

In many low- and middle income countries, one of the main barriers to consuming the recommended amount of fruit and vegetables as per the EAT-Lancet recommendations is their affordability [47]. In addition to high cost, the supply of fruit and vegetables from both domestic production and imports from other countries is often insufficient: in the Gambia, average per capita fruit and vegetable supply falls short of national demand [48, 49], and would need to be doubled/tripled (especially for fruits) to meet the EAT-Lancet recommendations. This trend is noticeable in other low- and middle-income settings. For example, in India, an additional US $1.0 was required per household member per day in order to purchase the amount of fruit and vegetables (as well as other food groups) recommended in the EAT-Lancet diet

[50]. High price volatility of fruit and vegetables in different seasons further complicated the affordability question [50].

Given the clear discrepancy between current supply and fruit and vegetable supply required for population-wide shifts to healthy and sustainable dietary guidelines in The Gambia, adequate action to improve supply streams would be crucial. This could involve various pathways including investments by government and development partners to increase the supply of fruits and vegetables, but also methods to overcome seasonal variability in supply, such as preservation methods and introduction of early and late cropping varieties.

The Gambia relies heavily on imported refined grains as the major staple foods [51] likely due to their relative low prices, high convenience for cooking and eating, and prestige associated especially with consumption of rice compared to alternative grains [52]. For alternative and more healthy wholegrains to gain dominance over refined rice in The Gambia, the factors that make rice attractive will need to be equalised. Promoting wholegrain alternatives such as pearl millet and maize to reduce reliance on rice and refined wheat bread could have multiple benefits: higher consumption of wholegrains would likely impact positively on both health and the environment. For instance, millet production is associated with lower greenhouse gas emissions compared to rice [53] and it can easily be eaten as wholegrain compared to rice that is almost always refined. In addition, millets are relatively more adaptable to the local climate than rice as millet has been grown traditionally over decades in The Gambia [54]. There are further advantages for promoting millet as an alternative to rice because it is already the second most consumed grain in the country (especially in rural areas) and has multiple local recipes [51]. The low consumption of millet is largely the result of inadequate supply and low convenience in its processing and preparation which limits uptake especially among busy urban dwellers—this needs to be addressed to enable nationwide scale-up.

Locally sourced fish is the main source of animal protein in the diet together with low amounts of poultry and livestock products in The Gambia. Although this combination is often estimated to ensure environmental sustainability [21], possible overexploitation of local fish stocks by foreign fishmeal factories [55] greatly threatens the sustainability and long term resilience of fish supply for the future [56]. This is particularly relevant as fish is often the only nutrient-rich food consumed in adequate amounts by those with less diverse diets. Hence a declining supply (and potential price increase) would make fish inaccessible and/or unaffordable in this group, which could disproportionally disadvantage them—reducing diet quality.

Currently average beef and lamb consumption is low or zero for the majority of the population, while a smaller proportion of (mostly) urban dwellers have higher intake than recommended by the EAT-Lancet diet. In the Global North red meat is grossly overconsumed by many and serves as a major source of food system emissions—the relatively small amounts of red meat consumption as recommended by sustainable and healthy dietary guidelines often mean a substantial cut in meat consumption for the majority of people in the Global North if they wish to adhere to such guidelines. In The Gambia, this is however more complex: given the double burden of malnutrition, low dietary diversity and the relatively low environmental impact of agriculture (including that of livestock—kept extensively and fed mainly on low-opportunity cost biomass such as grass with lower environmental impact compared to those kept intensively and fed with cereals [57]), blanket meat reduction strategies are less of a useful option to improve healthfulness and sustainability in the immediate term. In fact, for the majority of the Gambian (rural) population the small amount of red meat as recommended in healthy and sustainable dietary guidelines would in fact translate into an increase in red meat consumption as compared to their current diets. Therefore, a more targeted approach to nutrition education is required to facilitate changes in red meat consumption patterns across different population groups that are appropriate to need.

Cutting down on the amount of added sugar in the Gambian diet will improve diet quality. Until 2011, the Gambian government provided tax waivers on imported sugar [58]. In spite of the removal of tax exemptions, Food Balance Sheet data from the FAO show that daily sugar supply in Gambia has continued to increase (from 83 g person day$^{-1}$ in 2011 to 99 g person day$^{-1}$ in 2019) [59]. This may imply that sugar is still cheaper than the minimum threshold required to reduce demand. Possible strategies to reduce sugar consumption may involve a combination of approaches with complementary effects including taxation, food based dietary guidelines and social behaviour change communication.

### 4.4. Strengths and limitations

This study has several strengths. First, we used a national sample with multiple variables which allowed examination of diets at sub-national and household levels. The design of the survey also allowed us to assess diets in different seasons of the year for a more comprehensive understanding of the national diet. Our scoring system has also allowed a good understanding of the extent of deviation and conformity of different food groups to the EAT-Lancet diet targets and to identify leverage points for improvement.

However, the study also has several limitations. We estimated an average household intake per person and compared this to a reference diet. This did not allow us to explore potential non-equitable food distribution among household members (for example, children may be consuming less energy overall but they may also eat more seasonal fruits than adults) [60]. There was also a possibility for bias by comparing average intakes to a standard reference diet. For example, rural and more farming dominated households may be more physically active than urban dwellers, by comparing to the standard reference diet this likely introduced a bias in which overconsumption by urban dwellers is underestimated and underconsumption by rural dwellers is underestimated. The 7 d food frequency questionnaire method of dietary intake assessment is vulnerable to recall problems but is more likely to reflect the 'regular diet pattern' of households than shorter recall periods such as 24 h recalls. Additionally, the EAT-Lancet diet targets are more focused on adults [23] and may not apply directly to nutritionally vulnerable groups such as young children or pregnant and lactating women [61]. Furthermore, the EAT-Lancet diet is more plant-based, implying a dominant plant-source iron supply which is less bioavailable as compared to haem-based sources [62]. Therefore, for the diet to provide optimal iron nutrition and reduce existing high levels of iron deficiency and anaemia in the population [61], promotion of the EAT-Lancet diet in this setting needs to particularly emphasise adequate supply and consumption of appropriate amounts of livestock products (rich source of bioavailable iron and also enhance absorption of plant source iron) as well as fruit and vegetables (high in vitamin C to aid absorption of plant-source iron [63]). Our assessment of an average diet limited our ability to identify specific food group combinations that may exist within population sub-groups that are often identified through dietary pattern analysis [64]. However, the use of average diets of population groups (by region, settlement type etc) as done in this study may also be useful in relatively smaller populations such as The Gambia with more homogeneity in food supply and consumption [65].

## 5. Conclusion

We can conclude that the current Gambian diet is high in less healthy food groups such as refined grains and added sugar and is low in nutritionally important food groups such as fruits and vegetables, and average diets currently do not map well onto sustainable and healthy dietary guidelines. Opportunities to improve on the healthiness of diets, while potentially increasing sustainability and resilience, could be found by focussing on the substitution of refined grains by wholegrains, reducing added sugar consumption and year-round supply of fruit and vegetables.

## Data availability statement

The Integrated Household Survey 2015/16 data analysed in this study are publicly available from the World Bank (https://microdata.worldbank.org/index.php/catalog/3323).

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## Conflict of interest

None declared.

## Ethics statement

Ethics approval for this study was provided by The Gambia Government/MRC Joint Ethics Committee (reference: 21275).

## Patient consent for publication

Not applicable

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## *Supplementary material for paper 5*

**Table S1:** Food items making the EAT-Lancet food groups

| **EAT-Lancet food group** | **Food items making group from the IHS2015/2016 dataset** |
|---|---|
| All vegetables | Cabbage; Lettuce; Cucumber; potato leaves; cassava leaves; green leaves; bisap leaves; kren-kren; Carrot; tomato puree; fresh tomato; pumpkin; big red pepper; onion leaves; okra; garden eggs; onion; okra powder; bitter tomato; other vegetables |
| All fruits | Banana; Oranges; Mangoes; Lime; Apple; Paw-paw; watermelon; Pineapple; Grapes; Cabaa; Dates; Avocado; dahar |
| Unsaturated oils | Groundnut oil; vegetable oil; palm kernel oil |
| Beans, lentils and peas | green peas; dry beans; |
| Peanuts and tree nuts | Groundnut powder; peanut butter (roasted peanut paste); groundnuts-shelled; groundnuts-unshelled; Coconut; Cashew nuts |
| Wholegrains | Maize; maize flour |
| Potatoes and cassava | Irish potato; Sweet potato; cassava; Plantain; other roots, gari |
| Fish | Fresh bonga; smoked bonga; catfish; fresh grouper; fresh barracuda; dried couta; Oyster; dried fish; smoked fish; frozen fish; shrimps; snail fish; saul fish; Tilapia; crab; fried fish; canned fish; other fish |
| Palm oil | Palm oil |
| Added sugar | Sugar; honey |
| Refined grains* | Long grained rice; medium grained rice; small grained rice; Uncle Ben's rice; Basmati rice; Paddy rice, long grained, Millet; millet flour; Sorghum; Findi; sorghum flour; wheat flour; bread. |
| Beef and lamb | Beef; sheep; goat |
| Pork | Pork |
| Poultry | Poultry (imported); poultry (local); other poultry products |
| Dairy | Fresh milk; Sour milk; Evaporated milk; Powder milk; Cheese; Yoghurt |
| Eggs | Eggs |

*This group is dominated by rice and wheat (flour, bread).

**S1:** Estimation of metric equivalents of household measures

Where household measures were reported for intake of specific food items without metric equivalents, we measured the average of three replicates of the specified household measure using an electronic kitchen scale accurate to 1g (Jonelle Electronic scale, model 3004).

**S2:** Covariate measurement and cleaning

We assessed household wealth status using a combination of common household possessions and characteristics that are indicative of wealth in both urban and rural areas using Principal Component Analysis (PCA) [1, 2]. The items used in the PCA extraction included: number of livestock owned, type of dwelling, main material used for floor of dwelling, number of rooms in dwelling, type of cooking place, source of drinking water, source of lighting fuel, type of toilet, share in toilet use, main construction material used in external wall of dwelling, main material used for roofing and household possession of a set of 41 durable items (list of 41 items provided in Supplementary Table S2).

Using data on total remittances received by households from both local and foreign sources in the past 12 months, we calculated per capita amount of remittances by dividing by total household size.

Household dietary data were labelled as collected in the rainy season if reporting period fell between July and October, and in the dry season if reported between November and June.

Crop production diversity was computed as the sum of each household's production of a total of 14 different crops including staple crops, cash crops, vegetables, and fruits during the last 12 months.

Finally, total energy and other potentially interesting determinants of household food consumption, including sex of household head (male; female), ethnicity (Mandinka/Jahanka; Fula/Tubular/Lorobo; Wolof; Jola/Karoninka; Serahulleh; Other), education of household head (ever attended school; no schooling), household size (total number of people in household) and urbanisation status (urban; rural), were extracted from the dataset for use in the multivariable models.
List of household possessions included in wealth classification

| **List of durable household items included in wealth classification** |
|---|
| Furniture (3 or 4 piece sofa set); Furniture (chairs); Furniture (table); Furniture (dining table); Bed; Mattress; Carpet; Sewing machine; Cooker (gas/electric); Stove (electric); Stove (gas); Stove (kerosene); Microwave; Refrigerator; Freezer; Air conditioner; Fan; Radio; Radio (cassette recorder); HI-FI (radio/CD/cassette); Video/DVD player; Television; Generator; Solar panel; Washing machine; Camera/video camera; Iron (electric); Iron (charcoal); Computer (Desktop); Laptop/tablet; Fixed line phone; Mobile phone set; Bicycle; Motorcycle; Car (personal); House (not one living in); Truck/lorry; Bus; Boat/canoe; and Animal-drawn cart. |

**S3:** Further details on scoring system used to derive the SHDI
The following food groups: potatoes and cassava, beef and lamb, pork, poultry, eggs, and dairy were scored different from Method 2 by deducting points from the score dependent on the percentage of the target amount that was consumed (i.e. 3 points for consumption within the recommended range, 2 points for consumption within 50-100% of the target, but only 1 point for consumption within 25-50% and 0 points for the least consumption <25% of target or more than the upper bound of the target; Table 1). Due to availability and different health implications for consumption of different forms of grains in this population, this food group was split into two groups with 50-50 expected intake: wholegrains and refined grains. We assigned higher scores for high intake of wholegrains (more healthy) to encourage greater intake in this population (i.e. 3 points for intake above the target, 2 points for intake within 50-100% of the target and only 1 point for intake within 25-50% of the target intake). But higher intake of refined grains (less healthy) were down-scored to discourage over consumption in this setting (i.e. 3 points for intake <25% of the target, 2 points for intake within 25-50% of the target, 1 point for intake within 50-100% of the target, and 0 points for intake above the target).

**Table S2:** Exclusion criteria used in data cleaning

| **Criterion** | **Number excluded** |
|---|---|
| Per capita energy intake ±2 SDs from mean energy* | 481 |
| Total intake equal to zero or missing | 87 |
| Total excluded | 568 |

*Criteria used previously here: https://doi.org/10.1017/S1368980017000416

**Table S3:** Household characteristics and adherence to EAT-Lancet diet recommendations

| | **N (%)** | **Proportion of adherence to EAT-Lancet recommendations** Mean (95% CI) |
|---|---|---|
| Region/**city** | | |
| **National** | 12713 (100) | 21.1 (20.9-21.2) |
| Banjul/**Banjul** | 705 (5.55) | 23.5 (22.9-24.1) |
| West Coast/**Brikama** | 2820 (22.18) | 20.2 (19.9-20.5) |
| Lower river/**Mansakonko** | 1752 (13.78) | 21.1 (20.7-21.4) |
| North Bank/**Kerewan** | 2230 (17.54) | 22.5 (22.2-22.8) |
| Central River/**Janjanbureh** | 3111 (24.47) | 20.9 (20.7-21.2) |
| Upper River/**Basse** | 2095 (16.48) | 20.2 (19.8-20.5) |
| **Area of residence** | | |
| Urban | 3083 (24.25) | 22.6 (22.3-22.9) |
| Rural | 9630 (75.75) | 20.6 (20.5-20.8) |
| **Household wealth** | | |
| Poorest | 2543 (20.00) | 19.5 (19.2-19.8) |
| Poor | 2543 (20.00) | 20.3 (20.0-20.6) |
| Medium | 2542 (20.00) | 20.8 (20.5-21.1) |
| Wealthy | 2543 (20.00) | 21.7 (21.4-22.0) |
| Wealthiest | 2542 (20.00) | 23.2 (22.9-23.6) |
| **Household head** | | |
| Male | 10785 (84.83) | 20.9 (20.8-21.1) |
| Female | 1928 (15.17) | 22.2 (21.8-22.5) |
| **Household head ever attended school** | | |
| No | 9677 (76.13) | 20.7 (20.6-20.8) |
| Yes | 3034 (23.87) | 22.3 (22.0-22.6) |
| **Receipt of remittances (last 12 months)** | | |
| No | 7919 (62.29) | 20.8 (20.7-21.0) |
| Yes | 4794 (37.71) | 21.6 (21.3-21.8) |
| **Season** | | |
| Rainy | 2901 (22.82) | 20.5 (20.2-20.8) |
| Dry | 9812 (77.18) | 21.3 (21.1-21.4) |

**Table S4:** Background characteristics of sampled households, energy, and food group consumption

| EAT-Lancet food group | EAT-Lancet target intake (Possible range), g/day | Region Mean (95% CI) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Banjul | West coast | Lower river | North bank | Central river | Upper river |
| Total energy | 2500 kcal/day | 2235.5 (2158.5-2312.4) | 2011.0 (1977.3-2044.7) | 2610.7 (2550.1-2671.3) | 2410.0 (2364.6-2455.5) | 2912.9 (2862.4-2963.4) | 2857.2 (2800.7-2913.6) |
| Vegetables | 300 (200-600) | 190.5 (179.4-201.7) | 166.7 (161.9-171.6) | 149.7 (144.0-155.4) | 189.6 (183.0-196.2) | 114.3 (110.2-118.5) | 148.6 (142.8-154.4) |
| Fruits | 200 (100-300) | 101.0 (86.3-115.6) | 52.6 (48.1-57.1) | 57.0 (50.9-63.1) | 64.2 (57.9-70.5) | 42.2 (37.7-46.8) | 38.5 (33.9-43.6) |
| Unsaturated oils | 40 (20-80) | 23.1 (21.5-24.7) | 22.2 (21.6-22.9) | 24.2 (23.2-25.1) | 25.4 (24.6-26.2) | 18.6 (18.0-19.3) | 19.5 (18.6-20.4) |
| Beans, lentils, peas | 75 (0-150) | 2.7 (1.9-3.4) | 4.3 (3.8-4.9) | 9.8 (8.8-10.7) | 6.2 (5.5-6.9) | 13.9 (12.9-14.9) | 9.9 (8.9-10.8) |
| Peanuts and tree nuts | 50 (0-100) | 12.0 (9.8-14.2) | 10.1 (9.3-10.9) | 13.2 (12.2-14.2) | 10.7 (9.8-11.7) | 32.7 (30.8-34.6) | 26.9 (25.4-28.4) |
| Wholegrain | 116 (0-232) | 1.1 (0.3-1.9) | 5.8 (4.4-7.2) | 27.4 (23.2-31.7) | 28.7 (25.4-32.0) | 79.9 (74.3-85.4) | 73.1 (65.9-80.2) |
| Potatoes and cassava | 50 (0-100) | 38.7 (35.6-41.8) | 17.9 (16.7-19.2) | 17.8 (16.7-19.1) | 28.6 (27.0-30.2) | 11.3 (10.3-12.3) | 15.1 (13.8-16.3) |
| Fish | 28 (0-100) | 111.7 (104.3-119.2) | 91.8 (89.1-94.6) | 91.7 (88.1-95.3) | 88.9 (86.091.8) | 62.4 (60.3-64.4) | 67.0 (64.5-69.5) |
| Palm oil | 6.8 (0-6.8) | 9.8 (9.1-10.6) | 6.8 (6.5-7.1) | 9.3 (8.9-9.8) | 6.6 (6.3-6.9) | 6.6 (6.3-7.0) | 8.9 (8.5-9.3) |
| Added sugar | 31 (0-31) | 80.6 (75.0-86.2) | 66.1 (64.1-68.1) | 64.7 (62.4-67.0) | 61.7 (59.9-63.6) | 59.1 (57.4-60.8) | 80.1 (77.5-82.7) |
| Refined grains | 116 (0-232) | 354.7 (332.0-359.4) | 321.5 (315.1-327.9) | 433.1 (420.8-445.4) | 392.2 (383.0-401.5) | 481.8 (470.8-492.8) | 453.1 (440.8-465.4) |
| Beef and lamb | 7 (0-14) | 14.6 (12.7-16.6) | 9.2 (8.3-10.1) | 15.8 (14.3-17.3) | 9.5 (8.6-10.5) | 13.0 (11.9-14.0) | 15.0 (13.4-16.5) |
| Poultry | 29 (0-58) | 24.0 (20.9-27.0) | 10.8 (9.8-11.9) | 16.6 (15.2-18.1) | 15.5 (14.3-16.8) | 10.9 (9.9-11.8) | 5.4 (4.6-6.2) |
| Dairy | 250 (0-500) | 30.5 (26.0-35.1) | 18.4 (16.5-20.3) | 38.0 (34.8-41.1) | 20.0 (18.1-21.9) | 31.3 (28.9-33.7) | 26.7 (23.3-30.1) |
| Eggs | 13 (0-25) | 5.2 (4.4-5.9) | 1.3 (1.1-1.5) | 1.0 (0.8-1.2 | 1.4 (1.2-1.7) | 0.6 (0.5-0.8) | 1.1 (0.9-1.3) |

Pork is excluded from table as consumption ≤0.5g/day

**Table S5:** Distribution of food group consumption levels by household characteristics (1/2)

| Food group consumption levels | | Type of settlement<br>Mean (95% CI)<br>n (%) | | Season<br>Mean (95% CI)<br>n (%) | | Household head<br>Mean (95% CI)<br>n (%) | | Region<br><br>n (%) | | | | | | National |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Urban | Rural | Rainy | Dry | Male | Female | Banjul | West coast | Lower river | North bank | Central river | Upper river | |
| Vegetables | Lower than EAT-Lancet target | 1777 (57.6) | 7538 (78.3) | 2187 (75.4) | 7128 (72.6) | 8164 (75.7) | 1151 (59.7) | 427 (60.6) | 1993 (70.7) | 1306 (74.5) | 1448 (64.9) | 2591 (83.3) | 1550 (74.0) | 9315 (73.3) |
| | Within EAT-Lancet target | 1220 (39.6) | 1997 (20.7) | 671 (23.1) | 2546 (25.9) | 2507 (23.2) | 710 (36.8) | 265 (37.6) | 795 (28.2) | 434 (24.8) | 714 (32.0) | 491 (15.8) | 518 (24.7) | 3217 (25.3) |
| | Above EAT-Lancet target | 86 (2.8) | 95 (1.0) | 43 (1.5) | 138 (1.4) | 114 (1.1) | 67 (3.5) | 13 (1.8) | 32 (1.1) | 12 (0.7) | 68 (3.1) | 29 (0.9) | 27 (1.3) | 181 (1.4) |
| Fruits | Lower than EAT-Lancet target | 2417 (78.4) | 8323 (86.4) | 2689 (92.7) | 8051 (82.1) | 9153 (84.9) | 1587 (82.3) | 523 (74.2) | 2345 (83.2) | 1457 (83.2) | 1817 (81.5) | 2736 (87.9) | 1862 (88.9) | 10740 (84.5) |
| | Within EAT-Lancet target | 425 (13.8) | 919 (9.5) | 186 (6.4) | 1158 (11.8) | 1135 (10.5) | 209 (10.8) | 109 (15.5) | 334 (11.8) | 203 (11.6) | 278 (12.5) | 265 (8.5) | 155 (7.4) | 1344 (10.6) |
| | Above EAT-Lancet target | 241 (7.8) | 388 (4.0) | 26 (1.0) | 603 (6.2) | 497 (4.6) | 132 (6.9) | 73 (10.4) | 141 (5.0) | 92 (5.2) | 135 (6.1) | 110 (3.5) | 78 (3.7) | 629 (4.9) |
| Unsaturated oils | Lower than EAT-Lancet target | 1554 (50.4) | 5758 (59.8) | 1652 (57.0) | 5660 (57.7) | 6408 (59.4) | 904 (46.9) | 342 (48.5) | 1562 (55.4) | 934 (53.3) | 1050 (47.1) | 2092 (67.2) | 1332 (63.6) | 7312 (57.5) |
| | Within EAT-Lancet target | 1461 (47.4) | 3732 (38.7) | 1200 (41.4) | 3993 (40.7) | 4220 (39.1) | 973 (50.5) | 348 (49.4) | 1224 (43.4) | 779 (44.5) | 1138 (51.0) | 979 (31.5) | 725 (34.6) | 5193 (40.8) |
| | Above EAT-Lancet target | 68 (2.2) | 140 (1.5) | 49 (1.7) | 159 (1.6) | 157 (1.5) | 51 (2.6) | 15 (2.1) | 34 (1.2) | 39 (2.2) | 42 (1.9) | 40 (1.3) | 38 (1.8) | 208 (1.6) |
| Beans, lentils and peas | Lower than EAT-Lancet target | 3046 (98.8) | 9367 (97.3) | 2830 (97.6) | 9583 (97.7) | 10523 (97.6) | 1890 (98.0) | 703 (99.7) | 2795 (99.1) | 1724 (98.4) | 2198 (98.6) | 2964 (95.3) | 2029 (96.8) | 12413 (97.6) |
| | Within EAT-Lancet target | 31 (1.0) | 242 (2.5) | 68 (2.3) | 205 (2.1) | 238 (2.2) | 35 (1.8) | 1 (0.1) | 22 (0.8) | 26 (1.5) | 29 (1.3) | 136 (4.4) | 59 (2.8) | 273 (2.2) |
| | Above EAT-Lancet target | 6 (0.2) | 21 (0.2) | 3 (0.1) | 24 (0.2) | 24 (0.2) | 3 (0.2) | 1 (0.1) | 3 (0.1) | 2 (0.1) | 3 (0.1) | 11 (0.3) | 7 (0.3) | 27 (0.2) |
| Peanuts and tree nuts | Lower than EAT-Lancet target | 2821 (91.5) | 8527 (88.6) | 2610 (90.0) | 8738 (89.0) | 9633 (89.3) | 1715 (88.9) | 651 (92.3) | 2710 (96.10) | 1647 (94.0) | 2141 (89.3) | 2512 (80.7) | 1687 (80.5) | 11348 (89.3) |
| | Within EAT-Lancet target | 186 (6.0) | 770 (8.0) | 199 (6.9) | 757 (7.7) | 801 (7.4) | 155 (8.0) | 43 (6.1) | 90 (3.2) | 76 (4.3) | 60 (2.7) | 354 (11.4) | 333 (15.9) | 956 (7.5) |
| | Above EAT-Lancet target | 76 (2.5) | 333 (3.5) | 92 (3.2) | 317 (3.2) | 351 (3.2) | 58 (3.0) | 11 (1.6) | 20 (0.7) | 29 (1.7) | 29 (1.3) | 245 (7.9) | 75 (3.6) | 409 (3.2) |
| Wholegrain | Lower than EAT-Lancet target | 3029 (98.2) | 8210 (85.2) | 2485 (85.7) | 8754 (89.2) | 9382 (87.0) | 1857 (96.3) | 703 (99.7) | 2777 (98.5) | 1611 (91.3) | 2035 (91.3) | 2398 (77.1) | 1715 (81.9) | 11239 (88.4) |
| | Within EAT-Lancet target | 28 (0.9) | 619 (6.4) | 179 (6.2) | 468 (4.8) | 611 (5.7) | 36 (1.9) | 2 (0.3) | 29 (1.0) | 76 (4.3) | 120 (5.4) | 288 (9.3) | 132 (6.3) | 647 (5.1) |
| | Above EAT-Lancet target | 26 (0.8) | 801 (8.3) | 237 (8.2) | 590 (6.0) | 792 (7.3) | 35 (1.8) | 0 (0.0) | 14 (0.5) | 65 (3.7) | 75 (3.4) | 425 (13.7) | 248 (11.8) | 827 (6.5) |
| Potatoes and cassava | Lower than EAT-Lancet target | 2340 (75.9) | 8872 (92.1) | 2571 (88.6) | 8641 (88.1) | 9611 (89.1) | 1601 (83.0) | 510 (72.3) | 2516 (89.2) | 1572 (89.7) | 1811 (88.2) | 2904 (93.4) | 1899 (90.6) | 11212 (88.2) |
| | Within EAT-Lancet target | 491 (15.9) | 567 (5.9) | 222 (7.6) | 836 (8.5) | 838 (7.8) | 220 (11.4) | 133 (18.9) | 204 (7.2) | 144 (8.2) | 298 (13.4) | 134 (4.3) | 145 (6.9) | 1058 (8.3) |
| | Above EAT-Lancet target | 252 (8.2) | 191 (2.0) | 108 (3.7) | 335 (3.4) | 336 (3.1) | 107 (5.6) | 62 (8.8) | 100 (3.6) | 36 (2.1) | 121 (5.4) | 73 (2.4) | 51 (2.4) | 443 (3.5) |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fish | Lower than EAT-Lancet target | 605 (19.6) | 2067 (21.5) | 676 (23.3) | 1996 (20.3) | 2430 (22.5) | 242 (12.5) | 151 (21.4) | 407 (14.4) | 282 (16.1) | 367 (16.5) | 914 (29.4) | 551 (26.3) | 2672 (21.0) |
| | Within EAT-Lancet target | 1354 (43.9) | 5064 (52.6) | 1411 (48.6) | 5007 (51.0) | 5559 (51.5) | 859 (44.5) | 230 (32.6) | 1479 (52.4) | 860 (49.1) | 1107 (49.6) | 1633 (52.5) | 1109 (52.9) | 6418 (50.5) |
| | Above EAT-Lancet target | 1124 (36.5) | 2499 (25.9) | 814 (28.1) | 2809 (28.6) | 2796 (25.9) | 827 (42.9) | 324 (46.0) | 934 (33.1) | 610 (34.8) | 756 (33.9) | 564 (18.1) | 435 (20.8) | 3623 (28.5) |
| Palm oil | Lower than EAT-Lancet target | 876 (28.4) | 3718 (38.6) | 1001 (34.5) | 3593 (36.6) | 4040 (37.5) | 554 (28.7) | 197 (27.9) | 1056 (37.4) | 505 (28.8) | 753 (33.8) | 1386 (44.5) | 697 (33.3) | 4594 (36.1) |
| | Within EAT-Lancet target | 567 (18.4) | 1969 (20.4) | 591 (20.4) | 1945 (19.8) | 2223 (20.6) | 313 (16.2) | 83 (11.8) | 657 (23.3) | 312 (17.8) | 607 (27.2) | 569 (18.3) | 308 (14.7) | 2536 (19.9 |
| | Above EAT-Lancet target | 1640 (53.2) | 3943 (40.9) | 1309 (45.1) | 4274 (43.6) | 4522 (41.9) | 1061 (55.0) | 425 (60.3) | 1107 (39.3) | 935 (53.4) | 870 (39.0) | 1156 (37.2) | 1090 (52.0) | 5583 (43.9) |
| Added sugar | Lower than EAT-Lancet target | 250 (8.1) | 889 (9.2) | 277 (9.5) | 862 (8.8) | 959 (8.9) | 180 (9.3) | 73 (10.3) | 236 (8.4) | 192 (11.0) | 169 (7.6) | 298 (9.6) | 171 (8.2) | 1139 (9.0) |
| | Within EAT-Lancet target | 312 (10.1) | 1404 (14.6) | 410 (14.1) | 1306 (13.3) | 1500 (13.9) | 216 (11.2) | 87 (12.3) | 368 (13.0) | 215 (12.3) | 318 (14.3) | 549 (17.6) | 179 (8.5) | 1716 (13.5) |
| | Above EAT-Lancet target | 2521 (81.8) | 7337 (76.2) | 2214 (76.3) | 7644 (77.9) | 8326 (77.2) | 1532 (79.5) | 545 (77.3) | 2216 (78.6) | 1345 (76.8) | 1743 (78.2) | 2264 (72.8) | 1745 (83.3) | 9858 (77.5) |
| Refined grains | Lower than EAT-Lancet target | 227 (7.4) | 589 (6.1) | 154 (5.3) | 662 (6.7) | 693 (6.4) | 123 (6.4) | 62 (8.8) | 244 (8.6) | 90 (5.1) | 106 (4.7) | 180 (5.8) | 134 (6.4) | 816 (6.4) |
| | Within EAT-Lancet target | 586 (19.0) | 1632 (16.9) | 507 (17.5) | 2218 (17.4) | 1914 (17.7) | 304 (15.8) | 136 (19.3) | 693 (24.6) | 262 (14.9) | 378 (16.9) | 455 (14.6) | 294 (14.0) | 2218 (17.5) |
| | Above EAT-Lancet target | 2270 (73.6) | 7409 (76.9) | 2240 (77.2) | 7439 (75.8) | 8178 (75.8) | 1501 (77.8) | 507 (71.9) | 1883 (66.8) | 1400 (79.9) | 1746 (78.3) | 2476 (79.6) | 1667 (79.6) | 9679 (76.1) |
| Beef and lamb | Lower than EAT-Lancet target | 1993 (64.6) | 7118 (73.9) | 2091 (72.1) | 7020 (71.6) | 7707 (71.5) | 1404 (72.8) | 453 (64.3) | 2203 (78.1) | 1183 (67.5) | 1622 (72.7) | 2118 (68.1) | 1532 (73.1) | 9111 (71.7) |
| | Within EAT-Lancet target | 69 (2.2) | 226 (2.3) | 68 (2.3) | 227 (2.3) | 273 (2.5) | 22 (1.1) | 10 (1.4) | 52 (1.8) | 15 (0.9) | 67 (3.0) | 126 (4.1) | 25 (1.2) | 295 (2.3) |
| | Above EAT-Lancet target | 1021 (33.1) | 2286 (23.7) | 742 (25.6) | 2565 (26.1) | 2805 (26.0) | 502 (26.0) | 242 (34.3) | 565 (20.0) | 554 (31.6) | 541 (24.3) | 867 (27.9) | 538 (25.7) | 3307 (26.0) |
| Poultry | Lower than EAT-Lancet target | 2416 (78.4) | 8324 (86.4) | 2443 (84.2) | 8297 (84.6) | 9209 (85.4) | 1531 (79.4) | 498 (70.6) | 2458 (87.2) | 1359 (77.6) | 1798 (80.6) | 2671 (85.9) | 1956 (93.4) | 10740 (84.5) |
| | Within EAT-Lancet target | 360 (11.7) | 793 (8.2) | 278 (9.6) | 875 (8.9) | 954 (8.8) | 199 (10.3) | 128 (18.2) | 206 (7.3) | 222 (12.7) | 269 (12.1) | 243 (7.8) | 85 (4.1) | 1153 (9.1) |
| | Above EAT-Lancet target | 307 (10.0) | 514 (5.3) | 180 (6.2) | 640 (6.5) | 622 (5.8) | 198 (10.3) | 79 (11.2) | 156 (5.5) | 171 (9.8) | 163 (7.3) | 197 (6.3) | 54 (2.6) | 820 (6.4) |
| Dairy | Lower than EAT-Lancet target | 3055 (99.1) | 9426 (97.9) | 2847 (98.1) | 9634 (98.2) | 10579 (98.1) | 1902 (98.6) | 695 (98.6) | 2796 (99.2) | 1717 (98.0) | 2209 (99.1) | 3031 (97.4) | 2033 (97.0) | 12481 (98.2) |
| | Within EAT-Lancet target | 21 (0.7) | 180 (1.9) | 48 (1.7) | 153 (1.6) | 178 (1.7) | 23 (1.2) | 6 (0.9) | 19 (0.7) | 34 (1.9) | 21 (0.9) | 72 (2.3) | 49 (2.3) | 201 (1.6) |
| | Above EAT-Lancet target | 7 (0.2) | 24 (0.2) | 6 (0.2) | 25 (0.2) | 28 (0.3) | 3 (0.2) | 4 (0.6) | 5 (0.2) | 1 (0.1) | 0 (0.0) | 8 (0.3) | 13 (0.6) | 31 (0.2) |
| Eggs | Lower than EAT-Lancet target | 2806 (91.0) | 9463 (98.3) | 2791 (96.2) | 9478 (96.5) | 10431 (96.7) | 1838 (95.3) | 600 (85.1) | 2729 (96.8) | 1705 (97.3) | 2157 (96.7) | 3059 (98.3) | 2019 (96.4) | 12269 (96.5) |
| | Within EAT-Lancet target | 144 (4.7) | 79 (0.8) | 69 (2.4) | 154 (1.6) | 174 (1.6) | 49 (2.5) | 62 (8.8) | 40 (1.4) | 34 (1.9) | 30 (1.4) | 21 (0.7) | 36 (1.7) | 223 (1.8) |
| | Above EAT-Lancet target | 133 (4.3) | 88 (0.9) | 41 (1.4) | 180 (1.8) | 180 (1.7) | 41 (2.1) | 43 (6.1) | 51 (1.8) | 13 (0.7) | 43 (1.9) | 31 (1.0) | 40 (1.9) | 221 (1.7) |

Pork is excluded from table as consumption ≤0.5g/day.

**Table S5:** Distribution of food group consumption levels by household characteristics (2/2)

| Food group consumption levels | | Household wealth quintile n (%) | | | | |
|---|---|---|---|---|---|---|
| | | Q1 | Q2 | Q3 | Q4 | Q5 |
| Vegetables | Lower than EAT-Lancet target | 2270 (89.3) | 2026 (79.7) | 1868 (73.5) | 1676 (58.0) | 1475 (58.0) |
| | Within EAT-Lancet target | 261 (10.3) | 492 (19.4) | 646 (25.4) | 816 (32.1) | 1002 (39.4) |
| | Above EAT-Lancet target | 12 (0.5) | 25 (1.0) | 28 (1.1) | 51 (2.0) | 65 (2.6) |
| Fruits | Lower than EAT-Lancet target | 2339 (92.0) | 2161 (85.0) | 2152 (84.7) | 2140 (84.2) | 1948 (76.6) |
| | Within EAT-Lancet target | 143 (5.6) | 267 (10.5) | 292 (11.5) | 377 (14.8) | 377 (14.8) |
| | Above EAT-Lancet target | 61 (2.4) | 115 (4.5) | 98 (3.9) | 217 (8.5) | 217 (8.5) |
| Unsaturated oils | Lower than EAT-Lancet target | 1748 (68.7) | 1563 (61.5) | 1448 (57.0) | 1307 (51.4) | 1246 (49.0) |
| | Within EAT-Lancet target | 770 (30.3) | 943 (37.1) | 1056 (41.5) | 1180 (46.4) | 1244 (48.9) |
| | Above EAT-Lancet target | 25 (1.0) | 37 (1.4) | 38 (1.5) | 56 (2.2) | 52 (2.1) |
| Beans, lentils and peas | Lower than EAT-Lancet target | 2448 (96.3) | 2477 (97.4) | 2486 (98.0) | 2492 (98.0) | 2510 (98.7) |
| | Within EAT-Lancet target | 87 (3.4) | 60 (2.4) | 54 (2.1) | 45 (1.8) | 27 (1.1) |
| | Above EAT-Lancet target | 8 (0.3) | 6 (0.2) | 2 (0.1) | 6 (0.2) | 5 (0.2) |
| Peanuts and tree nuts | Lower than EAT-Lancet target | 2163 (85.1) | 2273 (89.4) | 2265 (89.1) | 2312 (90.9) | 2335 (91.9) |
| | Within EAT-Lancet target | 254 (10.0) | 177 (7.0) | 196 (7.7) | 178 (7.0) | 151 (5.9) |
| | Above EAT-Lancet target | 126 (4.9) | 93 (4.0) | 81 (3.2) | 53 (2.1) | 56 (2.2) |
| Wholegrain | Lower than EAT-Lancet target | 2016 (79.3) | 2187 (86.0) | 2255 (88.7) | 2317 (91.1) | 2464 (96.9) |
| | Within EAT-Lancet target | 201 (7.9) | 187 (7.3) | 136 (5.6) | 91 (3.6) | 32 (1.3) |
| | Above EAT-Lancet target | 326 (12.8) | 169 (6.6) | 151 (5.9) | 135 (5.3) | 46 (1.8) |
| Potatoes and cassava | Lower than EAT-Lancet target | 2449 (96.3) | 2362 (92.9) | 2310 (90.9) | 2180 (85.7) | 1911 (75.2) |
| | Within EAT-Lancet target | 68 (2.7) | 139 (5.5) | 169 (6.6) | 271 (10.7) | 411 (16.2) |
| | Above EAT-Lancet target | 26 (1.0) | 42 (1.6) | 63 (2.5) | 92 (3.6) | 220 (8.6) |
| Fish | Lower than EAT-Lancet target | 743 (29.2) | 556 (21.9) | 441 (17.3) | 373 (14.7) | 559 (22.0) |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Within EAT-Lancet target | 1338 (52.6) | 1397 (54.9) | 1372 (54.0) | 1308 (51.4) | 1003 (39.5) |
| | Above EAT-Lancet target | 462 (18.2) | 590 (23.2) | 729 (28.7) | 862 (33.9) | 980 (38.5) |
| Palm oil | Lower than EAT-Lancet target | 1244 (48.9) | 989 (38.9) | 847 (33.3) | 757 (29.8) | 757 (29.8) |
| | Within EAT-Lancet target | 474 (18.6) | 540 (21.2) | 580 (22.8) | 532 (20.9) | 410 (16.1) |
| | Above EAT-Lancet target | 825 (32.4) | 1014 (39.9) | 1115 (43.9) | 1254 (49.3) | 1375 (54.1) |
| Added sugar | Lower than EAT-Lancet target | 247 (9.7) | 237 (9.3) | 213 (8.4) | 187 (7.4) | 255 (10.0) |
| | Within EAT-Lancet target | 441 (17.3) | 424 (16.3) | 350 (13.8) | 278 (10.9) | 233 (9.2) |
| | Above EAT-Lancet target | 1855 (72.9) | 1892 (74.4) | 1979 (77.8) | 2078 (81.7) | 2054 (80.8) |
| Refined grains | Lower than EAT-Lancet target | 144 (5.7) | 165 (6.5) | 137 (5.4) | 143 (5.6) | 227 (8.9) |
| | Within EAT-Lancet target | 382 (15.0) | 446 (17.5) | 416 (16.4) | 434 (17.1) | 540 (21.2) |
| | Above EAT-Lancet target | 2017 (79.3) | 1932 (76.0) | 1989 (78.2) | 1966 (77.3) | 1775 (69.8) |
| Beef and lamb | Lower than EAT-Lancet target | 2088 (82.1) | 1956 (76.9) | 1834 (72.1) | 1684 (66.2) | 1549 (60.9) |
| | Within EAT-Lancet target | 60 (2.4) | 62 (2.4) | 55 (2.2) | 64 (2.5) | 54 (2.1) |
| | Above EAT-Lancet target | 395 (15.5) | 525 (20.6) | 653 (25.7) | 795 (31.3) | 939 (36.9) |
| Poultry | Lower than EAT-Lancet target | 2270 (89.3) | 2192 (86.2) | 2204 (86.7) | 2145 (84.5) | 1929 (75.9) |
| | Within EAT-Lancet target | 173 (6.8) | 218 (8.6) | 189 (7.4) | 235 (9.2) | 338 (13.3) |
| | Above EAT-Lancet target | 100 (3.9) | 133 (5.2) | 149 (5.9) | 163 (6.4) | 275 (10.8) |
| Dairy | Lower than EAT-Lancet target | 2470 (97.1) | 2494 (98.1) | 2504 (98.5) | 2506 (98.6) | 2507 (98.6) |
| | Within EAT-Lancet target | 60 (2.4) | 45 (1.8) | 34 (1.3) | 36 (1.4) | 26 (1.0) |
| | Above EAT-Lancet target | 13 (0.5) | 4 (0.2) | 4 (0.2) | 1 (0.04) | 9 (0.4) |
| Eggs | Lower than EAT-Lancet target | 2526 (99.3) | 2513 (98.8) | 2505 (98.5) | 2483 (97.6) | 2242 (88.2) |
| | Within EAT-Lancet target | 10 (0.4) | 15 (0.6) | 17 (0.7) | 31 (1.2) | 150 (5.9) |
| | Above EAT-Lancet target | 7 (0.3) | 15 (0.6) | 20 (0.8) | 29 (1.1) | 150 (5.9) |

Q1 and Q5 represent the lowest and highest quintiles respectively.

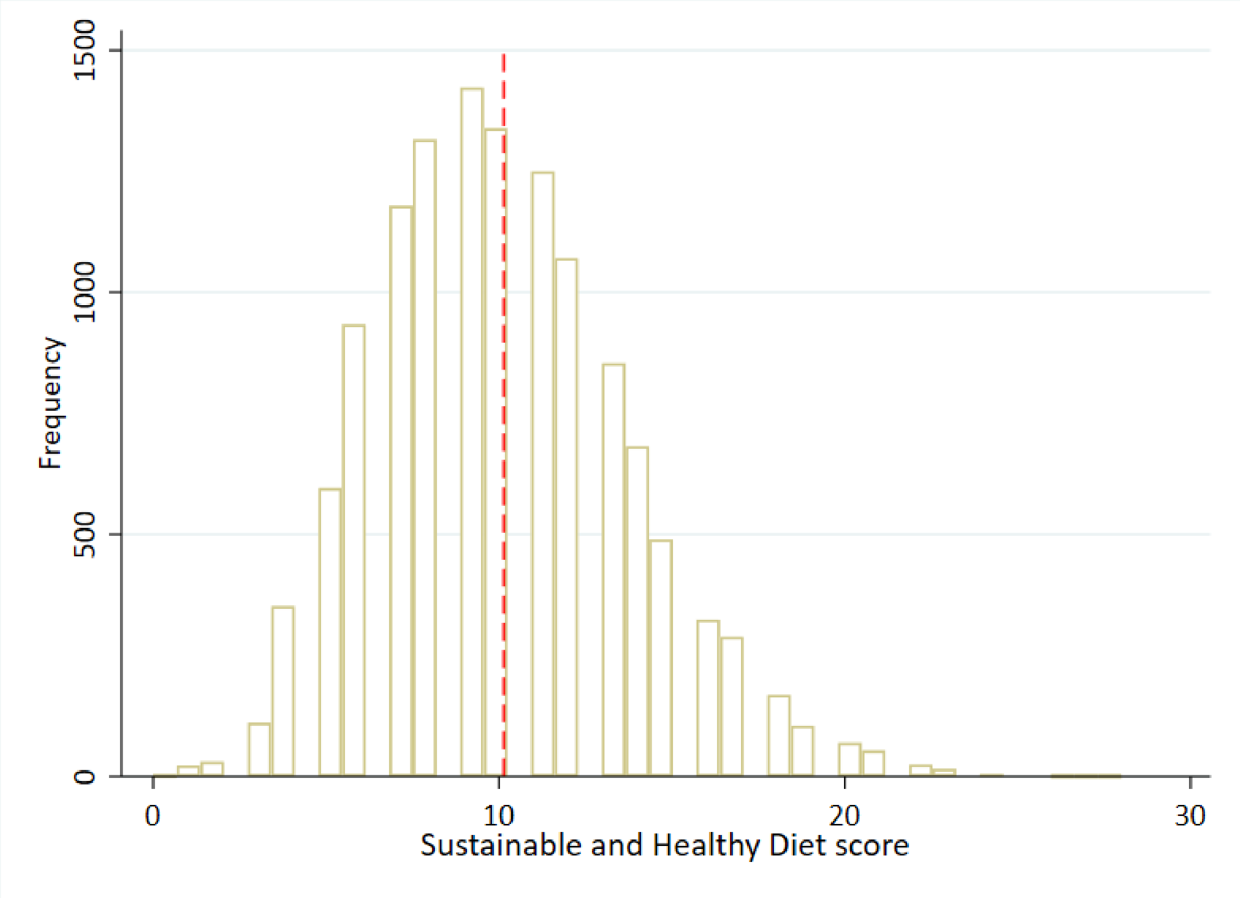


**Figure S1:** Distribution of the total SHDI scores [Red dashed line indicates the mean score of 10.14, rang of scores 0-28].

**Table S6**: Food group adhered to by households scoring 3 points for each food group

| EAT-Lancet food group | Households adhering to the guideline by number food groups and type of food groups commonly included | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 food group | | 2 food groups | | 3 food groups | | ≥4 food groups | |
| | n (%) scoring 3 points | n (%) scoring 2 points | n (%) scoring 3 points | n (%) scoring 2 points | n (%) scoring 3 points | n (%) scoring 2 points | n (%) scoring 3 points | n (%) scoring 2 points |
| All vegetables | 37 (0.8) | 604 (13.8) | 374 (9.1) | 595 (14.4) | 529 (24.3) | 339 (33.8) | **683 (51.8)** | 193 (14.6) |
| All fruits | 30 (0.7) | 302 (6.9) | 294 (7.1) | 281 (6.8) | 340 (15.6) | 184 (8.4) | 400 (30.3) | 106 (8.0) |
| Unsaturated oils | 28 (0.6) | 1354 (30.9) | 348 (8.4) | 1342 (32.6) | **544 (25.0)** | 663 (30.5) | **720 (54.6)** | 273 (20.7) |
| Beans, lentils and peas | 17 (0.4) | 157 (3.6) | 47 (1.1) | 196 (4.7) | 84 (3.9) | 133 (6.1) | 133 (10.1) | 102 (7.7) |
| Peanuts and tree nuts | 93 (2.1) | 508 (11.6) | 420 (10.2) | 488 (11.8) | 446 (20.5) | 222 (10.2) | 399 (30.2) | 107 (8.1) |
| Wholegrain | 46 (1.1) | 225 (5.1) | 277 (6.7) | 220 (5.3) | 276 (12.7) | 109 (5.0) | 228 (17.3) | 38 (2.9) |
| Potatoes and cassava | 23 (0.5) | 619 (14.2) | 336 (8.1) | 592 (14.4) | 486 (22.3) | 287 (13.2) | **652 (49.4)** | 134 (10.2) |
| Fish | **3346 (76.5)** | 502 (11.5) | **3524 (85.5)** | 240 (5.8) | **1942 (89.2)** | 65 (3.0) | **1227 (93.0)** | 23 (1.7) |
| Palm oil | 599 (13.7) | 420 (9.6) | **1656 (40.2)** | 155 (3.8) | **988 (45.4)** | 43 (2.0) | **587 (44.5)** | 9 (0.7) |
| Added sugar | 44 (1.0) | 242 (5.5) | 209 (5.1) | 170 (4.1) | 195 (9.0) | 51 (2.3) | 160 (12.1) | 14 (1.1) |
| Refined grains | 18 (0.4) | 181 (4.1) | 115 (2.8) | 136 (3.3) | 113 (5.2) | 85 (3.9) | 90 (6.8) | 38 (2.9) |
| Beef and lamb | 34 (0.8) | 4 (0.1) | 126 (3.1) | 8 (0.2) | 96 (4.4) | 2 (0.1) | 39 (3.0) | 2 (0.2) |
| Poultry | 51 (1.2) | 494 (11.3) | 418 (10.1) | 369 (9.0) | 365 (16.8) | 157 (7.2) | 319 (24.2) | 65 (4.9) |
| Dairy | 8 (0.2) | 130 (3.0) | 51 (1.2) | 163 (3.9) | 64 (2.9) | 111 (5.1) | 78 (5.9) | 101 (7.7) |
| Eggs | 2 (0.1) | 92 (2.1) | 50 (1.2) | 96 (2.3) | 63 (2.9) | 2 (3.5) | 108 (8.2) | 73 (5.5) |
| Pork | 0 (0.0) | 0 (0.0) | 1 (0.02) | 0 (0.0) | 0 (0) | 0 (0.0) | 0(0) | 0 (0.0) |
| Total | 4376 (100) | 4376 (100) | 4123 (100) | 4123 (100) | 2177 (100) | 2177 (100) | 1319 (100) | 1319 (100) |

Bolded numbers show the most likely food groups in each category of households.

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**Paper 6:** Long-term impact of West African food system responses to COVID-19

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**Please note that a cover sheet must be completed <u>for each</u> research paper included within a thesis.**

## SECTION A – Student Details

| | | | |
|---|---|---|---|
| **Student ID Number** | 1800648 | **Title** | Mr |
| **First Name(s)** | Zakari | | |
| **Surname/Family Name** | Ali | | |
| **Thesis Title** | Resilient and healthy food systems in low-income settings | | |
| **Primary Supervisor** | Prof. Andrew Prentice | | |

**If the Research Paper has previously been published please complete Section B, if not please move to Section C.**

**<u>SECTION B – Paper already published</u>**

| | | | |
|---|---|---|---|
| Where was the work published? | Nature Food | | |
| When was the work published? | 19th November 2020 | | |
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SPRINGER NATURE

**Long-term impact of West African food system responses to COVID-19**

**Author:** Zakari Ali et al

**Publication:** Nature Food

**Publisher:** Springer Nature

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**SECTION D – Multi-authored work**

| | |
|---|---|
| For multi-authored work, give full details of your role in the research included in the paper and in the preparation of the paper. (Attach a further sheet if necessary) | I proposed the study idea during the peak of the COVID-19 lockdowns in The Gambia. I discussed the study idea together with Dr Pauline Scheelbeek, Dr Rosemary Green and Prof. Alan Dangour to agree on the design. I performed the literature searches and wrote the first manuscript draft. Prof. Alan Dangour and Dr Pauline Scheelbeek made substantial contributions to the draft and made comments which I used to re-draft an updated manuscript. All co-authors sent me relevant literature, commented on the draft, and made suggestions on manuscript structure which I used to improve on the manuscript. I led the journal submission process and responded to reviewer comments in consultation with all co-authors. Each round of peer-review required substantial re-structuring and updates given the quick evolving nature of the literature around COVID-19 at the time. I performed the additional literature searches used to update the manuscript and respond to reviewer comments with assistance from my supervisors and co-authors. |

**SECTION E**

| | |
|---|---|
| **Student Signature** | [redacted] |
| **Date** | 2nd August 2022 |

| | |
|---|---|
| **Supervisor Signature** | [redacted] |
| **Date** | 12th October 2022 |

comment

# Long-term impact of West African food system responses to COVID-19

The COVID-19 pandemic continues to impact health and livelihoods in West Africa. Exposure of food system fragilities by the pandemic presents the opportunity for regional-specific reforms to deliver healthy diets for all and promote resilience to future shocks.

Zakari Ali, Rosemary Green, Robert B. Zougmoré, Siyabusa Mkuhlani, Amanda Palazzo, Andrew M. Prentice, Andy Haines, Alan D. Dangour and Pauline F. D. Scheelbeek

Long-term impacts of the COVID-19 pandemic on food systems may well be most heavily felt in low- and middle-income countries with fragile health systems and economies.

Although West Africa has so far been spared the worst of the pandemic in terms of infection rates, severity of disease and mortality[1], the World Bank estimates that in Nigeria alone, the largest economy in the West African region, 5 million people may become impoverished due to COVID-19[2]. Furthermore, the Permanent Interstate Committee for Drought Control in the Sahel (CILSS) estimates that the 51 million people who face food stress are likely to fall into food crisis without adequate income support[3].

Government responses to the pandemic have been broadly similar across West African countries[4]. Almost all have implemented curfews, travel restrictions, and some have imposed lockdowns in urban areas — albeit with a gradual easing of restrictions as populations become weary of government-imposed restrictions. Limited attention, however, has been given to the impact these measures have on the ability of governments to ensure safe and timely agricultural production, continue international agricultural trade, and secure access to healthy diets for all people. Previous epidemics in the West African region, such as the 2013–2016 Ebola outbreak, provided evidence of the relative fragility of food systems in the region. In the three countries most affected by the Ebola outbreak — Guinea, Sierra Leone and Liberia — more than 40% of regular farming lands were left uncultivated and the price of cereals such as rice increased by over 30% (ref. [5]). It is noteworthy that the 2020 climatic conditions in the region are predicted to be atypical, but favourable — above-normal total rainfall, and earlier onset and later cessation of rainfall[6] — and would in normal circumstances provide a unique opportunity for a productive harvest.

## Food system fragilities

The unfolding COVID-19 pandemic may pose unique challenges for West Africa. The agricultural workforce already has a relatively poor nutritional and health profile, and further pandemic-related ill health could reduce labour productivity during the busy planting and harvest seasons. Rural farming communities typically have little to no savings or food stores and many depend on daily-generated income for food[7]. Interruptions to day-wages and unexpected health expenditures may force households into poverty. The impact of lockdowns, market closures, and potential restrictions on regional and international food trade have likely impacted food prices — rises between 11% and 17% in cereals, especially imported rice are observed in Nigeria, Sierra Leone and Liberia[3]. These measures have particularly affected pastoralists and nomadic livestock herders, interrupted value chains, and reduced access to seeds and other on-farm labour — the availability of which is based on the agricultural calendars in the region[8]. Furthermore, the likely lengthy delays and significant competition in defining new trade agreements, including the African Continental Free Trade Area Agreement, are projected to put West African food systems under significant additional stress[9]. Of particular concern are supplies of nutritionally important but relatively perishable fresh fruit and vegetables[10]. Approximately 7 million school children in West Africa benefit from school feeding programmes[11], and for many households, these meals cover an important part of household food supply. School closure due to pandemic restrictions will increase pressure on family food supplies as children do not receive free school meals and parents stay at home for childcare[12]. The pressures of the pandemic fall on top of the existing strains from increased frequency and severity of droughts and extreme heat in West Africa, and in particular the Sahel region. In 2010 and 2012 Sahelian droughts caused widespread crop failure and left many households food insecure in Mauritania, Mali, Chad, Niger and Burkina Faso[13].

## Support for governments

International organizations including the International Monetary Fund, International Fund for Agricultural Development (IFAD), the African Development Bank (ADB) and the World Bank have all made major funding commitments and are supporting governments in the region in the fight against COVID-19. This provides policy context conducive to food system reforms that were unheard of pre-pandemic and are now increasingly important to guard against the potentially devastating impacts of future pandemics and other shocks. We propose a number of policy options to support the resilience and sustainability of West African food systems in the post-COVID-19 era where "surprise is the new normal"[14].

**Investments and partnerships.** Though many of the commitments from regional and international donors and development partners are aimed at reducing food insecurity and impoverishment in the short term, they offer governments the opportunity to increase investments in agriculture that can co-deliver long-term benefits. The ADB recently announced US$10 billion in support for African economies to safeguard against food insecurity impacts of the COVID-19 pandemic[15]. The programme prioritizes agricultural policies that support the most vulnerable through investments in farm inputs for food production and strengthen the capacity of regional organizations for food security. However, three months after this announcement, it has yet to become clear whether the substantial budgetary allocation for COVID-19-related food insecurity by the ADB could have negative consequences for other sectors receiving funding from the bank. Furthermore, there may be unforeseen consequences of this increase in funding that in turn could jeopardize future food security for other disadvantaged population groups. IFAD's Rural Poor Stimulus Facility programme aims to mobilize US$240 million to improve food security by supporting production (inputs and basic assets for crop, livestock and fisheries) and access to markets, by targeting funds for rural financial services, and through the use of digital services for weather and market information delivery[16]. While these programmes may have a short-term focus, opportunities exist to achieve longer-term impacts, for example through expansion of input support to include seeds that have a greater resilience in the face of future climate change (climate-smart crops) that farmers could continue to grow after the immediate support period ends. Strengthening public–private partnerships, and the use of innovative funding models[17], may also provide an opportunity to ensure programmatic and financial sustainability. The pandemic has resulted in a rebalancing of funding streams in the development community that may have negative impacts on other sectors; the balance is likely to shift again post-pandemic. Therefore, it is important to re-strategize current food system investments now to ensure that they have a lasting impact.

**Innovation.** West Africa's abundant supply of sunlight and agriculturally underutilized land (in mostly rural settings) is ripe for development — including rural development opportunities[18] that improve food safety, reduce post-harvest losses and increase food storage to raise productivity for farmers; with appropriate infrastructural planning and mandated safeguards to protect nature. Modern agricultural approaches — including urban farming of vegetables and novel foods including mycoproteins, insects for animal and human consumption and cellular agriculture[19] — are expanding rapidly with the potential for acceptability testing and adoption. Supporting these new approaches may provide multiple benefits including urban and peri-urban food production (with clear employment opportunities for growing urban populations) and strengthen important food supply chains. Peri-urban food production has many potential benefits, including shorter supply chains that may be particularly useful during infection-control enforcement, income generation possibilities, and opportunities for the greater engagement of women[20]. Governments should design 'smart' agriculture insurance programmes that can reduce inefficiencies and be cost effective in supporting agricultural investments[21]. The conversion of urban and peri-urban waste into fertilizer[22] to support food production (with the potential to reduce environmental pollution in cities and prevent infectious diseases) could be a 'low-regret' option to consider. Despite the many expected benefits of food system expansion, decision-making on how and to what extent to expand production should be based on a full evidence map of potential benefits and trade-offs. While successful urban production can efficiently complement rural production[23], the possibility to reduce the demand of similar products from rural farmers needs consideration. Furthermore, the expansion of agricultural land could bring several environmental risks, including substantial negative impacts on biodiversity and deforestation. West Africa's experience with Ebola virus and its link to agricultural land conversion[24] makes it important to plan production to minimize zoonotic spillover and protect the territorial rights of indigenous communities.

**Reconfigure trade policies.** Border restrictions due to COVID-19, even though food is often exempted, have disrupted food trade flow and the movement of livestock herders in West Africa, especially for informal trade that represents a substantial amount of total trade in the region[25]. Food trading arrangements need to consider both the financial and environmental costs of food production. International trade is a potent strategy for 'spreading risk', providing a buffer for regions exposed to climate change and severe local disruptions (such as during regionalized outbreaks). However, long supply chains (inter-regional or continental) may become unsustainable during a severe shock when major food supplying countries adopt a protectionist approach to trade, limiting exports to dependent countries. Trade policies should be reconfigured in a balanced approach, dispersed enough to avoid major disruption in supply in cases of localized harvest failure, but also optimized to consider multiple impacts, including on subsidies, taxes and the environment (such as embedded environmental footprints).

**Early warning systems.** An integrated system that combines existing systems that monitor food prices, crop diseases, weather patterns and other environmental changes is needed to support efforts already made in the region to improve early warning. Local, national and regional communication could be improved with better, integrated early warning and notification systems — which are even more crucial with border closure measures in place, as the current COVID-19 border closures has made it more difficult to address and mitigate agricultural pests[26]. A systemic and structurally designed regional early warning system for pests and diseases such as locusts and fall armyworm — through strengthening the capacity of institutions and organizations in the region, such as CILSS and the Economic Community of West African States trade department — will enable systematic and sustainable data collection and analysis for better preparedness. Functional early warning systems can help countries to take early steps to protect lives and livelihoods when a pandemic or other crisis strikes[27].

**Healthy agricultural workforce.** There are clear opportunities to strengthen occupational health in primary care protocols and enhance protection for subsistence farmers from the health effects of climate change, including intense heat and dehydration[28]. Accelerated access to universal health coverage, particularly for the most vulnerable (women and children), could improve health. One way to ensure quick assessment, and for support during future disruptions, is by using mobile phone technology. The technology has already aided governments and support services to identify vulnerable populations and simplify the administrative barriers to access support services[29]. Mobile phone technology can be used to deliver personalized agricultural advice to small-scale farmers and vulnerable groups when access or physical contact is restricted, as seen during the COVID-19 pandemic.

## Conclusions

These strategies and policies underscore the extent to which the environment, food systems and public health are intimately intertwined, while this linkage will only become stronger under projected climate and environmental change[30]. Food system policy should consider and carefully map out the possible trade-offs to other parts of the system that would require a coordinated intersectoral government effort.

The COVID-19 pandemic is having a devastating global impact and all sectors of society are considering how to manage the immediate impacts and rebuild in the future. Building back a stronger, resilient and more environmentally conscious food system is critical both to ensure greater preparedness for future crises, but also to improve the environmental, nutritional and health outcomes of West African food systems in the future. ❐

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## Author contributions

Z.A., R.G. and P.F.D.S. conceived the study. Z.A., R.G., S.M., A.D.D. and P.F.D.S. performed the literature searches and wrote the paper. R.B.Z., A.P., A.H., A.M.P. and A.D.D. interpreted and critically revised the manuscript for important intellectual content. All authors approve of and agree to take responsibility for the final version of this Comment.

## Competing interests

The authors declare no competing interests.

# ANNEXES

## *Annex 1: Measures of research impact used in thesis*

### Notes on measures of research impact used in the thesis

Where relevant, I have used Google Scholar (GS) citations as a measure of impact for the studies. GS provides a relatively more comprehensive assessment of impact including citations in theses, books and book chapters and other gray literature that are important but often not indexed in traditional (English dominated) databases such as Web of Science and Scopus[5]. Additionally, citations from credible, new, and upcoming journals that are not yet indexed in traditional databases are tracked in GS giving a more comprehensive measure of impact.

Indeed, new ways for measuring research impact other than citations and journal impact factors are increasingly becoming available and promoted. Metrics such as number of reads, full text accesses[6] and mentions (in social media and news outlets) may even be a better measure of research impact than number of citations especially for newly published papers that have simply not been around long enough to be cited[7].

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[6] Number of reads and accesses reported in the thesis are those tracked by journal websites and excludes other external sources such as reads/full access downloads on ResearchGate or institutional repositories.

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## *Annex 2: Surveys and databases hosting adolescent nutrition data*

### *Annex Table 1: Surveys and databases reporting adolescent nutrition data*

| Name of survey (Organisation/institution) | Coverage | Data collection period | Relevant adolescent nutrition data collected | Age range considered | Sex |
|---|---|---|---|---|---|
| Adolescent Data Hub (ADH) | 138 LMIC | Continually updated database | Dietary intake, anthropometry, micronutrient status | 10-19 years | Boys and girls |
| Demographic and Health Surveys (DHS) | 90 LMIC | Every five years on average | Anthropometry, dietary intake, haemoglobin level | 15-19 years | Girls (and sometimes boys) |
| Global School-Based Student Health Survey (GSHS) | 97 countries | Non-specified | Dietary behaviours, anthropometry, hygiene | 13-17 years | Boys and girls |
| Global Burden of Disease Database (IHME) | Global (204 countries and territories) | Periodically updated database | Iodine deficiency, vitamin A deficiency, dietary iron deficiency, protein energy malnutrition, other nutritional deficiencies | 5-19 years | Boys and girls |
| Non-Communicable Disease Risk factor Collaboration (NCD-RisC) Database | 200 countries and territories | Database updated annually | BMI | 5-19 years | Boys and girls |
| Health Behaviour in School Age Children (HBSC) | 50 countries (Europe & North America) | Every 4 years | Self-reported weight and height | 11, 13 and 15 years | Boys and girls |
| Iodine Global Scorecard 2021– Iodine Global Network | 194 WHO member states | Database updated annually | Median urinary iodine concentration (UIC) | 5-19 years | Boys and girls |
| UNICEF Multiple Indicator Cluster Surveys (MICS) | 118 LMIC | Every five years | Anthropometry, dietary intake, haemoglobin level | 15-19 years | Girls (and sometimes boys) |
| Childhood Obesity Surveillance Initiative (COSI) – WHO European Region | Over 40 member states of the WHO European region | Every two years | Anthropometry, school food environment, physical activity, dietary behaviours | 6.0-9.9 years | Boys and girls |

*Source: Ali & Lelijveld (2021)*[8]

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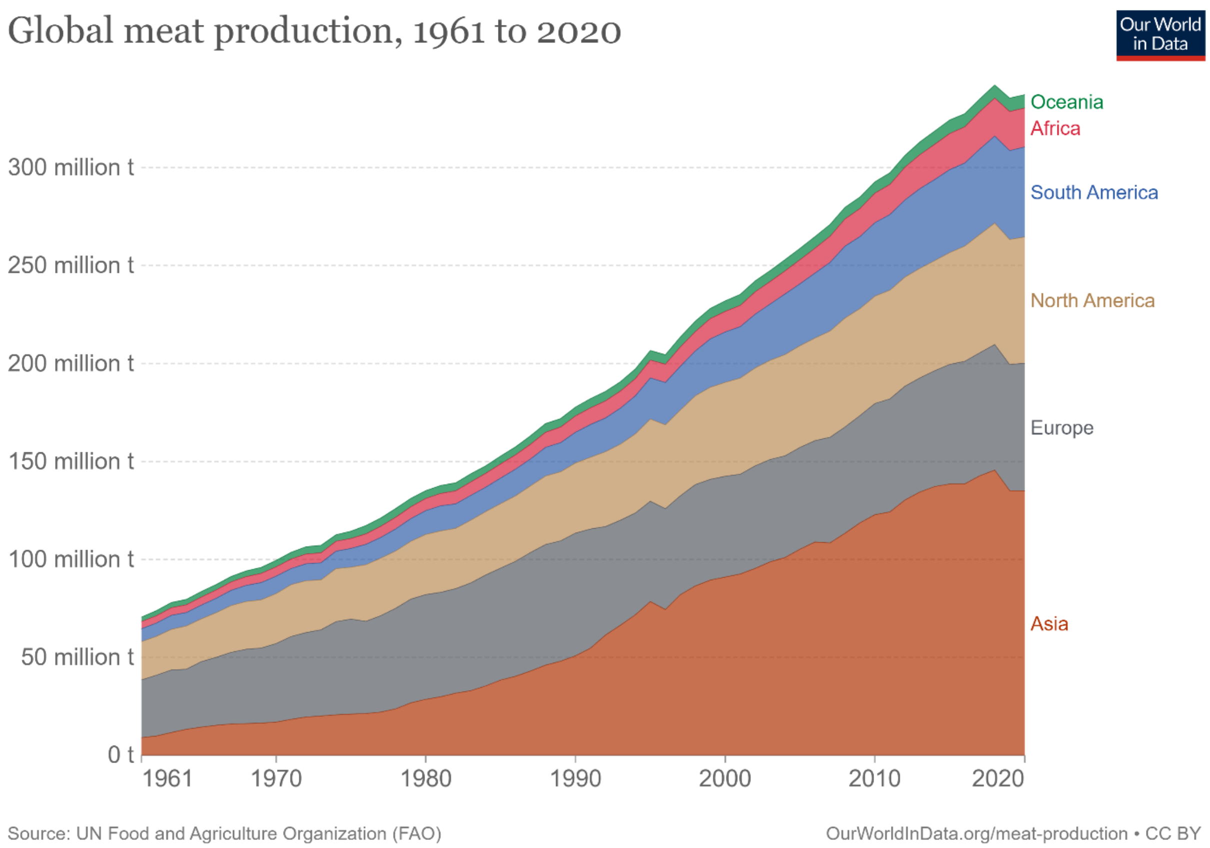
## *Annex 3: Global meat production by world region*




Source of figure: OurWorldInData (2022)[9]. Production in Asia is dominated by China and on per capita terms, Europe and North America produce most excess meat.

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