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

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ABSTRACT

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

1. Introduction

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

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

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

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studies provide evidence that availability of fresh products is positively associated with dietary intake (Martin et al., 2012; Westbury et al., 2021; Ziso et al., 2022), that food prices are positively associated with dietary quality (Beydoun et al., 2011) and that these need to be considered among key socio-economic determinants of diets (Darmon and Drewnowski, 2015). Results from low and middle income countries document that increased availability of healthy food options is associated with improvements in child nutrition in some contexts (O'Meara et al., 2023; Westbury et al., 2021). These results also emphasize the ubiquity of ultra-processed foods (Colozza, 2022; Monteiro et al., 2013), consumption of which is associated with higher risk of non-communicable diseases (Chen et al., 2020; MacHado et al., 2019).

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

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

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

2. Methods

2.1. Data sources and standardization

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

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

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

2.2. Selection of data for this paper

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

2.3. Calculation and analysis of indicators

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

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

2.3.1. Market assortment

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

2.3.2. Price per 100 kcal

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

2.3.3. Relative caloric price

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

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

2.3.4. Dietary intake indicators

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

2.4. Aggregation and analysis of indicators

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

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

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

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

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

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

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

3. Results

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

3.1. Food environment indicators

3.1.1. Market assortment

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

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

3.1.2. Price per 100 kcal

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

3.1.3. Relative caloric price

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

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

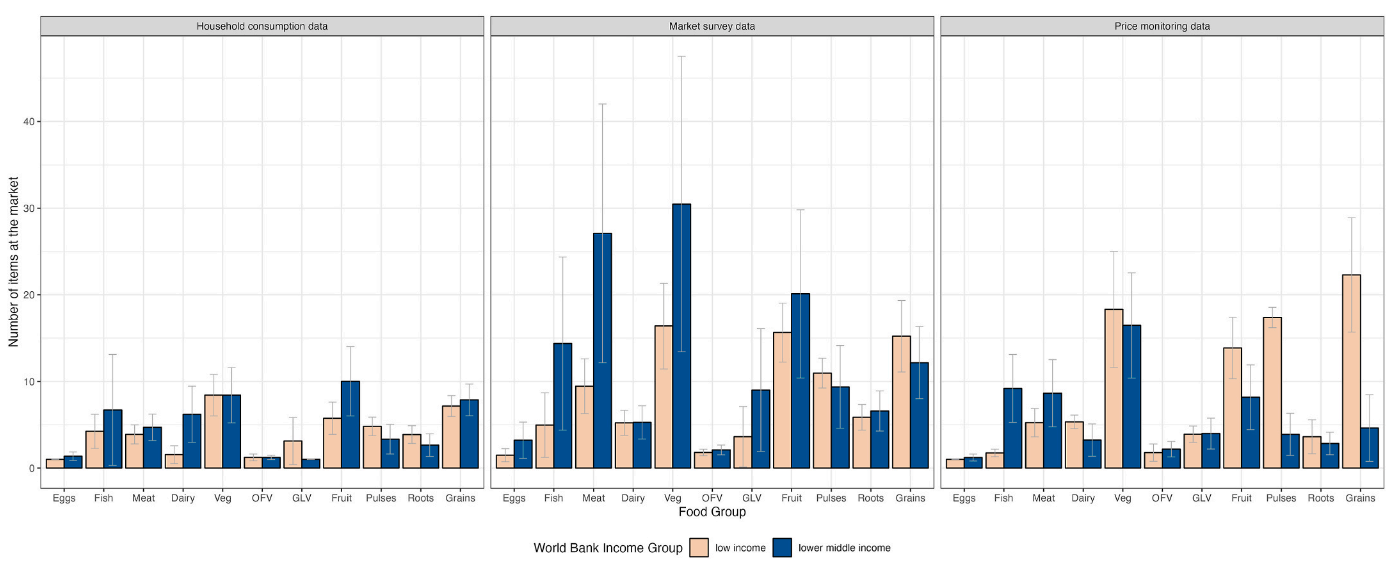

Fig. 1. Market assortment (number of items per food group) by datatype and income group.
Note: Data shown are means and standard deviations across subnational areas, for median number of items in each food group shown. Number of subnational areas (total n = 247) per subgroup varies as follows: price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

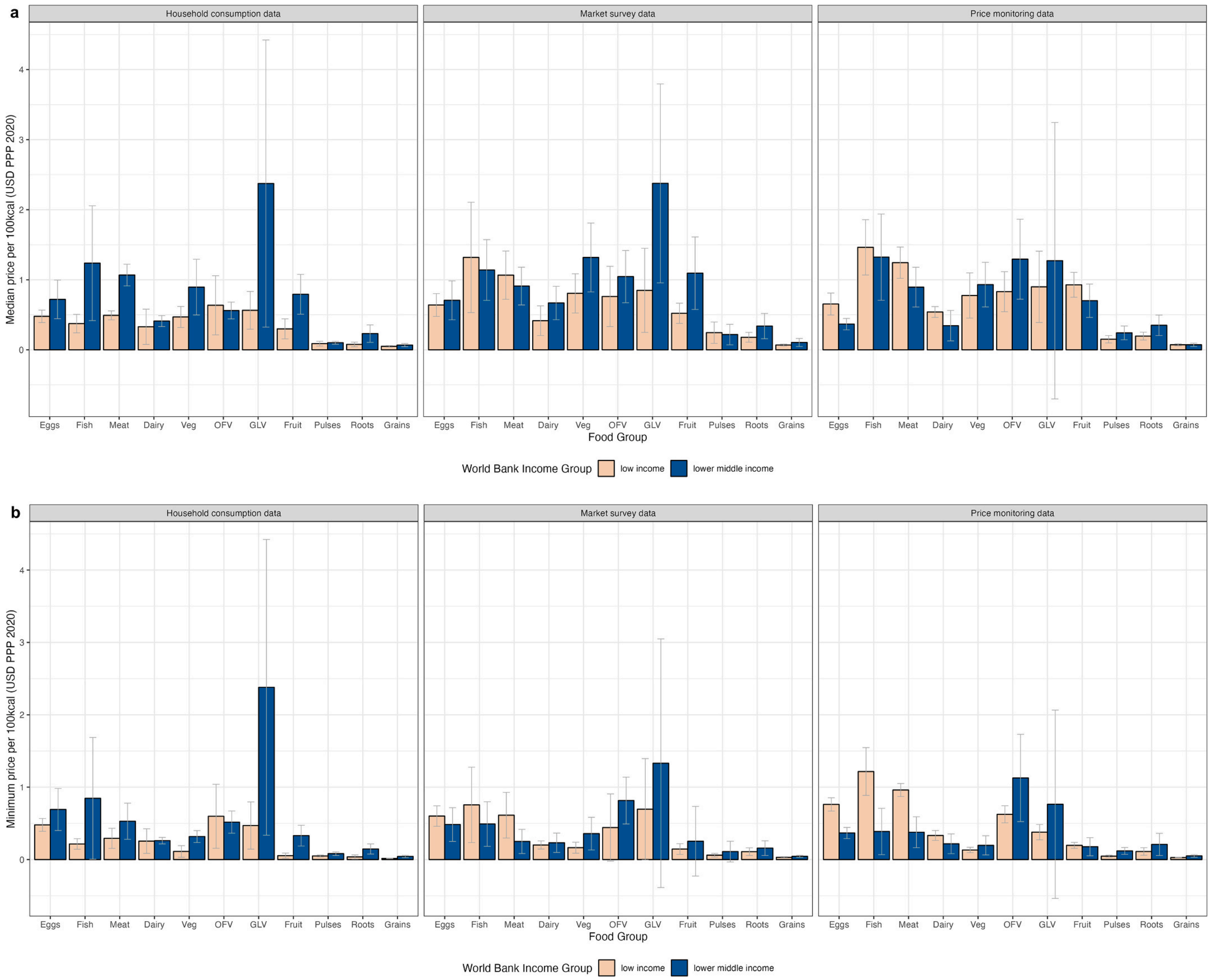

Fig. 2. a–b: Price per 100 kcal for selected food groups in international USD by datatype and income group.
Note: Data shown are means and standard deviations across subnational areas, for median (2a) and minimum (2b) price per 100 kcal for each food group shown. Number of subnational areas (total n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

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

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

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

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

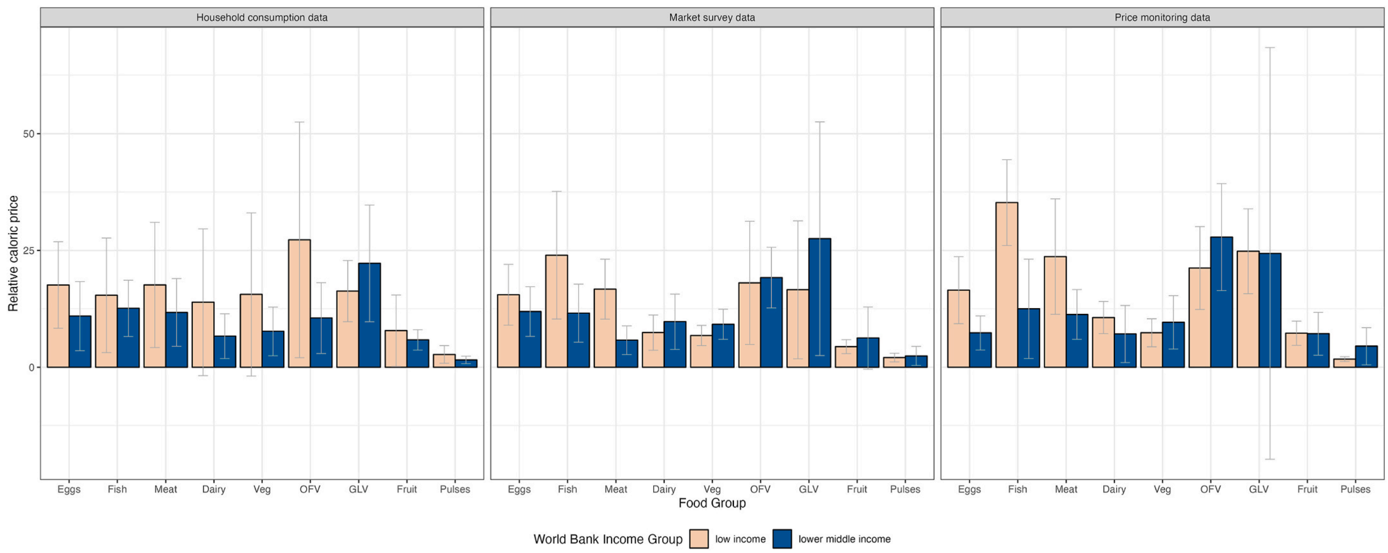

Fig. 3. Relative caloric price (RCP) by datatype and income group.
Note: Data shown are means and standard deviations across subnational areas, for relative caloric price for each food group shown. Number of subnational areas (total n = 247) per subgroup varies as follows: price monitoring in low income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

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

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

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

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

4. Discussion

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

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

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

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

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

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

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

across countries in different income groups.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

5. Limitations

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

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

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

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

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

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

6. Conclusion

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

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

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

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CRediT authorship contribution statement

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

Declaration of competing interest

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

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

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

Appendix

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

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

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