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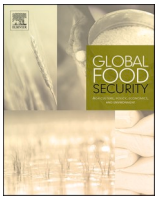

# The global food environment transition based on the socio-demographic index

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A B S T R A C T

Food environments are a critical point for reorienting the food system towards sustainable diets, as they are directly where consumers make decisions about which foods to acquire. Using global data, we examined shifts in food environments, and the availability, affordability, convenience, and quality of foods within them, over time on the basis of socio-demographic index (SDI) country groupings. Our findings provide evidence of a food environment transition where built environments have shifted from traditional to modern retail outlets between 2005 and 2019 and the availability and affordability of nutrient-rich foods has increased alongside growing sales of ultra-processed and ready-to-eat foods. This transition has implications for the identification of policy and program levers for promoting healthy and sustainable diets and reducing malnutrition globally.

## 1. Introduction

Over the past five decades, food system drivers such as globalization and urbanization have led to dietary shifts from traditional diets to Westernized diets in many low- and middle-income countries (LMICs) in what is recognized as the nutrition transition (Hawkes, 2006; Popkin and Gordon-Larsen, 2004). Poor diets are among the top risk factors contributing to the global burden of disease (Afshin et al., 2019; GBD 2019 Risk Factors et al., 2020 Risk Factors et al., 2020; Global Panel on Agriculture and Food Systems for Nutrition, 2016; Key et al., 2002; Stanaway et al., 2018; Swinburn et al., 2019). At the same time, food production and consumption practices have placed greater stress on ecosystems than any other human activity (Foley et al., 2011; West et al., 2014; Willett et al., 2019) while being critically dependent on multiple ecosystem services including water, soil fertility, pollination, and climate regulation (IPCC, 2013). There is a clear need to reorient food systems towards the production and consumption of sustainable diets – "*diets with low environmental impacts that contribute to food and nutrition security and to healthy lives for present and future generations*" (Burlingame, 2012) – in order to simultaneously improve human and planetary health globally.

Food environments are a critical point for intervening to reorient the food system towards sustainable diets given that numerous food system processes converge here and, this is directly where consumers make decisions about which foods to acquire (Downs et al., 2020). While several definitions of the food environment exist, including those that delineate between the external and personal environment (Turner et al., 2018), we define the food environment as the "*consumer interface within the food system that encompasses the availability, affordability, convenience, quality and promotion, and sustainability of foods and beverages in wild, cultivated, and built spaces that are influenced by the socio-cultural and political environment and ecosystems within which they are embedded.*" (Downs et al., 2020). Numerous studies have documented dietary shifts globally associated with the nutrition transition (Popkin et al., 2020). Localized changes in food environments (Byker Shanks et al., 2020) as well as regional shifts towards more supermarkets and ultra-processed foods have been captured in the literature (Baker and Friel, 2014; Reardon et al., 2003, 2012, 2021). However, there is a lack of studies examining global shifts in food environments and their multiple elements (availability, affordability, convenience, quality and promotion, and sustainability) over time and how this varies based on socio-demographic factors characterizing countries.

The overall objective of this article is to analyze trends in food environments and their multiple elements over time in countries globally and, to make comparisons between countries on the basis of their socio-demographic Index (SDI) classification—a metric that takes into account

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incomes per capita, average educational attainment, and fertility rates. We evaluate food environments over time using country-level data for built environments and food availability, affordability, convenience, and quality. In addition, we compare these data over time based on SDI and examine dietary and nutrition outcomes using Global Burden of Disease data. This study posits that a global food environment transition has occurred over time and across countries based on SDI. We define the food environment transition as: *the dynamic shift in the consumer interface of the food system over time that influences the availability, affordability, convenience, promotion, quality, and sustainability attributes of foods within the environments in which they are acquired.*

## 2. Methods

### 2.1. Data sources

National-level data for built food environments as well as food availability, affordability, convenience, and quality were retrieved from Food and Agriculture Organization FAOSTAT data (FAOSTAT, 2019), Euromonitor International (Euromonitor International), Global Food Security Index (GFSI) data (The Economist Intelligence Unit, 2018), World Health Organization (WHO) Global Burden of Food Borne Illnesses data (World Health Organization, 2015), and GFSI Food Safety Index data (Chaudhary et al., 2018). Specifically, Food and Agriculture Organization FAOSTAT data (FAOSTAT, 2019) were used to examine shifts in the availability of different food groups over time from 1961 to 2013.

Given the gaps in the existing data, we include a combination of a narrative review and original data analyses to provide a more thorough overview of the different food environment elements. While we posit that access to different types of food environment (wild, cultivated, and informal and formal built food environments) shifts from low to high SDI groupings (Downs et al., 2020), our analyses focus on the built environment as there is a lack of global data to depict shifts from wild and cultivated to built environments. In order to assess shifts in the built environment, as well as the food environment aspect of convenience, Euromonitor International food retailing, food service, and sales of fresh and processed food data were analyzed for 2005–2019 based on 2019 fixed rates. Modelled and/or projected data were excluded from our primary analysis but were included in supplemental display items for 2005–2024. The Global Food Security Index (GFSI) data were used to examine diet diversification and household expenditure on food over time (The Economist Intelligence Unit, 2018). Diet diversification in the GFSI database was assessed using FAO data to measure the share of non-starchy foods in total dietary energy consumption (The Economist Intelligence Unit, n.d.). Comprehensive data examining the relative affordability of foods over time across SDI country groupings does not exist, and thus we referred to World Bank income levels and regions data that suggests significant price differentials across different food groups (Headey and Alderman, 2019). Specifically, to examine the relative affordability of food among SDI country groupings, we used relative caloric prices of different food categories as classified by Headey & Alderman et al. (2019) using the 2011 International Comparison Program and USDA Food Composition tables. The World Health Organization (WHO) Global Burden of Food Borne Illnesses data and the GFSI Food Safety Index (Chaudhary et al., 2018) data were used to examine food safety as a component of overall food quality. The GFSI food safety score was calculated by the Economist Intelligence Unit as a composite indicator that measures the enabling environment for food safety based on a country's agency to ensure the safety and health of food as well as the percentage of the population with access to potable water and ability to store food safely (The Economist Intelligence Unit, n.d.). Both the WHO and GFSI food security data were retrieved from Chaudhary et al. (2018).

Global data were used to examine both trends related to food environment types and dimensions as well as diet and nutrition outcomes across SDI groupings. More specifically, we examined dietary risk factors (high intakes of sodium, sugar-sweetened beverage, trans fat and processed meats; low intakes of fruits and vegetables, nuts/seeds, legumes, seafood, fiber and oils/foods rich in polyunsaturated fats) and the burden of malnutrition (i.e., prevalence of obesity in adult women and undernutrition in girls 5–19 years) based on SDI groupings using the Global Burden of Disease data (Afshin et al., 2019; Swinburn et al., 2019). We considered a SDI country grouping to have a dietary risk factor if age-standardized DALY's per 100,000 exceeded 100 based on the analyses conducted by Afshin et al. (2019).

### 2.2. SDI country groupings

In order to depict different stages of the food environment transition as well as to examine variation between countries on the basis of level of development and other socio-economic factors, we used the 2017 socio-demographic index (SDI) classification scheme for given countries (Global Health Data Exchange, 2018). The SDI is a measure for classifying the development stage of countries using a composite average ranking of incomes per capita, average educational attainment, and fertility rates (Global Health Data Exchange, 2015). Comparing data based on SDI quintile groupings allows for depicting the ways in which food environments transition over time and across stages of development for low, low-middle, middle, high-middle, and high SDI groupings (see Supplemental Table 1 for sample sizes used in figures or analyses; Supplemental Figs. 1–3 for maps showing which countries were used in analysis).

### 2.3. Analyses

Linear mixed models (Pinheiro et al., 2020) were used to examine changes in the dimensions of the food environment across time among the five SDI groupings. There were no data available for the low SDI country grouping for the discounters and internet retailing, for all food service types or for fresh and ready meals. A random intercept was incorporated in each model to account for repeated measures on each country. Data which were not normally distributed (i.e., retail, food service, availability of food groups, retail of fresh and processed foods) were transformed using a log (base e). When the element of the food environment had a value of zero for the response, the log (y+1) transformation was used in the transformation. Additionally, if the response was a percentage then a logit transformation was used. The logit transformation is defined as: $\log[p/(1-p)]$ for the percentage p. All models using Euromonitor data were fit using observed data rather than modelled or future projections.

A generalized additive model (GAM) (Wood, 2017) was also fit to each food environment dimension across time and SDI groupings. GAMs are a flexible technique that can capture non-linearities in the trends over time using spline smoothers. When a GAM shares little differences from the linear patterns for the responses, it suggests that using a more complex model is not necessary and linear regression could be used for all food categories with year as a continuous variable. The GAM models for all food environment responses with the exception of the availability of animal fats, showed little to no difference from the linear patterns for log(responses), suggesting that linear versions of time could be used for every SDI grouping across years with year as a quantitative variable (see Supplemental Figs. 4–8). A p-value of $<0.05$ was used to denote significant differences in changes over time in the food environment elements among the five SDI country groupings.

## 3. Results

### 3.1. Transitions in built food environments

Within the built food environment, we find that as countries become more developed, there is a shift from informal (i.e., traditional) markets

**Table 1**
Statistically significant differences from an ANOVA for the interaction between year and SDI Quintile test for each parameter in Figs. 1–3, 5 and Supplementary Figs. 13 and 15.

| Corresponding Parameter | | Degrees of freedom | F-statistic, p-value |
|---|---|---|---|
| Fig. 1. | **Built Environment: Grocery/Retail Type** | | |
| | Modern | 4, 1382 | 149.9025, <0.0001 |
| | Traditional | 4, 1382 | 118.5172, <0.0001 |
| | Convenience Stores | 4, 1074 | 108.8453, <0.0001 |
| | Discounters | 3, 752 | 40.4356, <0.0001 |
| | Hypermarkets | 4, 1185 | 83.2013, <0.0001 |
| | Supermarkets | 4, 1382 | 91.002, <0.0001 |
| | Internet | 3, 926 | 84.7311, <0.0001 |
| Fig. 2. | **Built Environment: Foodservice Type** | | |
| | Chained | 3, 753 | 45.09834, <0.0001 |
| | Cafes/Bars | 3, 753 | 156.54065, <0.0001 |
| | Full-Service Restaurants | 3, 753 | 84.44162, <0.0001 |
| | Limited-Service Restaurants | 3, 753 | 171.3930, <0.0001 |
| | Self-Service Cafeterias | 3, 634 | 31.76747, <0.0001 |
| | Street Stalls/Kiosks | 3, 753 | 64.05580, <0.0001 |
| Fig. 3. | **Food Supply Availability** | | |
| | Animal Fats | 4, 7996 | 9.51948, <0.0001 |
| | Cereals | 4, 7996 | 118.8949, <0.0001 |
| | Eggs | 4, 7996 | 158.34214, <0.0001 |
| | Fish | 4, 7996 | 32.94505, <0.0001 |
| | Fruit | 4, 7996 | 46.83922, <0.0001 |
| | Meat | 4, 7996 | 142.79576, <0.0001 |
| | Milk | 4, 7996 | 58.91224, <0.0001 |
| | Offals | 4, 7996 | 78.74495, <0.0001 |
| | Pulses | 4, 7975 | 2.721146, 0.028 |
| | Starchy Roots | 4, 7996 | 141.85156, <0.0001 |
| | Vegetables | 4, 7996 | 89.95545, <0.0001 |
| | Vegetable Oils | 4, 7996 | 30.0255, <0.0001 |
| Fig. 5. | **Convenience: Type of Foods (Fresh/Processed)** | | |
| | Confectionary | 4, 1382 | 135.6014, <.0001 |
| | Fresh Food | 3, 753 | 84.0301, <.0001 |
| | Packaged Food | 4, 1382 | 152.9199, <.0001 |
| | Ready Meals | 3, 1206 | 38.4241, <.0001 |
| | Savory Snacks | 4, 1396 | 48.4418, <.0001 |
| | Soft Drinks | 4, 1382 | 163.3024, <.0001 |
| | Sweet biscuits, Snack Bars, and Fruits Snacks | 4, 1396 | 116.2491, <.0001 |
| **Supplemental Figures** | | | |
| **S13** | **Affordability: Household Expenditure** | 4,673 | 4.871172, 0.0007 |
| **S15** | **Quality: Dietary Diversity** | 4,673 | 5.803955, <0.0001 |

such as wet markets and street vendors to formal markets including modern retailers such as supermarkets and hypermarkets (see Supplemental Fig. 1 for maps of countries included in analysis). We found a statistically significant relationship between year of data and SDI country grouping (low, low-middle, middle, middle-high, high SDI) for retail value, suggesting variation in patterns of change for retail value with SDI grouping over time (see Table 1).

Specifically, as countries develop, consumers have increased access to modern food retailers (i.e. built formal food environments) as the retail value attributed to traditional retailers (i.e. built informal and formal food environments) declines (Fig. 1 panels a and b). For example, the mean retail value at modern markets among the 31 high SDI countries increased from $1708 USD/capita/year in 2005 to $2352 USD/capita/year in 2019. Over the same period, mean retail value at traditional markets decreased from $550 to $485 USD/capita/year among high SDI countries. In contrast, among the five low-SDI countries included in the analyses, the mean retail value at traditional markets was $67 USD/capita/year in 2019 as compared to $21 USD/capita/year at modern retail markets. Within built formal food environments, the type of retailers is further shifting. Across the lower to higher SDI gradient, countries progressively spend more money per capita at convenience stores (mean $3 USD/capita/year of less among low and low-middle SDI countries in 2019 as compared to $274 USD/capita/year among high SDI countries), discounters (mean $25 USD/capita/year among low-middle SDI countries in 2019 as compared to $488 USD/capita/year among high SDI countries), hypermarkets (mean $27 USD/capita/year among low-middle SDI countries in 2019 as compared to $514 USD/capita/year among high SDI countries), and supermarkets (mean $48 USD/capita/year among low-middle SDI countries in 2019 as compared to $1118 USD/capita/year among high SDI countries), with the latter being the most prominent retailer in high SDI countries (Fig. 1 panels c–f). Mean retail value at supermarkets far outweighs that from other retailers. However, this pattern may not necessarily be replicated as countries transition from lower to higher SDI given that in lower SDI countries, consumers are in some cases spending more money at hypermarkets than at supermarkets. The growth in food and drink internet retailing among higher SDI countries (mean $8 USD/capita/year in 2005 as compared to $64 USD/capita/year in 2019) suggests that over time, if current trends continue, this could become a more dominant place for food acquisition over time (Fig. 1, panel g (2005–2019); Supplemental Fig. 9 (2005–2024; includes projected data)). However, current mean retail values for supermarkets are over 17 times higher than internet retailing among high SDI countries. When comparing the total expenditures (mean retail value) of convenience, discounters, hypermarkets, supermarkets, and internet retailing, the proportions are highest for supermarkets across all SDI countries with the exception of high-middle, where hypermarkets are similarly prevalent (Supplemental Fig. 10).

Within the built formal food environment, the shift in grocery retailers has coincided with shifts in food service outlets (see

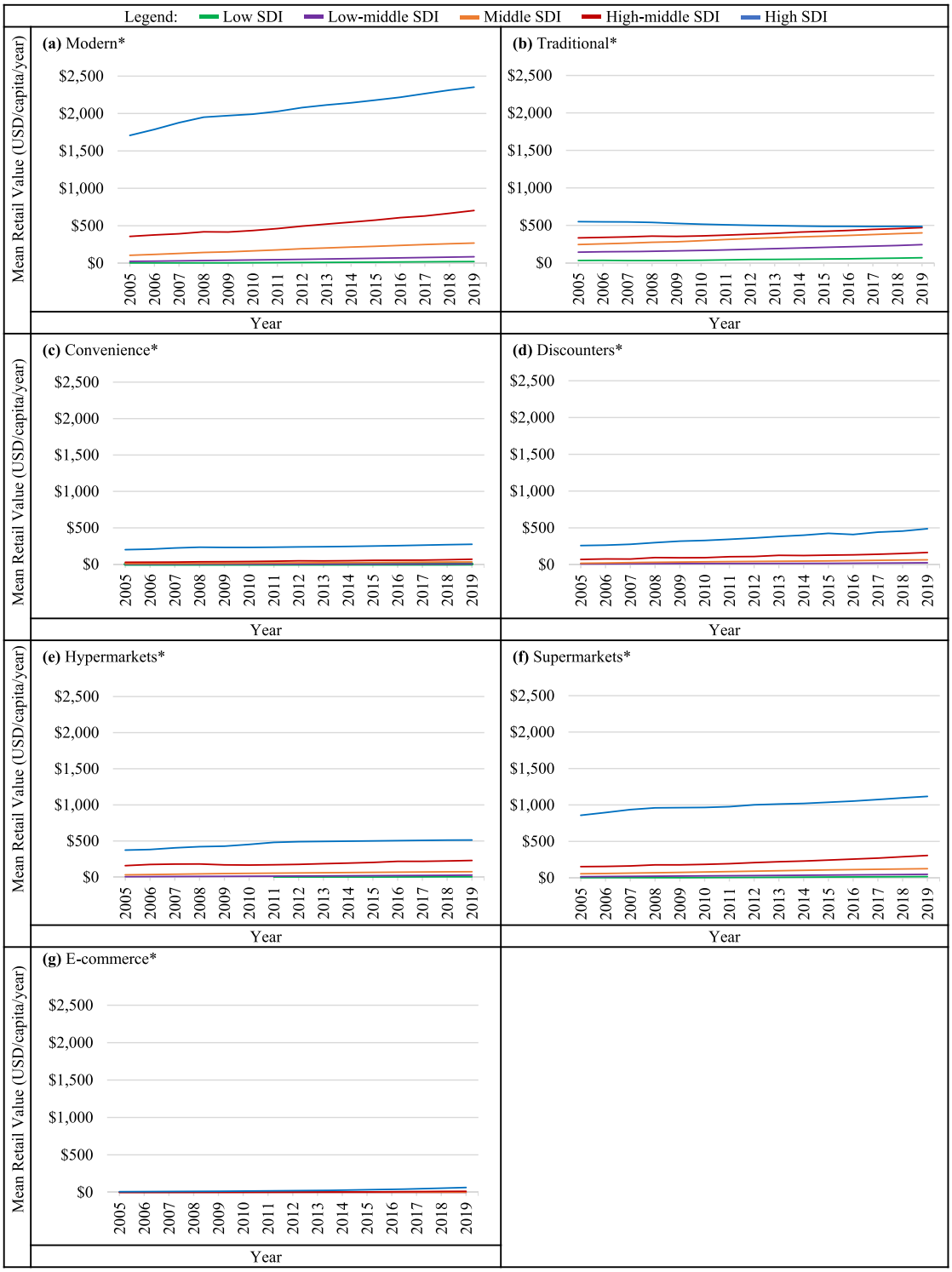


**Fig. 1.** The mean retail value of (a) modern grocery retailers versus (b) traditional grocery retailers based on SDI country groupings, and shifts in the retail value in formal grocery store retailers (c) convenience stores, (d) discounters, (e) hypermarkets, (f) supermarkets, and (g) food and drink E-commerce (Non-store Retailing) over time (2005–2019) based on SDI country groupings (Euromonitor International).

Supplemental Fig. 2 for maps of countries included in analysis). Despite the emphasis on chained food service outlets in the food environment literature (Adam and Jensen, 2016; Chen and Florax, 2010; International Food Information Council, 2020; Martinez et al., 2018), and for targeting policies such as calorie labeling only applying to chained restaurants (Adam and Jensen, 2016; Chen and Florax, 2010; Martinez et al., 2018), our findings indicate that a higher proportion of money spent at food service outlets across all SDI groupings is at traditional, independent retailers (ranging from 72% among high SDI countries to 91% among low-middle SDI countries in 2019) rather than modern, chained establishments (Fig. 2, panels a & b). Mean retail value of food service outlets progressively increases over time, among all food service

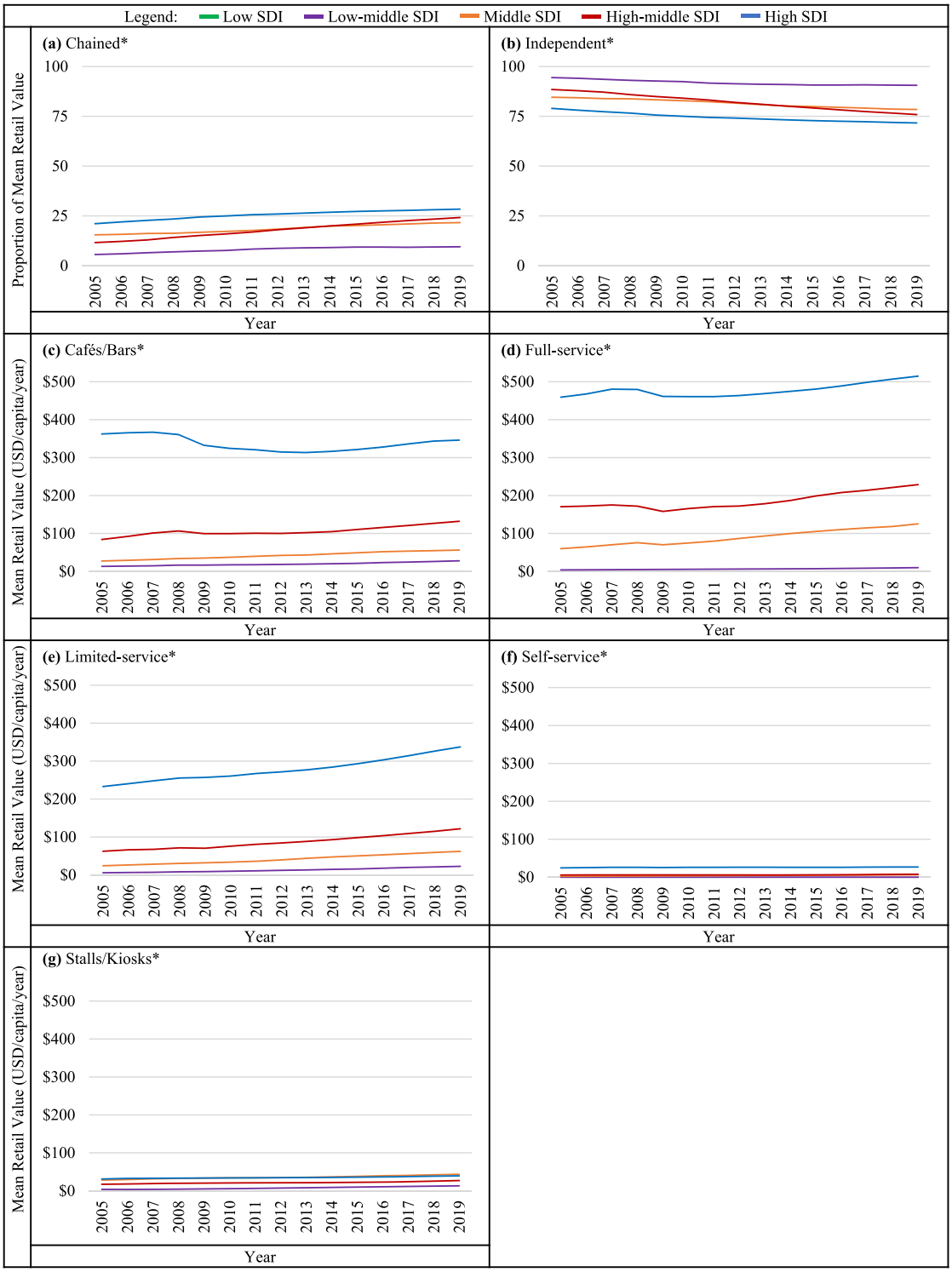


**Fig. 2.** The proportion of (a) chained and (b) traditional food service retail and shifts in the retail value at different food service outlet types (c) cafés and bars, (d) full-service restaurants, (e) limited-service restaurants, (f) self-service cafeterias, and (g) street stalls and kiosks over time (2005–2019) based on SDI country groupings (Euromonitor International).

types and SDI country groupings, and is highest among higher SDI grouping countries (Fig. 2), with overall high retail value and proportion of retail value attributed to cafes/bars and full-service restaurants as compared to other food service types (Fig. 2 panels c–g; Supplemental Fig. 11). The retail value is highest among high SDI countries ($12,596 USD/capita/year in 2019 as compared to $430 among low-middle SDI countries) and it is projected to continue increasing among cafes/bars, full- and limited-service restaurants (Supplemental Fig. 12). We found a statistically significant relationship between year and SDI grouping after accounting for random country-to-country variation across all food service types (Table 1).


**Fig. 3.** Shifts in the availability of food over time (1961–2013) by SDI grouping low through high for (a) cereals, starchy roots, and pulses; (b) eggs, fish, milk, and meat; (c) fruits and vegetables; and (d) animal fats and vegetable oils (FAOSTAT, 2019).

### 3.2. *Transitions in food availability*

Previous research highlights how the availability of foods globally has shifted from predominantly dietary staples to a higher variety of processed foods from fewer crop species, with less variability in food availability across seasons and regions (Khoury et al., 2014). Our study found differences in the availability of foods and shifts over time with a statistically significant relationship between year and SDI grouping after accounting for random country-to-country variation (Table 1).

While the availability of cereals and starchy roots is higher among

lower SDI countries (Fig. 3, panel a), the availability of most nutrient-rich food groups are lower (Fig. 3, panels b–c). Lower SDI countries have over 5 times less calories (146 kcal/capita/day) from animal source foods (i.e., fish and seafood, milk, meat, and eggs) available within the food supply as compared to high SDI countries (775 kcal/capita/day), with the availability of animal source foods progressively increasing with development stage (Fig. 3b). While the relationship between fruit availability and SDI grouping isn't as distinctive, the availability of fruit has decreased in low SDI countries (91 kcal/capita/day in 1961 as compared to 86 kcal/capita/day in 2013), while their availability has increased over time among higher SDI countries (85 kcal/capita/day in 1961 as compared to 112 kcal/capita/day in 2013) (Fig. 3c). The availability of vegetables is lowest among low SDI countries and remains relatively stagnant whereas its availability is increasing in all other SDI groups (Fig. 3c). Animal fats have remained relatively stable in lower SDI countries whereas they have been declining over time in higher SDI countries (Fig. 3d). Concurrently, the availability of vegetable oils has increased markedly in all countries (ranging from an 88% increase in high SDI countries to a 177% increase among low-middle SDI countries between 1961 and 2013). In 2013, the highest availability was in high SDI countries (395 kcal/capita/day in 2013) and the lowest was in low-middle (197 kcal/capita/day) and low

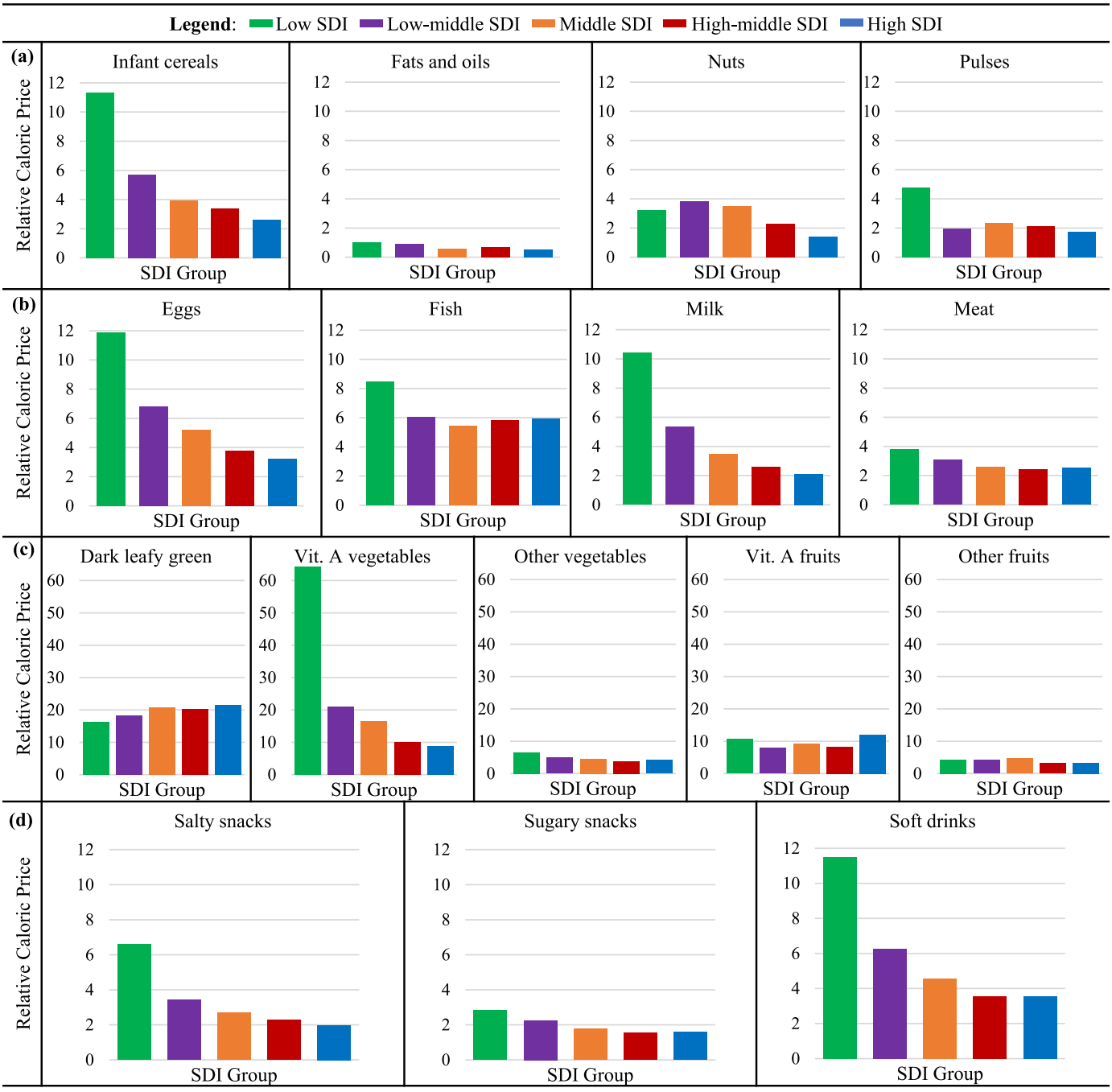


**Fig. 4.** Relative Caloric Prices (RCPs) for each SDI grouping low through high for (a) cereals, fats and oils, nuts, and pulses; (b) eggs, fish, milk, and meat; (c) dark leafy greens, vitamin A rich vegetables, other vegetables, vitamin A rich fruits, and other fruits; and (d) salty snacks, sugary snacks, and soft drinks (Source data normalized from 2011) (Headey and Alderman, 2019). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

SDI (204 kcal/capita/day) countries (Fig. 3d).

### 3.3. Transitions in food affordability

Our findings indicate that the affordability of foods increases across the SDI groupings from low to high SDI with consumers spending a smaller portion of their incomes on food (Supplemental Fig. 13). The percentage of household expenditures on food progressively decreases from low to high SDI country groupings, with low SDI countries spending an average of 43% of their household expenditures on food as compared to 12% among high SDI countries (The Economist Intelligence Unit, 2018). This trend likely coincides with the higher cost and lower affordability of nutrient-rich foods in low SDI countries, which are also less widely available in these countries (Figs. 3 and 4). An overview of the relative caloric prices (RCP) for different food categories among SDI country groupings is illustrated in Fig. 4. The RCP tends to be higher among the lower SDI countries as compared to other SDI groupings, particularly most animal source foods (e.g., RCP for eggs was 11.9 in low SDI countries as compared to 3.2 in high SDI countries) and fortified infant cereals (e.g., 11.3 in low SDI countries as compared to 2.6 in high SDI countries).

### 3.4. Transitions in food convenience

As countries experience socio-demographic transitions towards increased development, their reliance on convenience foods generally increases. Convenience foods include ultra-processed foods and ready meals designed for consumption with minimal preparation and branded in ways aimed to increase their desirability (Baker and Friel, 2014). Across the gradient of low to high SDI countries, there is an increase in packaged foods, ready meals, and ultra-processed foods (Fig. 5; see Supplemental Fig. 2 for maps of countries included in analysis). We find an interaction between year and SDI grouping on the retail of different food categories after accounting for random country-to-country variation. The purchase of ready meals is relatively high within high SDI countries and relatively low among countries in earlier stages of development (mean retail value in 2019 was $66 USD/capita/year in high SDI countries as compared to $0.2 USD/capita/year among low-middle SDI countries). Furthermore, while the purchase of soft drinks is beginning to grow at a slower rate among high SDI countries, albeit at a high level, their purchase among relatively lower SDI countries continues to rapidly increase (Supplemental Fig. 14). For example, between 2005 and 2019 there was a 26% increase in the mean retail value of soft drinks among high SDI countries as compared to a 95%

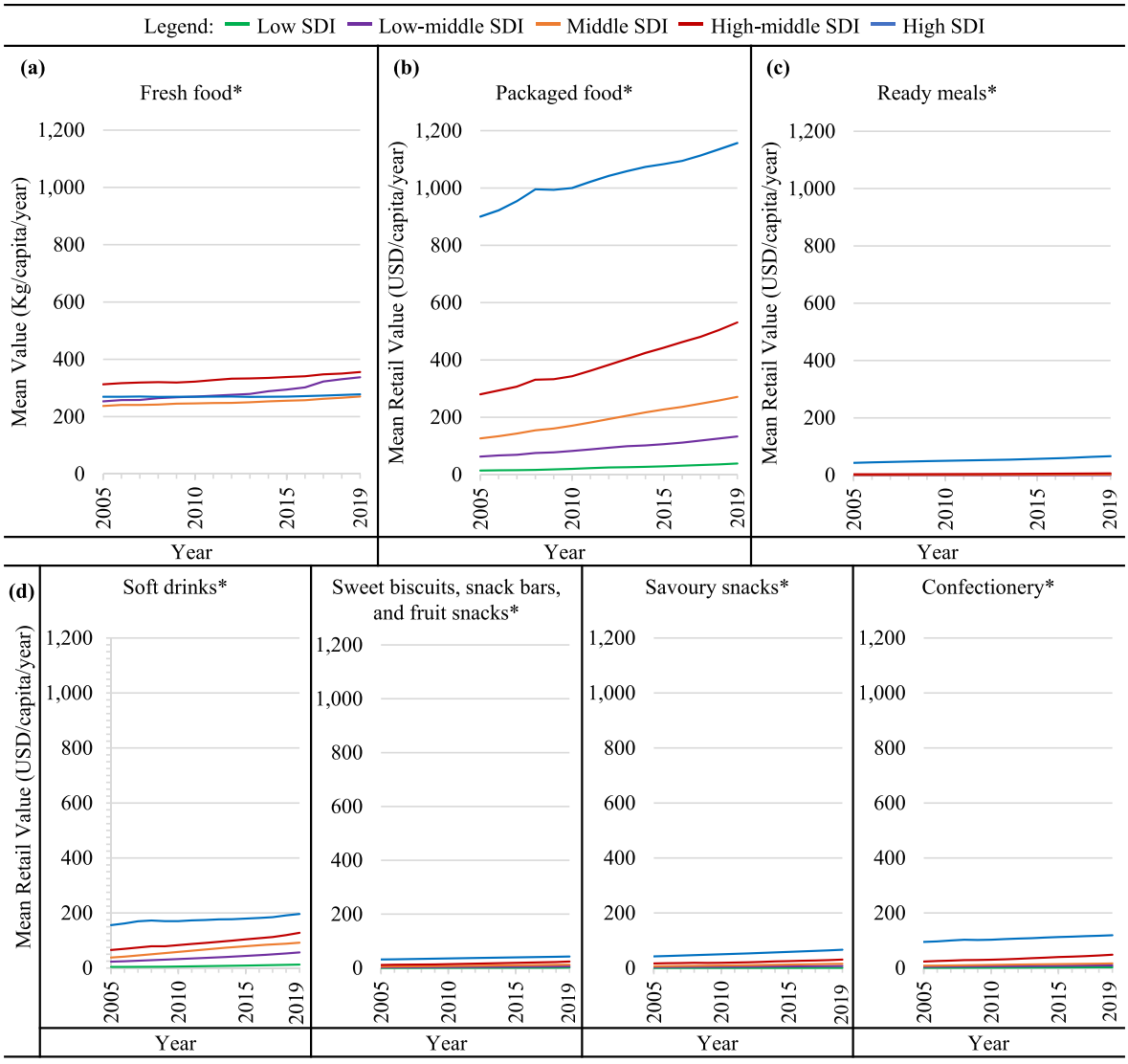


**Fig. 5.** Shifts in the retail of fresh, packaged and ultra-processed foods over time (2005–2019) based on SDI country grouping low through high for (a) fresh food, (b) packaged food, (c) ready meals, and (d) soft drinks, sweet biscuits/snack bars/fruit snacks, savoury snacks, and confectionary (Euromonitor International).

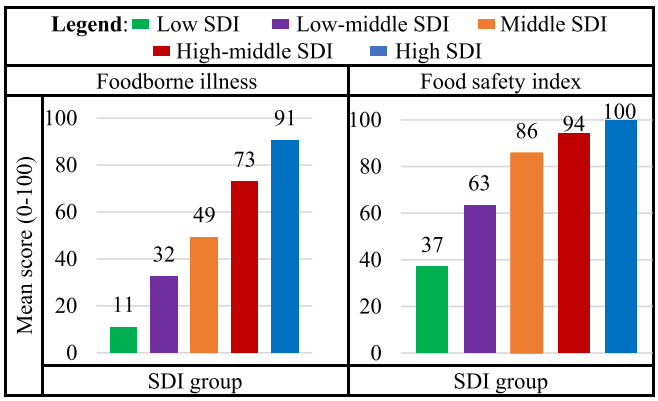


**Fig. 6.** Average food safety scores by SDI country grouping low to high (Chaudhary et al., 2018).

increase among high-middle SDI countries, a 142% increase among middle and 145% increase among low-middle and a 223% increase among low SDI countries. While the retail value of soft drinks being purchased among lower SDI countries is much lower than higher SDI countries, if current growth trends continue the mean retail value will increase dramatically.

### 3.5. Transitions in food quality, promotion and sustainability properties

Consumers' food choices are shaped by many factors including the quality, safety, and appearance of food, as well as the way in which it is marketed and the information available to them at the point of food acquisition (e.g., labeling) (Ahmed et al., 2018a; Herforth and Ahmed, 2015). Findings of our study indicate that the safety of foods, which is a key aspect of food quality, increases from low to high SDI countries (Fig. 6). The average mean foodborne illness score was 11 out of a possible 100 (denoting the best possible score) in low SDI countries as compared to 91 among high SDI grouping countries. The food safety index score followed a similar pattern with low SDI countries having the lowest mean score and it increasing progressively from low to high SDI country groupings.

### 3.6. Links between the food environment transition and diets and nutrition

We applied findings of our food environment analyses combined with global burden of disease and GFSI dietary data (Afshin et al., 2019; Swinburn et al., 2019) to present an overview of the linkages between the food environment transition, diets and malnutrition through data analysis (Table, 2) and a framework. This framework illustrates that low SDI countries that have relatively low availability and affordability of nutrient-rich foods (Figs. 3 and 4) and lower affordability of foods overall (Fig. 4; Supplemental Fig. 13) also have a higher burden of undernutrition yet a low burden of obesity (Afshin et al., 2019; Swinburn et al., 2019). Conversely, countries with high SDI have relatively high availability and affordability of foods (Figs. 3 and 4 and Supplemental Fig. 13) compared to low SDI countries and have a low prevalence of underweight (Swinburn et al., 2019). Diet diversification significantly varies among countries of all SDI groupings, where dietary diversity increases from low (37% in 2018) to high SDI countries (69% in 2018) (Supplemental Fig. 15; Table 1). Although the prevalence of obesity among women and dietary risk factors are high in high SDI countries, the prevalence is lower than that in middle and high-middle SDI countries (Swinburn et al., 2019) (Supplemental Fig. 16). For example, the mean obesity prevalence among adult women was 11.5% among women in low SDI countries in 2014 as compared to 29% in high-middle and 23.2% in high SDI countries.

## 4. Discussion

This study provides evidence of a global food environment transition where shifts across SDI country groupings were observed over time. We found a shift in built food environments from traditional (built informal and formal food environments) to more modern retailers (built formal food environments). This study further found differences in the food environment elements of food availability, affordability, convenience and safety, the latter being a proxy for quality. These shifts in types of food environments, as well as the elements of the food environment, have important implications for the dietary and nutrition transitions that many countries are undergoing globally and the malnutrition burden associated with them.

The types of food environments that consumers interact with influences the foods they acquire and consume. This study highlights a shift towards built formal food environments comprised of more ultra-processed foods along with higher safety standards. Specifically, among higher SDI countries, modern retail have become the dominant retail form, with the largest proportion of retail value attributed to supermarkets. While modern supermarkets can help to provide more stringent food safety standards and more diversity, they also provide a subtantial amount of ultra-processed foods (Machado et al., 2017; Wertheim-Heck et al., 2019). While ultra-processed foods are likely to contain fewer biological hazards than fresh perishable food from a food safety perspective (Grace, 2015), there is mounting evidence of the myriad negative impacts (e.g., increased risk of metabolic syndrome, cardiovascular disease, etc.) that consuming them in high quantities have on overall health (Pagliai et al., 2021). Consumers often are faced with making a trade-off between food safety and other food attributes such as its affordability, nutritional quality, etc. (Liguori et al., 2022).

Alongside the increase in the dominance of modern retail, there has been a decline in that of traditional retailers including both informal food environments such as wet markets and formal food environments such as small food outlets, and mom and pop shops (i.e., small, family-owned or independent stores). These traditional retailers can be an important source of accessible affordable, and nutritious foods, particulalry in more rural areas of LMICs (Downs and Fanzo, 2016). While wet markets have come under scrutiny in the aftermath of the COVID-19 pandemic, they are an important source of fresh, nutritious foods and are a key avenue for smallholders to sell their produce (Editorial, 2020). In response to the COVID-19 pandemic, there has also been a shift towards online grocery retailing (International Food Information Council, 2020). While we found that the retail value from online grocery retailing was relatively low as compared to other types of retailers, it was rapidly increasing particularly among high SDI countries. While the permanence of the shifts seen in online retailing attributed to COVID-19 is unclear, it is likely that online retailing will continue to play a prominent role in the future. The increasing role of online shopping and food delivery was also recently highlighted in a review of the digital food environment literature (Granheim et al., 2022). Our findings, along with those by Granheim et al. (2022), highlight the need for food environment research to examine online environments alongside the physical spaces within which foods are acquired, and to develop appropriate tools for their measurement.

Along with healthy foods being available in the food environment, they also need to be affordable and convenient to local communities in order to be accessible. The cost of energy-dense processed foods has become markedly cheaper while fruits and vegetables have become more expensive; between 1990 and 2012, the price of fruits and vegetables increased by approximately 2–3% annually, or 51–91% over the entire period (Wiggins et al., 2015). Multiple studies suggest that healthy diets are more costly than those that are less healthy (Headey and Alderman, 2019; Rao et al., 2013). A meta-analysis found that healthy diets were on average approximately $10.50/week more expensive than less-healthy diets among select low-, middle-, and high-income countries in Africa, Asia, Europe, New Zealand, North

America, and South America, and that this difference was similar across countries adjusting for purchasing power parity (Rao et al., 2013). However, there are exceptions. Studies conducted in Australia found that healthy diets can be cheaper than current, unhealthy diets, albeit they may still be unaffordable for lower socioeconomic status groups (Lee et al., 2016; Lewis et al., 2021).

Our analyses indicate that lower SDI countries have lower availability (using FAO food supply data which is solely a proxy for availability within food environments) and affordability of key nutrient-rich food, with the exception of fruit where there was less variability across SDI country groupings in its availability and affordability. This indicates a clear need to increase both the availability and affordability of nutritious foods, as well as increasing their promotion, given that their low consumption is a dietary risk factor among all SDI country groupings. It is likely that this may require a combination of interventions including economic incentives such as subsidies or cash-transfers combined with behavior change communication and education programs. Given that many households make trade-offs between food affordability and quality (Global Panel on Agriculture and Food Systems for Nutrition, 2016), increasing purchasing power to enable better food choices is imperative in many settings.

While we found a rise in the retail value attributed to both convenience stores as well as convenience foods over time and across SDI groupings, convenience goes beyond the types of foods and retail outlets that consumers engage with. While we were limited by the existing data, in order to gain a more accurate assessment of how changes in convenience could influence diets, the amount of time it takes to acquire, prepare and clean food needs to also be considered given these factors are recognized barriers for the consumption of healthy food (Ahmed et al., 2020). These trends regarding the rise of convenience stores and foods, as well as barriers to preparing healthy foods based on time can also explain dietary shifts.

There are several other key elements of the food environment – quality, promotion and sustainability – for which there are significant gaps in the publicly available data at the national level for counties around the world. Previous studies provide evidence to suggest that as countries transition from low to high SDI, they are exposed to more marketing (Hawkes, 2006; Herforth and Ahmed, 2015), labeling (Mandle et al., 2015; Rimpeekool et al., 2017), and dietary information (Albert et al., 2007; Behrens et al., 2017; Herforth et al., 2019; Sunguya et al., 2014). Sustainability properties of food, such as the amount of packaging used or whether it includes an organic label, have the potential to influence food choices among some consumers (Downs et al., 2020); however, limited data exists. Information related to the degree of packaging, the carbon and water footprints of foods, environmental, animal welfare and labor equity labeling, etc. could help to better describe the sustainability properties of the foods available within food environments. In terms of the promotion of foods, additional information related to the marketing of different food groups would help to better ascertain the messaging that consumers receive. From a quality perspective, additional information related to the "freshness" and sensory properties of perishable foods would help to describe the quality of foods available more completely within food environments. While we found a food safety gradient across SDI country groupings, with food safety becoming progressively higher from low to high SDI, these data did not capture all aspects of food safety that influence consumers' food choices. For example, with regards to food quality, perceptions regarding pesticide use and sensory desirability have been found to influence consumers' likelihood of consuming nutritious foods (Ahmed et al., 2018b; Downs et al., 2019; Raneri and Wertheim-Heck, 2019). Future research needs to not only examine the objective food environment (external food environment) but also consumers' perceptions of their food environments (personal food environment) in order to more comprehensively understand the linkages between food environments, diets, nutrition, and health outcomes.

Despite there being considerable variation across SDI country groupings in terms of retailing as well as food environment elements, there is large overlap in the dietary risk factors experienced across country groupings. These findings potentially indicate that the food environment transition has a dynamic relationship with the dietary transition. Diets low in nuts and seeds, fruits, whole grains and those high in sodium are key dietary risk factors for nearly all countries globally. Moreover, among higher SDI countries higher consumption of processed meat was a key dietary risk factor. This points to the need for all countries, including high SDI countries, to consume more plant forward diets that include fruits, vegetables, nuts and seeds, along with more whole grains which are nutrient dense and promote the health of populations globally. These dietary shifts would also lead to marked reductions in environmental footprints associated with the food system (Herforth et al., 2017; Willett et al., 2019).

Given the food environment transition documented here, it is clear that food environment interventions are necessary to shift consumption patterns towards sustainable diets, including more plant-based foods. However, there is limited evidence informing the most effective and feasible approaches to accomplish such a transformation (Bailey and Harper, 2015). Food environment interventions will need to differ based on a given countries SDI status and the food environment types that consumers have access to. In higher SDI countries where formal built environments are predominant, interventions aimed at increasing the availability of high-quality, palatable plant-based foods in dining and restaurants (e.g., Menus of Change initiative) as well as those that reduce the availability of meat within school lunches, work place cafeterias etc. can create small shifts towards more emphasis on plant-based and sustainable diets (Bailey and Harper, 2015; Downs et al., 2022). Such interventions need to be combined with approaches that increase the affordability (e.g., subsidies), convenience, and desirability of plant foods as well as other incentives for their consumption. In lower SDI countries, and particularly in rural areas, interventions within the natural environment to improve production practices to close yield gaps and nutrient composition of plant foods such as pulses could help to increase their consumption. In all SDI country groupings, food-based dietary guidelines supported by comprehensive food composition data should emphasize the importance of plant-based diets and inform food procurement policies and meal programs.

### 4.1. Limitations

Our analyses are limited by the global data available. Overall, there are significant gaps in terms of the retail data available for low SDI countries. Food promotion, labelling and sustainability are key food environment elements that can influence food choices, yet publicly available data to track trends over time are lacking. While our analyses, and the framework derived from them, summarizes the existing evidence of the food environment transition at the global level, it fails to capture the transitions that are occurring within a country as well as the nuances of local food environments. Food environments can differ dramatically within a country and contribute to inequity in terms of diets and health outcomes (Global Nutrition Report, 2020; Hilmers et al., 2012). There is thus a need for primary data collection to comprehensively assess food environment elements, including those that are missing from global data sources, examine how they are changing over time, and how they influence diet and nutrition disparities. Moreover, primary data collection is needed to better capture the natural food environment, including both wild and cultivated food environments, which is largely missing from global data, reducing our ability to examine shifts in the places that foods are acquired over time and across SDI groupings. Natural food environments can contribute significantly to the diets of many marginalized communities (Ghosh-Jerath et al., 2018; Powell et al., 2013, 2015; Smith et al., 2019) and should therefore be included in food environment assessments, programs, and policies, particularly in efforts to support conservation of ecological resources as well as equity and food sovereignty of

communities relying on the resources.

## 5. Conclusion

This study highlights that a global food environment transition has occurred over time and across SDI country groupings. Specifically, the types of food outlets where consumers acquire food from, as well as food availability, affordability, convenience, and quality have shifted over time and differ significantly across stages of development on the basis of SDI country groupings. We posit that these global food environment trends characterize a food environment transition that parallels the dietary and nutrition transition with implications for the multiple burdens of malnutrition. Identifying the patterns within the food environment transition that a given country, community or region fits within allows for better identification of levers for policies and interventions aimed at improving food choices both within the context of health and sustainability. The national and global evidence of food environment transitions presented here can thus enable the identification of food system interventions aimed at reorienting food supply and food choices towards diets for supporting planetary health.

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## Authors contributions

SMD, SA and JF conceived of the study. SMD and SA drafted the initial draft of the article and TW and KL conducted the data analysis and created figures. All authors contributed to the writing the final version of the manuscript.

## 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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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gfs.2022.100632.

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