RESEARCH PROGRAM ON Agriculture for Nutrition and Health
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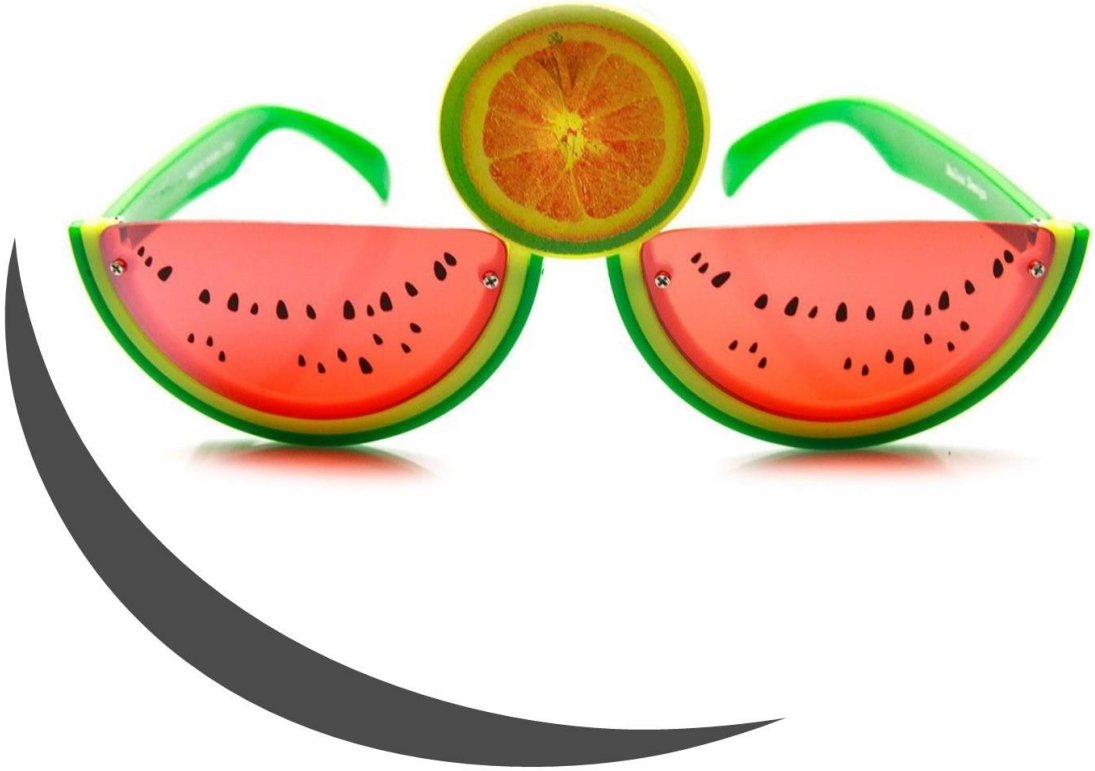
Fruits and Vegetables consumption in Low- and Middle-Income Countries

Comprehensive review of fruits and vegetable intake and determinants using a food systems approach



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Fruits and Vegetables Consumption in Low- and Middle-Income Countries. A comprehensive review of fruits and vegetables intake and determinants using a food systems approach

April 2020

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List of abbreviations

ANH Academy	Agriculture, Nutrition, and Health Academy
CFS	Committee on World Food Security
CHD	Coronary heart disease
CVD	Cardiovascular disease
DALY	Disability-adjusted life year
FAO	Food and Agriculture Organisation of the United Nations
FPI	Food price index
FV	Fruits and vegetables
FBS	Food balance sheet
GDD	Global dietary database
GDP	Gross domestic product
GHG	Greenhouse gas
HCES	Household Consumption Expenditure Survey
HIC	High-income countries
HLPE	High Level Panel of Experts on Food Security and Nutrition
INDDEX	International Dietary Data Expansion project
IYCF	Infant and Young Child Feeding
LMIC	Low- and middle-income countries
NCD	Non-communicable diseases
NFCS	National Food Consumption Survey
WHO	World Health Organization

Summary

Present food systems are not able to provide the foods everyone needs to live a healthy and productive life, reflected in the too-slowly reducing levels of stunting; the stubbornly high prevalence of micronutrient deficiencies; and the fast-rising levels of overnutrition and obesity, and diet-related non-communicable diseases. Low-quality diets are the number one cause of mortality and morbidity worldwide and the public health burden is particularly high in low- and middle-income countries (LMIC). The importance of fruits and vegetables (FV) for health has long been recognized, but overall consumption of fruits and vegetables is below recommended levels.

To understand why this is so, this report investigates the consumption of FV worldwide and especially in LMIC, using a food systems lens. Guided by the High Level Panel of Experts (HLPE) framework of food systems and healthy diets, a comprehensive literature review was carried out on the drivers, food system components and food system outcomes related to FV consumption.

The report starts with a comprehensive review of the known health effects and potential risks of FV consumption, followed by an overview of recommendations on amounts of FV to be eaten as reflected in different global guidelines. Specific attention is given to reviewing often relatively non-specific messages on FV in national food-based dietary guidelines (FBDG) for the limited number of LMIC which have them. In addition, the report reviews the extent to which people adhere to the recommendations, addressing the low intake of FV worldwide and especially in LMIC determined by factors related to age, gender, income, socio-economic status and education, although consumption data are not widely available. Next, this report addresses the different food system components to understand the bottlenecks in food systems that need to be addressed to improve intake of FV. These cover the supply of FV in different regions, the effect of seasonality, and the impact of losses and waste. Results indicate that globally, FV supply is sufficient for adequate consumption, but not in numerous low-income countries in Asia, the Pacific and sub-Saharan Africa. The food environment connects the supply with the consumer, and this report reviews where consumers purchase their FV, primarily still at market-based vendors even where supermarket penetration is rising. This report also looks into the effects of (seasonal) fluctuation of prices of FV, with highest impact in LMIC where FV are among the first categories to be dropped from the diet when prices rise. Economic access to FV is low as a large proportion of the population in low-income countries cannot afford the recommended five servings of FV per day. Very little is known about factors that affect accessibility, such as physical distance, mode of transport, time to reach points of sale, the role of convenience, and information on the importance of FV given in the food environment. Even less is known about consumer choices and motives, and how beliefs, knowledge and taboos, and food safety concerns influence consumption of FV in LMIC. Lastly, this report pays attention to the environmental sustainability impact an increase in FV intake as recommended in guidelines might have in terms of greenhouse gas emissions, eutrophication and land use for most LMIC.

The report ends with highlighting key research gaps and challenges that need to be addressed to further the agenda on improving FV intake for health in a sustainable and inclusive way. An annotated bibliography is given at the end of the report.

Acknowledgements

This report is written in the framework of the CGIAR Research Program on Agriculture for Nutrition and Health (A4NH), and especially for the research flagship Food Systems for Healthier Diets. The support of Janet Hodur, A4NH, in editing the report to its final stage is highly acknowledged. Also, the support of Giulia Pastori and Elise Talsma from the Division of Human Nutrition and Health, Wageningen University, by sharing their experience and knowledge is highly appreciated.

1. Introduction

Food systems should deliver the food everyone needs to live a healthy and productive life. Yet diet-related factors have become the number one cause of mortality and morbidity worldwide (Forouzanfar *et al.*, 2016). The public health burden is particularly high in low-and middle-income countries (LMIC), as we observe malnutrition in all its forms, including undernutrition, micronutrient deficiencies and overweight/obesity, which increasingly occur side by side (Pinstrup-Andersen, 2007) in the same country, community, household, or even individual. Micronutrient deficiencies are among the most pervasive forms of malnutrition, affecting about two billion people worldwide (WHO, WFP and UNICEF, 2007). Women and children are particularly vulnerable to micronutrient deficiencies and undernutrition due to higher growth and physiology requirements. However, global trends toward more sedentary lifestyles and a shift from traditional diets toward a more energy-dense and monotonous diet, known as the nutrition transition (Popkin, Adair and Ng, 2012a; Khoury *et al.*, 2014), contribute to a growing burden of largely preventable diet-related non-communicable diseases (NCDs) (Bennett *et al.*, 2018).

A strategy to address micronutrient deficiencies is increased consumption of fruits and vegetables (FV) (WHO/FAO, 2003a; WHO, 2009). In addition to critical micronutrients, FV provide other health benefits through intake of phytochemicals and fibre (Mozaffarian, 2016). These properties can help prevent development of diet-related NCDs. The importance of FV in the diet has long been recognised. This report investigates consumption of FV, worldwide and especially in LMIC, using a food systems lens as shown in Figure 1 (De Brauw *et al.*, 2019), based on the Committee on World Food Security's (CFS) High Level Panel of Experts on Food Security and Nutrition (HLPE) framework (HLPE, 2017). The HLPE framework structures food systems into three key dimensions: (1) external **drivers** that influence the global food system performance, (2) core **food system components** that shape the interactions between food supply and demand, and (3) **food system outcomes** that indicate how safe, healthy, sustainable and affordable diets can be reinforced and sustained.

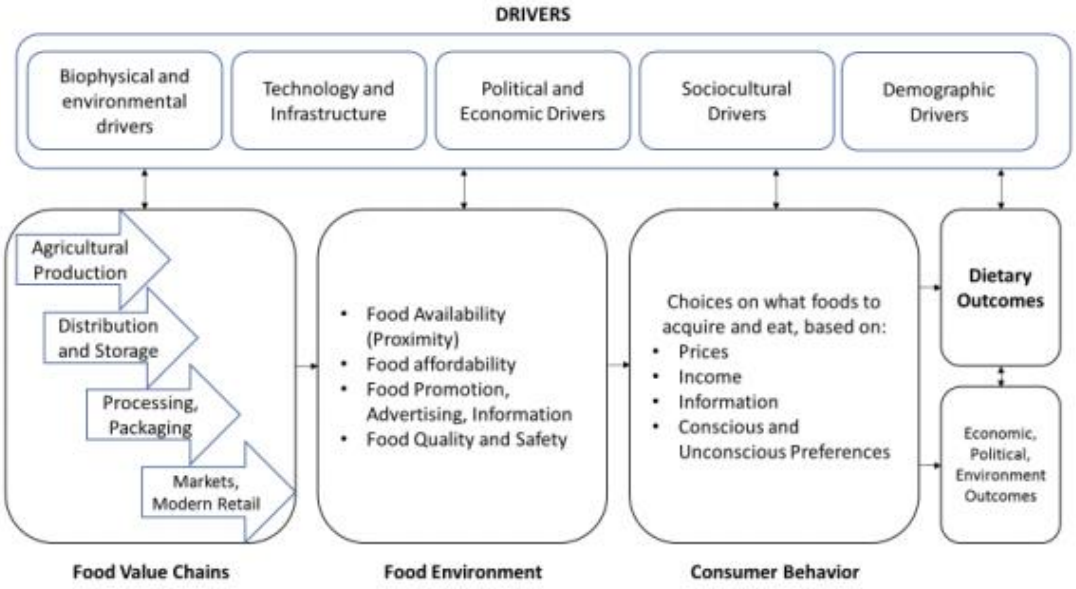

Figure 1. Conceptual framework of food systems for diets and nutrition (De Brauw *et al.*, 2019), based on the HLPE framework (HLPE, 2017).

Different definitions of FV can be observed. While botanically some vegetables may be considered fruits, we follow the Food and Agriculture Organization of the United Nations (FAO) definition, which excludes roots and tubers (potatoes, cassava etc.), legumes, and nuts (WHO/FAO, 2003b).

2. Objective

The objective of this literature review is to review and analyze current research on FV consumption worldwide, with a focus on LMIC, using a food systems perspective.

Sub-objectives

1. To review health and nutrition outcomes of FV consumption
2. To review recommendations on FV consumption
3. To review current consumption patterns worldwide, and particularly in LMIC
4. To review food system determinants of FV consumption worldwide and in LMIC
5. To review sustainability of FV in the diet worldwide and in LMIC
6. To identify research gaps related to FV consumption worldwide and in LMIC (on basis of the above)

3. Health and nutrition aspects of fruits and vegetables

3.1 Healthy components

Fruits and vegetables are nutritional powerhouses: they are rich in micronutrients, fibre and phytochemicals, and have a low energy content.

Micronutrients

Micronutrients play an important role in the functioning of the human body. Essential micronutrients are those that cannot be produced by the human body and thus must be ingested through food, with the exception for vitamin D, which is mainly produced in the body through exposure to the sun. Micronutrients are categorized as vitamins or minerals, and both are present in FV. It is important to note that the bioavailability of micronutrients can be influenced by anti-nutrients or interactions with other micronutrients. Several micronutrients have received attention globally because their intake remains problematic and adequacy is most difficult to secure without a diverse diet. These include iron, zinc, vitamin A, folate, and iodine (Development initiatives, 2018).

Vitamin A is delivered through B-carotene as a precursor in orange and yellow FV, as well as green leafy vegetables. Although vitamin A is also present in animal source foods in the form of the higher-bioavailable retinol, FV are a particularly important source of vitamin A in LMIC where animal source foods are not consumed in high quantities. This also holds true for iron: meat is a rich source, but as consumption is low, dietary iron sources are mostly plant-based, including FV but also cereals and legumes. Micronutrients also interact with one another in important ways. For example, vitamin C enables the body to increase iron absorption from plant-based foods by two to three times (Teucher, Olivares and Cori, 2004). The combined consumption of FV with iron-rich foods can enhance iron status, as FV are the main source of vitamin C in most diets and iron absorption is especially low in plant-based diets.

It is important to consider the contribution to micronutrient intake from FV in the local context. The contribution might be dependent on other sources such as supplementation and fortified products.

Fibre

Fibre is an important component of the diet, aiding digestion. Fibre is found in plant foods, including FV. A diet low in fibre has been identified as a risk factor for various NCDs and mortality (Liu, Wang and Liu, 2015). Of the global population, 13.8 and 15.0 percent of men and women, respectively, were at risk for a low-fibre diet in 2015 (Forouzanfar *et al.*, 2016). As the nutrition transition causes a shift away from whole foods to refined (Popkin, Adair and Ng, 2012b), fibre intake in LMIC might be decreasing. Fruits and vegetables can play an important role in contributing to the fibre intake, especially in areas were the nutrition transition is happening. Even though fibre is considered an important nutrient, global and LMIC data on fibre consumption and the contribution of FV to it are missing.

Phytochemicals

Phytochemicals, also called bioactive compounds, are present in FV. In the strictest sense, phytochemicals are defined by plant scientists as chemicals produced by plants. However, the term is generally used by both human nutrition science and plant science to describe chemicals from plants that may affect human health and wellbeing but are not essential nutrients.

As there are no known effects or symptoms as a consequence of their deficiency, no target intake levels have been determined (Van Breda and De Kok, 2018).

Even though there are no recommendations, the role of phytochemicals in health is recognised. Much of the preventive effect of FV on disease is thought to be provided by their complex mixture of phytochemicals, including the well-documented preventive activities of antioxidants (Rodriguez-Casado, 2016; Van Breda and De Kok, 2018).

Processing

Processing FV may decrease their nutritional value by removing fibre and key nutrients (Mozaffarian, 2016), and preparation methods can have significant effects on nutrient content, particularly in LMIC, where these foods are more likely to be eaten cooked. Vitamins are not heat-resistant and (partly) degrade after prolonged heating. While minerals are more heat-resistant, they can still leak into cooking water. Peeling fruits or vegetables will lower the fibre content. Data on cooking and processing habits and the consequences on the quality of FV in LMIC is lacking and needs further investigation.

3.2 Unhealthy components

Although FV are generally a healthy contribution to the diet, some adverse aspects have been reported.

Preservation methods

An association between consumption of canned fruits and an increased risk for cardiovascular disease (CVD)-related and all-cause mortalities has been found in one study (Aasheim *et al.*, 2015), although the mechanism of this association is not yet understood. Kim and colleagues report an increased risk for stomach cancer related to consumption of pickled vegetables (Kim *et al.*, 2010).

Fruit juice

Fruit juice is not included in most food-based dietary guidelines because of its high sugar content and thus the risk it will contribute to overconsuming sugar and calories. This includes not only juices with added sugar, but also 100 percent fruit juices because they usually have had fibre removed.

3.3 Diversity

Different species/varieties

Different species of FV provide different nutrients. Nutrient densities are different per species, and even within species of FV, depending on soil and other growth circumstances (de Valença and Bake, 2016). While green leafy vegetables and orange-coloured FV are generally high in B-carotene, citrus fruits are generally high in vitamin C, while berries are known for their antioxidant properties. The vitamin, mineral, and fibre content for most FV is documented and described in food composition tables. This is, however, not the case for all phytochemicals, they are hardly included in food composition tables.

Subcategories of FV may have different associations with health outcomes (Yip, Chan and Fielding, 2019). In most epidemiological studies, fruits are seen as one group, as are vegetables, with no additional subcategories defined. In studies that do subclassify, we see that a higher consumption of citrus fruits, green leafy vegetables, and B-carotene– and vitamin C–rich FV is associated with a lower coronary heart disease (CHD) risk (Bhupathiraju *et al.*, 2013). Variety in and of itself, however, was not associated with CHD (Bhupathiraju *et al.*, 2013). A similar finding from Oude Griep et al. shows, independent of quantity, variety in FV was related neither to incident CHD nor to incident stroke (Oude Griep *et al.*, 2012).

Fruits are mostly consumed raw and vegetables mostly cooked. Treatment impacts nutrient retention and thus health outcomes. Though certain FV might have a comparable nutrient density in the raw form, cooking will decrease the vegetables' nutrient content.

Underutilised species

Fruits and vegetables are food groups that contain rich reservoirs of genetic diversity (Jamnadass *et al.*, 2011), however knowledge on these have been limited as focus has been given to the most remunerative species such as tomato, onions, peppers, eggplants, okra, watermelon, cabbage and carrots (Grubben *et al.*, 2014). Specifically, very little is known about the so-called orphan, traditional varieties, and wild edible species of vegetables and fruits that are mainly maintained by custodian farmers exclusively for home consumption or for informal trade (Borelli *et al.*, 2020). Availability of these species are often limited to the specific geographical area where they are found. These often neglected and underutilized species are marginalized, if not entirely ignored (Padulosi, Thompson and Rudebjer, 2013). However, these species are often referred to as having superior nutrient content (Hunter *et al.*, 2019). The nutrient content differences among varieties of the same species can be greater than the

differences between species, but most research left this varietal level largely unexplored. Food composition data have largely been limited to an aggregate level, and miss information on significant compositional differences related to agro-ecological zone, seasonality and genetic diversity (Hunter *et al.*, 2019), also because the costs of nutritional analysis is high. The contribution of these underutilized and neglected species to nutrient intake are therefore difficult to assess, and most of these species are not taken into consideration in national food-based dietary guidelines. Underutilised local species of FV need further nutritional analysis and attention as they can be rich sources of nutrients.

3.4 Safety

Even though it is hard to think of foods that are more nutritious than FV, adverse health effects have been reported and can be a reason for consumers to limit their consumption. Although most consumers worry about contamination through the use of pesticides, insecticides etc., most of the burden of foodborne disease in LMIC comes from biological hazards and is the result of consumption of fresh perishable foods such as fruits, vegetables and meat (Grace, 2015), The food safety aspects of FV will be further explored in this section.

Microbial contamination/Parasites

Contamination of FV in the value chain occurs via various routes, including use of unclean water and direct contamination through livestock (Schreinemachers, Simmons and Wopereis, 2018). While the magnitude of foodborne disease caused by FV in LMIC is not fully known, nearly half of foodborne illnesses in the United States are caused by germs on fresh produce (CDC, no date). One study in Hyderabad, India, estimates that 29 percent of foodborne diseases come from FV (Sudershan *et al.*, 2014). Microbial pathogens may cause a burden of 18 million Disability-Adjusted Life Years (DALYs) each year in LMIC, with foodborne parasites at least the same (Grace, 2015). While the proportion of this burden caused by consumption of FV is unknown, the contribution is thought to be considerable based on case studies from the US and Hyderabad (CDC, no date; Sudershan *et al.*, 2014).

Chemicals: Pesticides/herbicides

Pesticide use is common in FV farming. Farmers in some areas, including Southeast Asia, have been reported to spray excessively (Schreinemachers *et al.*, 2020). The use of pesticides is greater on high-value crops like vegetables than on low-value crops (not serving as cash-crops), as farmers tend to spray to protect their investment (Schreinemachers, Simmons and Wopereis, 2018).

Farm workers are especially at risk for short- and long-term health consequences, as they are exposed excessively and directly. Pesticides cause direct adverse toxic effects like vomiting following high-dose acute exposure (Bonner and Alavanja, 2017). Epidemiological evidence suggests a relation between occupational pesticide exposure and different types of cancer (Bonner and Alavanja, 2017).

Consumer risk of exposure is less known, as regulatory monitoring systems in LMIC are limited, especially for domestic non-export crops. This uncertainty can cause consumers to distrust the safety of FV, thus limiting their choices and impacting consumption (see paragraph 6.2).

3.5 Associated disease and risk

Although intake of FV has been inversely associated with all kinds of disease, from asthma to cognitive impairment (Wallace *et al.*, 2019), we focus on diet-related NCDs, obesity, and micronutrient deficiencies here.

NCDs

Recent evidence shows diets low in vegetables and fruits are among the top four diet-related risk factors in LMIC for mortality and DALYs (Afshin *et al.*, 2019). The protective effects of FV against overall mortality (Wang *et al.*, 2014; Aune *et al.*, 2017) and several NCDs (Hu *et al.*, 2014; Wang *et al.*, 2014; Aune *et al.*, 2017), are shown in multiple meta-analyses, with the strongest link to protection against CVD (Angelino *et al.*, 2019b; Wallace *et al.*, 2019). It should be noted that most evidence emerges from high-income countries with some from Asian countries; no epidemiological evidence from Africa or Latin America was included in any of the reviews studied, which might reduce the generalizability of these

findings to LMIC. Considering the high prevalence of micronutrient deficiencies in LMIC and the mitigating effect of fruits and vegetables consumption, the association between consumption and disease or all-cause mortality is possibly different in LMIC compared to high-income countries (HIC). It is not known whether and how the underlying highly prevalent micronutrient deficiencies and undernutrition may affect the association of fruit and vegetables intake with NCDs, limiting the applicability of the existing evidence in LMIC. Miller et al. did include LMIC in their study and find a similar protective effect for FV and mortality (Miller *et al.*, 2017).

Studies show different dose-response relationships for the amount of FV required to be protective for disease and all-cause mortality. A threshold around five servings of FV per day was observed by Wang and colleagues, after which the risk of all-cause mortality did not decline further (Wang *et al.*, 2014), while Aune and colleagues observed reductions in risk up to 800 g/day for all outcomes except cancer (600 g/day) (Aune *et al.*, 2017). In their meta-analysis review, Yip et al observe clear increases in protective associations with the first 300g/day of intake, but little further increase thereafter (Yip, Chan and Fielding, 2019). Increasing the consumption of fruits and/or vegetables to 300g/d could translate to a 10 to 30 percent decrease in risk for most of the associated burden of diseases (Yip, Chan and Fielding, 2019).

Obesity

Consumption of FV has been suggested as a strategy to prevent obesity. They are rich in fibre, thus increasing satiety, and have a low energy density. Studies do not provide convincing evidence that increasing fruits and vegetables intake without combining this approach with efforts to reduce intake of overall energy or reduce energy requirements results in weight loss (Ledoux, Hingle and Baranowski, 2011; Kaiser *et al.*, 2014; Wallace *et al.*, 2019).

Micronutrient deficiencies/undernutrition

The effects of micronutrient deficiencies in the human body and the related public health burden are well documented. Two billion people are estimated to suffer from micronutrient deficiencies worldwide (WHO, WFP and UNICEF, 2007), with pregnant women and children under 5 years of age at the highest risk (Bailey, West and Black, 2015). The largest health burden of micronutrient deficiencies in LMIC is caused by deficiencies of vitamin A, iron, zinc, folate and iodine (Micronutrient Initiative, 2009). Evidence from home-garden interventions shows the impact of increased fruits and vegetables consumption on micronutrient intake (Ruel, Quisumbing and Balagamwala, 2018). The potential of FV to improve micronutrient status in LMIC however, needs further study.

4. Recommendations worldwide and in LMIC

The benefits of FV go beyond a single or mix of nutrients and bioactive substances (WHO/FAO, 2003b), and cannot be attributed only to certain species. Therefore, recommendations are given as a food category rather than for the nutrients themselves (WHO/FAO, 2003b).

4.1 Recommendations - Quantity

The World Health Organization (WHO) recommends consumption of 400 grams or more of vegetables and fruits daily for the general population, with no differentiation between fruits and vegetables (WHO/FAO, 2003b).

Some global dietary guidelines suggest a higher intake than the broadly-applied 400 grams, like the environmentally conscious EAT-Lancet diet, recommending 100 to 300g per day for fruits and 200 to 600 grams per day for vegetables for a 2500kcal diet (Willett *et al.*, 2019). The DASH diet, developed specifically to treat hypertension, advises five to six servings each of vegetables and fruits for a 2600kcal diet (U.S. Department of Health and Human Services, 2006), resulting in about 692g of fruits and fruit juices and 345g of vegetables, including a limited amount of potatoes (Karanja *et al.*, 1999). In their analysis of health risks, Siegel et al (Siegel *et al.*, 2014a) use quantities from Lock et al. which suggest 330g per day for children up to four years of age, 480g per day for those age five to 14 years, and 600g per day for those 15 years and older (Lock *et al.*, 2004). The Global Burden of Disease defines the range at 200 to 300g and 290 to 430g per day for fruits and vegetables, respectively (Gakidou *et al.*, 2017). In Table 1, different recommendations with supporting evidence are shown.

Table 1. Recommendations for fruits and vegetables consumption (Pastori and Talsma, 2019)

Initiative	Vegetables	Fruits	Evidence statement in recommendation
American guidelines / Healthy Eating Index	2.5 cup-equivalents per day Including: All fresh, frozen, canned, and dried options in cooked or raw forms, including vegetables juices. Based on 2000 kcal diet	2 cup-equivalents per day Including: Whole fruits and 100% fruit juice. Whole fruits include fresh, canned, frozen, and dried forms. Since fruit juice has less fibre, at least half of the recommendation should come from whole fruits. Based on 2000 kcal diet	Vegetables are an important source of many nutrients, including dietary fibre potassium, vitamin A, vitamin C, Vitamin K, copper, magnesium, vitamin E, vitamin B6, folate, iron, manganese, thiamin, niacin, and choline. Each of the vegetables subgroups contributes different combinations of nutrients.
DASH diet	3-4 servings per day (1600 kcal) 4-5 servings per day (2000 kcal) 5-6 servings per days (2600 kcal) Serving size: 1 cup raw leafy vegetables 1/2 cup cut-up raw or cooked vegetables 1/2 cup vegetable juice (e.g. broccoli, carrots, collards, green beans, kale, lima beans, potatoes, spinach, squash, sweet potatoes, tomatoes).	4 servings per day (1600 kcal) 4-5 servings per day (2000 kcal) 5-6 servings per day (2600 kcal) Serving size: 1 medium fruit 1/4 cup dried fruits 1/2 cup fresh, frozen, or canned fruit 1/2 cup fruit juice (e.g. apples, apricots, bananas, dates, grapes, oranges, grapefruits, grapefruit juice, mangoes, melons, peaches, pineapples, raisins, strawberries, tangerines)	Major decrease of blood pressure from the combination diet (DASH).
EAT	300 g per day (range 200-600 g/day) Disaggregation: Dark green vegetables 100 g/day, red and orange vegetables 100 g/day, other vegetables 100 g/day Excluding: Potatoes	200 g per day (range 100-300 g/day)	FV are an essential source of many micronutrients, including pro-vitamin A for prevention of night blindness. Substantial evidence indicates that FV consumption is also important for prevention of cardiovascular disease; benefit is mostly achieved by consuming about five servings per day, although higher intakes might provide some benefits. High intake of vegetables reduces blood pressure and is associated with reduced risk of type 2 diabetes. Increasing intake of most non-starchy vegetables has been associated with reduced weight gain in long-term follow-up of adults in the USA. High FV consumption is weakly associated with reduced cancer incidence after adjusting for differences in other lifestyle factors such as smoking and BMI
	Or five servings of FV per day (most benefit from these foods is probable if a mix is included as suggested).		
GBD	290g - 430g per day (fresh, frozen, cooked, canned, or dried vegetables) Excluding:	200g - 300g per day (fresh, frozen, cooked, canned, or dried fruits) Excluding: Fruit juices and salted or pickled fruits).	Risk from a diet low in fruits: Lip and oral cavity cancer, nasopharynx cancer, esophagus cancer, larynx cancer, tracheal, cronchus, and lung cancer, ischemic heart disease, ischemic stroke, diabetes mellitus.

	Legumes and salted or pickled vegetables, juices, nuts, and seeds, and starchy vegetables such as potatoes or corn. Exposure to diet low in vegetables is defined as average daily consumption of less than 360 g per day of vegetables.	Exposure to a diet low in fruits is defined as average daily consumption of less than 250g per day of fruits.	Risk from a diet low in vegetables: esophageal cancer, ischemic heart disease, ischemic stroke, hemorrhagic stroke.
Healthy Eating Plate	Half of the plate. Aim for color and variety, and remember that potatoes don't count as vegetables on the Healthy Eating Plate because of their negative impact on blood sugar.		Higher intake of FVs is associated with reduced risk of death from CVD. Especially cruciferous vegetables such as broccoli, cauliflower, cabbage, Brussels sprouts, bok choy, and kale; and citrus fruits such as oranges, lemons, limes, and grapefruits.
Mediterranean diet	>2 serves of every meal (100g) or 6 serves per day	1-2 serves of per meal or 3 serves daily	N/A
Nordic diet	>400 g per day Including: Cabbages >29 g/d, Root vegetables >150 g/d, legumes 30 g/d.	>300 g per day Including: Berries 50-100 g/d,	With increasing intake of fruits or vegetables there is a proportional decrease in the risk of CVD, overweight and obesity, and probably of certain cancers.
WHO	≥ 400g (i.e. five portions) of FVs per day Excluding: Potatoes, sweet potatoes, cassava and other starchy roots.		Prevention of obesity and weight gain: Convincing evidence high dietary intake of non-starch polysaccharides (NSP). Prevention of type 2 diabetes: Probable evidence that NSP decreases the risk of developing type 2 diabetes. Prevention of CVD: Convincing evidence for CVD (coronary heart disease, stroke, lower blood pressure). Probable evidence for consuming NSP. Prevention of cancer: Probable evidence for following cancers types: oral cavity, esophagus, stomach, colorectal Prevention of osteoporosis: Possible evidence
World Cancer Research Center	Eat a diet high in all types of plant foods including at least five portions or servings (at least 400 grams or 15 ounces in total) of a variety of non-starchy vegetables and fruits every day. Consume a diet that provides at least 30 grams per day of fibre from food sources. If you eat starchy roots and tubers as staple foods, eat non-starchy vegetables, fruis and pulses (legumes) regularly too if possible.		Strong evidence that consumption of foods containing dietary fibre protects against colorectal cancer and against weight gain, overweight and obesity. There is limited evidence that consumption of non-starchy vegetables and fruits, and some of their constituents, reduces the risk of a range of cancers and protects against weight gain, overweight and obesity.

Other than the DASH diet, none of the renowned recommendations take into account body size or energy expenditure, nor are there specialised global recommendations for age or gender. Nevertheless, it is not expected children can eat the same amount as adults, as their overall food intake is lower. It has been estimated that boys and girls up to age four and those aged five to 14 years consume about 45 percent and 20 percent less FV than adults aged 30 to 59 years, respectively (Lock *et al.*, 2004).

A complicating factor when considering portion size is that, as vegetables are prepared, moisture loss can result in weight change. This is especially the case for green leafy vegetables: 100g of spinach reduces to 77g after cooking, for example (Matthews and Garrison, 1976). Despite this, WHO does not differentiate between cooked and raw in their recommendations (indicated as 'as is consumed'), making it unclear whether the recommendation refers to the amount that goes into a dish raw or the final weight after cooking. The recommended amount and the differentiation between raw and cooked depends on the epidemiological evidence that feeds into the recommendation. As studies do not specify the quantities as cooked/raw or a mix, conclusions on the quantities to be consumed in what form remain indecisive.

In national dietary guidelines, the 400g WHO recommendation generally translates to five servings of FV. Another FAO/WHO source suggests 80 gram portions (Lever and Fischer, 2018), although it has been recognised fruits portions are generally larger than vegetables portions (Agudo, 2005). While national dietary guidelines should use locally known measures to communicate with their population, scientists should use uniform measures (grams) for comparability of results across literature. Currently, scientists use different measures, and inclusion of foods in food groups are not standardised, see Table 2.

Table 2. Examples of quantification of recommendation in literature (Pastori and Talsma, 2019)

Authors/data source	Quantification	Recommendation used	Inclusion/exclusion of foods
Micha et al. GDD/FBS/STEPS (Micha *et al.*, 2015)	Fruits serving (100g) Veg serving (100g)	Fruits: ≥ 300g/d Veg: ≥400g/d	-Veg group includes legumes -not reported if tubers/roots were included
Frank et al. STEPS/NFCS (Frank *et al.*, 2019)	Serving (80g)	≥5 80g servings (400g of fruits and veg)	-tubers and legumes were excluded
Hall et al./ World Health Survey (Hall *et al.*, 2009)	Fruits serving: -One medium size piece of fruit -One half cup cooked, chopped or canned fruits -One half cup fruit juice, not artificially flavored. Veg serving: -1 cup of raw green leafy veg -half cup of other veg cooked or chopped raw -half cup of veg juice	≥5 servings (400g of fruits and veg)	Not reported
Miller et al./ PURE cohort (Miller *et al.*, 2016)	Serving	Fruits: 2 servings Veg: 3 servings	Not reported
Ruel et al./ HCES (Ruel, Minot and Smith, 2005)	Kg/cap/year	146kg/cap/year (400g)/d)	Excluded: nuts, pulses, sugar crops, starchy root crops (sweet potatoes, cassava yam, plantain). Included: white potatoes

Fruits and vegetables in FBDG – overview

Food-based dietary guidelines (FBDG) attempt to translate evidence regarding the relationship between foods, diet patterns, and health into specific, culturally appropriate, and actionable recommendations (Herforth *et al.*, 2019). Those guidelines can be used to influence consumer behaviour but can also inform national nutrition and health policies. Evidence on the utilization of FBDG by the general public, however, is scarce (Brown *et al.*, 2011), and the effect of FBDG on FV consumption is unstudied to our knowledge. Where FBDG have existed for a number of years, they have not been shown to be effective in changing consumer behaviour or helping to reduce the incidence of NCD (Brown *et al.*, 2011). Nevertheless, even though FBDG may not be the silver bullet in convincing consumers to change their dietary patterns, they still play an important role in health, nutrition, and agriculture policy and can serve as a tool of accountability.

Most HIC have FBDG, however they are often absent in LMIC. Developing and updating FBDG is a strenuous process which requires conducting and tallying results of a representative national food consumption survey. Without these surveys, promotion of FV consumption through FBDG is not yet possible in many countries. The number of African countries with FBDG is particularly limited: only seven out of 54 African countries have FBDG according to FAO (Herforth *et al.*, 2019). Where they do exist, recommended quantities are not always specified, instead appearing as "Eat vegetables and fruits every day" (Namibia) or "Eat plenty of fruits and vegetables" (South Africa). A worldwide overview of the key messages about FV is given in Herforth et al. 2019 (Herforth *et al.*, 2019), shown in Table 3. For some guidelines, a visual aid helps to visualise the proportion of vegetables and fruits in the diet.

Table 3. FBDG key messages about fruits and vegetables conveyed by more than 5 countries (Herforth *et al.*, 2019).

	Number[1]	% (of 90)
Any key message about fruits and vegetables	84	93.3
Eat daily (or with every meal)	62	68.9
"Eat plenty of vegetables and fruit every day" (South Africa)	—	—
Five (or more) servings a day, or 400 g (or more)	30	33.3
"Consume three or more servings of vegetables and at least two servings of fruit per day" (Mongolia)	—	—
"Eat vegetables, fruits and berries frequently (a minimum of 500 g/day, excluding potatoes)" (Finland)	—	—
Variety within	38	42.2
"Choose a variety of fruits and vegetables every day" (Bahamas)	—	—
Eat plenty or "a lot"	19	21.1
"Consume plenty of vegetables, fruits and tubers" (China)	—	—
Eat more	16	17.8
"Increase your consumption of fruits and vegetables. Eat five portions of fruits and vegetables a day" (Cyprus)	—	—
Eat different colors or particular colors	17	18.9
"Eat at least one dark green and one orange vegetable each day. Go for orange vegetables such as carrots, sweet potatoes and winter squash. Go for dark green vegetables such as broccoli, romaine lettuce and spinach" (Canada)	—	—
"Eat five fruits and vegetables of different colours and flavours every day to fill you with health and vitality" (Dominican Republic)	—	—
"Eat plenty of green leafy vegetables, red and yellow vegetables and fruits every day; and include a variety of other vegetables and fruit" (Kenya)	—	—
Special mention/emphasis on whole, raw, or unprocessed	10	11.1
"Eat more than 400 g of various fruits and vegetables every day. Eat some of them raw" (FYROM)	—	—
Eat fresh fruits/vegetables	9	10.0
"Increase your daily intake of fresh fruits and vegetables of different colors" (Panama)	—	—
Eat seasonal fruits/vegetables	6	6.7
"Prefer vegetables and fruits that are locally grown in season. Whenever possible, buy organic and agro-ecological based foods, preferably directly from the producers" (Brazil 2014)	—	—
Eat local fruits/vegetables	7	7.8
"Eat more local fruits and vegetables" (Fiji)	—	—
Not mentioned but implied in diversity message (by reference to food guide)[2]	3	3.3
"Eat foods from each food group every day to have a complete diet" (Portugal)	—	—
No key message conveyed but fruits and vegetables are shown in food guide	6	6.7

[1] Sums to more than 90 because some countries have multiple messages about fruits and vegetables. Also many key messages contain more than 1 idea and are counted for several. For example, "Eat five servings (approx. 400 g) of vegetables, fruits and berries every day. Try to choose local and fresh products" [Latvia] is counted under "Eat daily," "Five (or more) servings," "Fresh," "Local," and "400 g/day (or more)."

[2] Considered to be implied when a key message directs the reader to eat all food groups, and fruits and vegetables are separate food group(s) in the food guide (this is so in nearly all food guides).

4.2 Recommendations - Quality

Even though the method of preparation greatly impacts the nutritional quality of FV, WHO dietary recommendations do not address this variation. In LMIC in Asia and Africa, vegetables are mostly consumed cooked, while in Europe and the United States, they are eaten raw as well as cooked (Miller *et al.*, 2017). Current dietary guidelines are mostly based on European and US data, and as a result may not be appropriate to use in other regions where preparation methods differ (Miller *et al.*, 2017).

Beyond this, however, *over*cooking vegetables is common in many parts of the world and causes vitamin and mineral degradation. Although the magnitude and consequences of overcooking are not studied widely, educating consumers about this fact and changing behavior around cooking habits should be an important aspect of nutrition programs and guidelines to reduce nutrient loss and improve nutritional status.

4.3 Recommendations - Diversity

The WHO recommends consuming a sum of 400 grams or more of FV per day; however, because they do not specify what species of FV to consume (WHO/FAO, 2003b), they inadvertently imply fruits and vegetables are interchangeable. Some, but not all, national guidelines advise eating a variety of FV.

Although dietary recommendations have many similarities, different countries choose different strategies to separate fruits and vegetables into groups. Orange FV are high in carotenoids and thus often placed in a separate group, though many dark green leafy vegetables are also high in carotenoids. While some countries divide groups on basis of colour, from a nutrient perspective this does not always work well (Slavin and Lloyd, 2012). For example, vitamin C-rich FV are spread over different botanical categories, including bell peppers, citrus fruits, and berries.

The most dominant vegetables in the global food economy are the so-called global vegetables: tomatoes, cucurbits (pumpkin, squash, cucumber, gherkins) and allium (onions, shallots) (Schreinemachers, Simmons and Wopereis, 2018). While dominant on the global market, these vegetables are not a rich source of the five micronutrients most lacking in the diet in LMIC. This is also true for fruits: bananas, melons, and apples are the most produced fruits worldwide (Rabobank, 2018) but are not good sources of the problem micronutrients.

5. Current consumption patterns worldwide and in LMIC

5.1 Quantity

Globally, most adults do not meet the WHO recommendations for FV consumption (Hall *et al.*, 2009; Murphy *et al.*, 2014; Del Gobbo *et al.*, 2015; Micha *et al.*, 2015; Frank *et al.*, 2019), placing them at higher risk for malnutrition, morbidity, and mortality. Intake of FV is especially low in LMIC where, on average, 3.61 portions of FV are consumed per day, based on 80g portions (Frank *et al.*, 2019). Consequently, only 18 percent of consumers in LMIC reach the WHO recommendation of 400g daily intake (Frank *et al.*, 2019). Similar results are found by Hall et al., with 21 percent of LMIC consuming less than the five recommended servings (Hall *et al.*, 2009). While some LMIC do come close to the recommended amount of vegetables with a mean of 2.46 servings, fruits servings remain low, with a mean daily intake of 1.15 servings (Frank *et al.*, 2019).

Region disaggregated

Comparing LMIC regions, the Middle East and Central Asia come closest to meeting the WHO recommendations, with 31.2 percent of population on target, compared to only eight percent meeting the recommendations among adults in Latin America and the Caribbean (Frank *et al.*, 2019), see Figure 2. In most regions, vegetables are consumed in greater amounts than fruits, though exceptions exist, such as the Caribbean (Micha *et al.*, 2015).

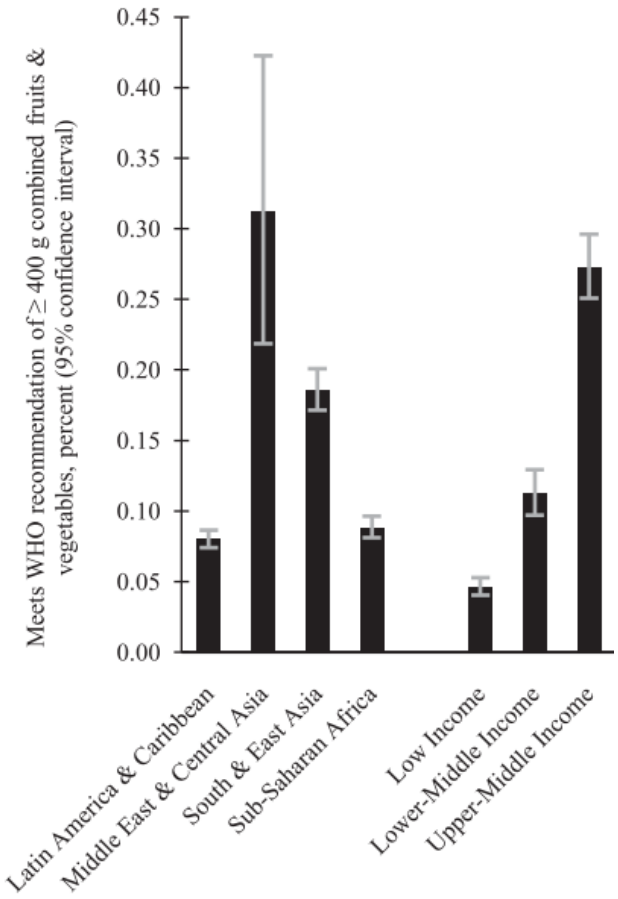

Figure 2. Percentage of population meeting WHO fruits and vegetables consumption recommendations, (Frank *et al.*, 2019).

Gender disaggregated

Intake of FV is mostly similar between men and women, in LMIC (Frank *et al.*, 2019) and worldwide (Micha *et al.*, 2015), although women generally consumed slightly more fruits (+21.7 g per day) and vegetables (+15.9 g per day) (Micha *et al.*, 2015). Some regional differences exist, as well, with women in Latin America and the Caribbean more likely to meet recommendations (Frank *et al.*, 2019).

Income or other demographics disaggregated

Low income is a strong predictor for insufficient FV consumption, on country level in terms of GDP (Frank *et al.*, 2019) and World Bank class (Miller *et al.*, 2016) as well as at household (Ruel, Minot and Smith, 2005) and individual levels (Hall *et al.*, 2009; Miller *et al.*, 2016; Frank *et al.*, 2019). Amounts consumed in grams are not reported with disaggregation for wealth quintiles or income levels, but the prevalence of meeting the WHO recommendation for combined fruits and vegetables intake is only 11.2 percent in the lowest wealth quintile, while 24.5 percent meet the recommendations in the richest quintile (Frank *et al.*, 2019).

Education level is also a predictor of achieving recommended consumption levels, with those achieving secondary education or greater more likely to do so than those with no formal education (Frank *et al.*, 2019). Generally, it is observed that people with higher socio-economic status consume more FV (Mayén *et al.*, 2014).

Rural-urban disaggregated

While rural consumers are more likely to be home-producers of FV, urban consumers generally have a higher income and more access to sale points. Hall et al. find no global association of urbanicity with low FV consumption, with differences observed in 11 of 52 countries, where urban residents had a higher risk of low FV consumption in 10 out of 11 countries observed (Hall *et al.*, 2009). The contrary is observed by Ruel et al. in countries in sub-Saharan Africa, where urban consumers have higher FV intake (Ruel, Minot and Smith, 2005). This is also observed in the review by Mayen et al. who find that people in urban areas consume more FV (Mayén *et al.*, 2014). Further study is necessary to understand the patterns of FV consumption in urban and rural areas in LMIC.

Age disaggregated

Adults

The prevalence of meeting the WHO recommendations in LMIC does not differ significantly across adult age groups (Frank *et al.*, 2019) though in Latin America and the Caribbean, older people were more likely to meet recommendations (Frank *et al.*, 2019).

Adolescents

Global data from the Global School-Based Student Health Survey shows a frequency of consumption of fruits (1.43x/d) and vegetables (1.75x/d) among adolescents, but average intake is likely far below the minimum amount recommended by the WHO (Beal, Morris and Tumilowicz, 2019). About a third (30.3 percent) of school-aged children do not eat any fruits daily (Development initiatives, 2018), see Figure 3. Small differences are observed between regions for daily fruits intake (Development initiatives, 2018). Among adolescent girls, inadequate FV intake is highest in South Asia (Keats *et al.*, 2018). However daily vegetables intake is highest among adolescent boys and girls in Asia (Development initiatives, 2018).

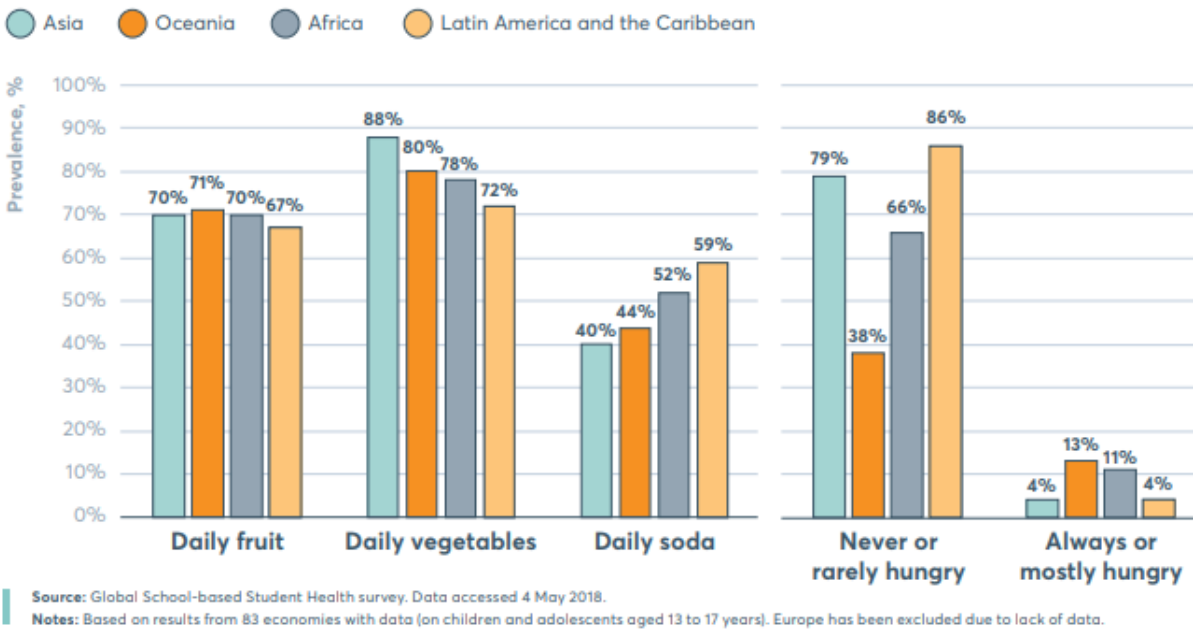

Figure 3. Prevalence of daily fruits, vegetables and soda intake among school-age children and adolescents. Global Nutrition Report 2018 (Development initiatives, 2018).

Children

Nutritional data of children age six to 24 months are monitored through IYCF (Infant and Young Child Feeding) indicators. Globally, the food groups of other FV and vitamin A-rich vegetables were consumed by 20.8 and 41.1 percent, respectively, on the day prior to the survey. Data on amounts consumed are not available for this age group (White *et al.*, 2017). Global data for consumption of FV in children age two to 13 years is not available.

Trends

Worldwide, between 1990 and 2010, fruits intake increased modestly 77.0g /d to 81.3g/d (Micha *et al.*, 2015). Mean vegetables consumption (including legumes) worldwide was stable across this time at 208.8g/day in 2010 (Micha *et al.*, 2015). As income increases, it is anticipated that FV consumption will also increase, as income is a predictor of intake as noted earlier in this section (5.1). Global demographic trends such as rising income and rates of urbanization should be studied to predict effects on FV demand.

5.2 Quality, diversity, safety

Data on the quality of the produce consumed globally and in LMIC is limited, not indicating if the FV consumed have been peeled, cooked, processed etc. Nutrient content can vary as a result of these processes, making it difficult to assess intake. Global data on the diversity of FV consumed is also scarce. Reports from the data sources presented in Section 5.1 do not get specific on species consumed. Safety of the produce consumed is also not reported. In general, data sources do not elaborate on form of consumption, focusing on quantity rather than quality, diversity and safety.

5.3 Dietary data availability and limitations

Availability of global datasets containing representative and recent country estimates of dietary intake data is limited. Although FAO Food Balance sheets are an up-to-date source of information, they measure availability for consumption rather than actual consumption. They also do not include production of indigenous FV, making them a poor source of dietary intake data. Household Expenditure surveys like the LSMS (World Bank) also have limitations, as they are designed to measure expenditure, not consumption, at the household, rather than individual, level, and generally include a limited number of food items. More detailed efforts include the 2002-2004 World Health Survey (*WHO | World Health Survey*, no date; Hall *et al.*, 2009), but the survey has not been repeated since. The Global Dietary

Database (GDD), used for the Global Burden of Disease studies, summarizes data from nationally representative dietary intake surveys in 266 countries (Tufts University, 2019), being a rich source of information on FV intake. WHO introduced the STEPwise surveillance which includes consumption of FV as an indicator of risk factors for NCD (Riley *et al.*, 2016). Although intake data is available from 122 countries (WHO, no date), the planned three- to five-year repetition for surveillance is proving difficult (Riley *et al.*, 2016), and no recent global data are available. Frank et al analysed STEPwise data from 18 countries, plus 10 nationally representative food consumption surveys (Frank *et al.*, 2019).

As noted earlier, national food surveys are time- and resource-intensive, and generally not conducted on a regular basis in LMIC. The limited availability of regularly updated data constrains the interpretation and monitoring possibilities of FV intake globally and in LMIC. The need for better data is underscored in the Global Nutrition Report (Development initiatives, 2018) which notes one of the five critical steps to address malnutrition is to prioritize and invest in the data needed and capacity to use it .

Although current data sources have their limitations, new developments are on the way (Development initiatives, 2018). The Gallup Diet Quality Worldwide project is a module in the Gallup World Poll aimed at providing comparable global information on adult diets. If successful, the aim is to roll the program survey out across more than 140 countries by 2021 (Development initiatives, 2018). The International Dietary Data Expansion (INDDEX) project works on multiple channels to improve metrics and data (Development initiatives, 2018). Another initiative is Intake, which aims to support the collection and use of dietary data in LMIC (Development initiatives, 2018).

6. Determinants of fruits and vegetables consumption in the food system worldwide and in LMIC

Food consumption is influenced by many factors that range from individual levels of influence to dimensions of their environment (Wallace *et al.*, 2019). Food systems significantly influence the FV intake of populations, as they comprise all the processes involved in keeping people fed: growing, harvesting, packing, processing, transforming, transporting, marketing, consuming and disposing of food (Global Panel on Agriculture and Food Systems for Nutrition, 2016). Factors causing low FV consumption are multidimensional and will be unravelled using a food systems perspective in this chapter. We also investigate factors affecting quality, diversity and safety of FV consumption.

6.1 Food value chains

The consumption of FV is determined to a large extent by the supply. The food supply chain impacts not only the quantity, but also the quality, diversity and safety of FV.

Although home production is thought to be an important source of FV in LMIC, it is unknown what percentage of produce is sourced from home gardens, or own production. Differences in sources of acquisition (own production versus sale) are expected for urban and rural consumers, but data here is lacking.

Quantity

Production/consumption gap

Global supply of FV is estimated to fall 22 percent short of population needs (Siegel *et al.*, 2014b) using a 600g age-adjusted recommendation (600g/d >15y) (Lock *et al.*, 2004). The situation is worst in low-income countries, followed by lower-middle income countries, which have a lower supply-to-need ratio than high-income countries (Siegel *et al.*, 2014b). Mason D'Croz estimates 2015 global per capita daily supply at 546g, which is above the 400g WHO recommendation (Mason-D'Croz *et al.*, 2019), however this is not distributed evenly as sub-Saharan Africa and South Asia have a supply of only 206g and 326g, respectively (Mason-D'Croz *et al.*, 2019).

Loss and waste contribute to a reduction of production efficiency of FV, leading to a reduced supply for consumption. In 2005, an estimated one-third of all FV produced globally were lost during production, storage and processing (Kader, 2005). However, new estimates in the *State of Food and Agriculture* Report specially devoted to food loss and waste (FAO, 2019) show lower percentages of losses. Overall, about 14 percent of food produced was lost from farm up to, but not including, the retail stage, varying from 6 percent in Australia and New Zealand to 21 percent in Central and Southern Asia. Levels of losses are higher in FV (22 percent) compared to cereals and pulses at all stages in the food supply chain, especially in situations where storage or processing conditions are inadequate. Losses for FV vary greatly, especially in sub-Saharan Africa and South Eastern Asia (ranging from five to 50 percent), see Figure 4 (FAO, 2019). Losses at retail and consumer levels are not included in these estimates but recent studies suggest that levels of consumer waste in LMIC may be much lower than initially assumed. Figure 4 shows the estimated losses of FV in different regions of the world by supply chain stage (FAO, 2019), illustrating that losses in lower-income regions are especially high during storage and processing and packaging in Eastern and South Eastern Asia, and during on-farm post-harvest operations and wholesale and retail in sub-Saharan Africa. This variation may be partly due to the differences in types of FV that are produced, but also related to the presence of poor or no packaging; transportation in open unrefrigerated trucks; being subject to mechanical injury owing to compression, abrasion and rough handling during handling operations; and transportation, making FV highly vulnerable to deterioration.

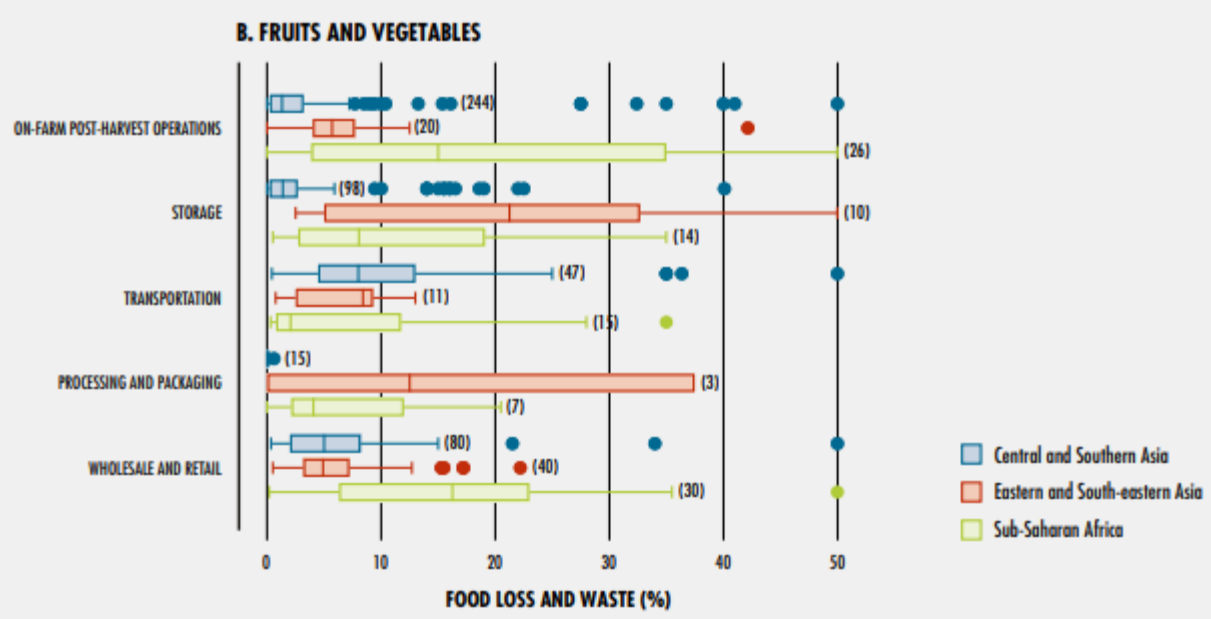

Figure 4. Range of reported food loss and waste percentages for fruits and vegetables by supply chain stage, 2000-2017 The number of observations is shown in brackets. The dates, 2000–2017, refer to when the measurements were taken; however, the date of publication was used if the study dates were not available or were unclear (FAO, 2019).

Trends

In 2050, the global average FV availability is predicted to vary between 608 to 862 grams per person per day, depending on different socio-economic scenarios (Mason-D'Croz *et al.*, 2019). Nevertheless, numerous low-income countries in Asia, the Pacific and sub-Saharan Africa are expected to fail to supply at least 400g per capita per day in 2050 (Mason-D'Croz *et al.*, 2019). Predicted figures in sub-Saharan Africa are particularly low and, independent of different socio-economic scenarios, do not meet the 400g threshold. When taking a 33 percent (high estimate) food waste into account, figures look even less positive, as only 19 countries would meet the 400g availability threshold in 2050, compared to 60 countries that would fail to meet it (Mason-D'Croz *et al.*, 2019), see Figure 5.

While useful in indicating food supply, the Mason D'Croz and Siegel studies are limited by its use of Food Balance Sheets (FBS) data, which only consider formal agriculture and do not include home gardens or the harvesting of wild and indigenous crops (Siegel *et al.*, 2014a; Mason-D'Croz *et al.*, 2019). This may lead to an underestimation of the FV available for consumption, but Del Gobbo et al. observe an overestimation of 75 percent for vegetables consumption when comparing FBS data with individual-based dietary surveys from the Global Dietary Database (Del Gobbo *et al.*, 2015). The supply gap presented might thus be larger than expected.

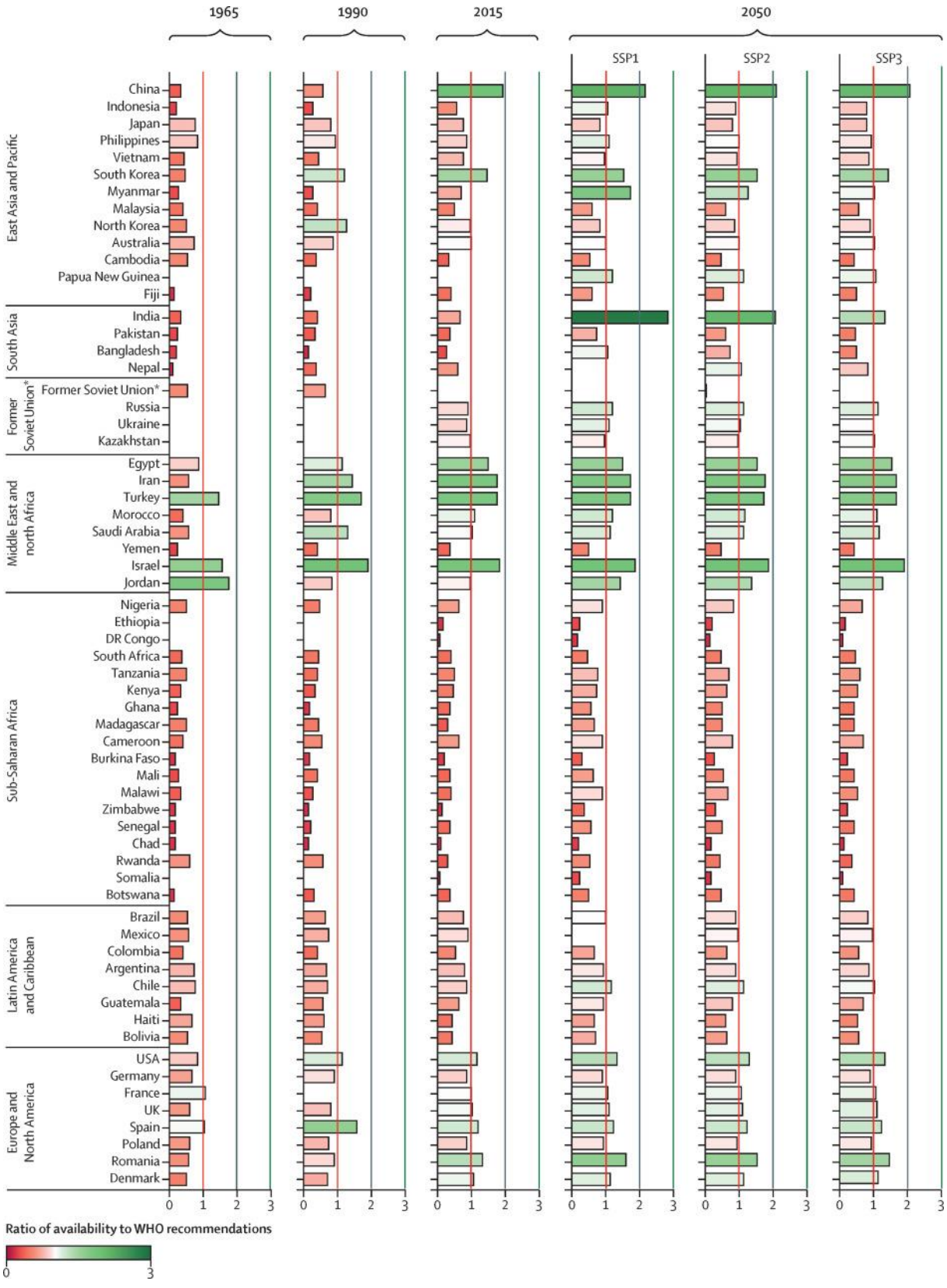

Figure 5. Countries ratios of fruits and vegetables availability to WHO minimum recommendation (400g). Copied from Mason D'Croz et al (Mason-D'Croz *et al.*, 2019). SSP= Shared Socioeconomic Pathway: "*SSP 1 is the most optimistic scenario envisioning a more sustainable development pathway with a global population by 2050 of 8·5 billion people with per-capita gross domestic product (GDP) of US$34 000; SSP 2 is a middle-of-the-road scenario, where global population grows to 9·2 billion people with per-capita GDP of $25 000; and SSP 3 is the most pessimistic scenario with global population reaching nearly 10 billion people with a per-capita GDP of $18 000*" (Mason-D'Croz *et al.*, 2019).

Quality, Diversity, Safety

Although FV are widely promoted for their micronutrient content, it is unknown how much the current FV supply contributes to micronutrient adequacy in LMIC. Arsenault et al. assessed adequacy of supplies through FBS data. Estimates suggest that adequacy of vitamin A and C could be met by increasing production of crops dense in these nutrients (Arsenault, Hijmans and Brown, 2015). Some micronutrient gaps, however, would probably have to be met by other means like supplementation (Arsenault, Hijmans and Brown, 2015).

FV are perishable crops which decrease in quality easily as they travel through the value chain. Different factors in the value chain have an impact on the quality of FV. While nutrient content in the soil can already influence the nutrient content in the crop (de Valença and Bake, 2016), choosing which variety to produce can also make a large difference in terms of nutritional content. Beyond the farm, while HIC have well-developed cold chains, this is often not the case in LMIC. During storage, transport, and retail, fresh FV are exposed to heat and bruising, impacting the shelf life and nutritional quality.

6.2 Food environment and consumer behaviour

Low FV intake among poorer consumers is thought to be mainly due to a combination of low availability, access, and acceptance (Global Panel on Agriculture and Food Systems for Nutrition, 2016), and is thus largely influenced by the food environment. Within the food system, the food environment is the dimension where the consumer interacts with the food system and its actors. While different definitions exist, we follow the Agriculture, Nutrition, and Health (ANH) Academy framework as shown in Figure 6 (ANH Academy, 2017), which distinguishes the external and personal domain within the food environment. In this section, we elaborate on those aspects which impact FV consumption.

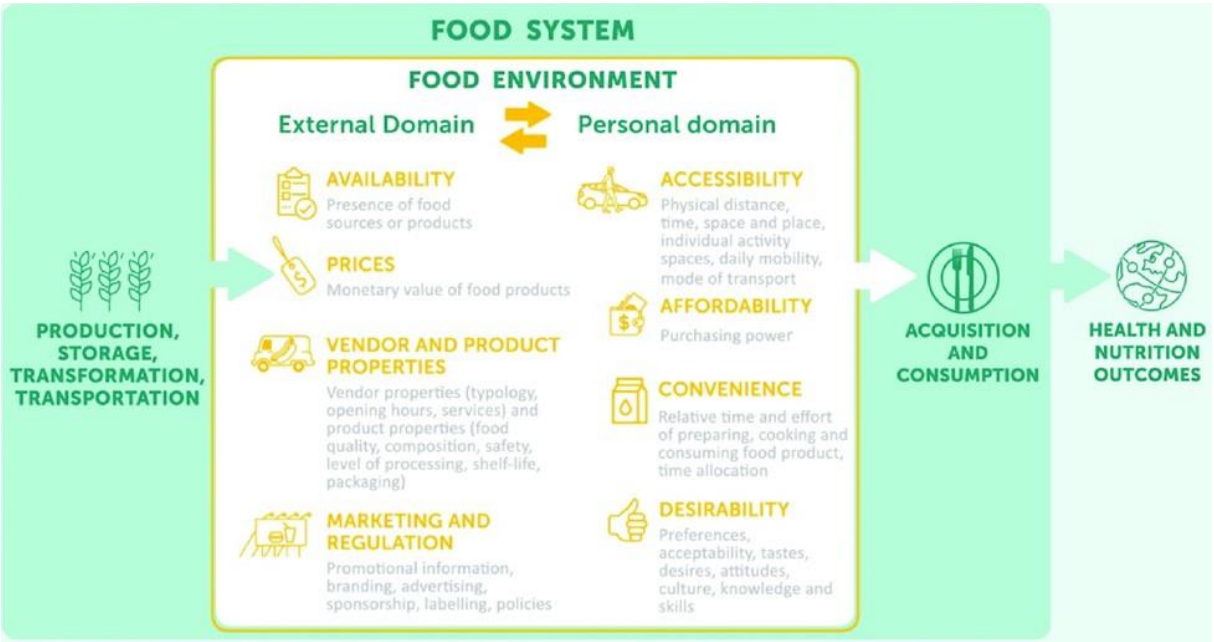

Figure 6. The ANH-FEWG food environment conceptual framework (ANH Academy, 2017))

External food environment

Availability

The ANH Academy Food Environment Framework distinguishes between 'availability' and 'accessibility,' where availability refers to whether or not a vendor or product is present within a given context (ANH Academy, 2017). As noted under Section 6.1, supply of FV is insufficient to meet WHO recommendations in LMIC. Next to low availability in terms of quantity, diversity of available FV for sale in LMIC is also

observed to be lower than in high-income countries, with rural areas being worse off than urban (Miller *et al.*, 2016).

Seasonality is an important determinant of availability of FV, as most species are not available for consumption throughout the whole year in LMIC. Although the impact of seasons on FV availability and consumption is often assumed, this has not been studied widely across LMIC. Nevertheless, seasonal availability can be a determinant in nutritional status throughout the year, documented in studies on the availability of beta carotene-rich foods and vitamin A intake in studies in Burkina Faso, South Africa and Hawaii (Meldrum *et al.*, 2019). Seasonal scarcity or abundance can also influence food price, discussed below, and thus consumption. Data on consumers experiencing limited availability of FV and the association with consumption (quantity, diversity etc) are lacking.

Prices

The proportion of individuals meeting the 400g per day WHO recommendation increases as the country's FAO food price index (FPI; indicating greater stability of food prices) declines (Frank *et al.*, 2019). The impact of food price on FV consumption is estimated to be highest in low-income countries, where a price increase of 10 percent for FV predicts a reduction in consumption of 7.2 percent, compared to 6.5 percent in middle-income countries and 5.3 percent in high-income countries (Cornelsen *et al.*, 2015). Food price fluctuations in other food groups could also impact consumption of FV, as household budget is limited. When food prices go up, fruits, vegetables, and animal source foods are the first foods to be dropped from the diet, or to be consumed in smaller amounts (Ruel *et al.*, 2010). However, a 10 percent increase in cereal prices is associated with a small but significant (0.7 percent) increase in FV consumption in low-income countries (Cornelsen *et al.*, 2015), possibly indicating a likelihood of limited substitution, which could especially be explained as roots and legumes were included in the group of vegetables.

Vendor and product properties

Supermarket penetration is increasing worldwide, including in LMIC, yet market-based vendors are still the primary food source for the majority of people worldwide (Turner *et al.*, 2018). As a result, when studying food environments in LMIC, it is important to recognise the co-existence of formal and informal markets as well as non-market-based food sources, such as own production, wild food harvest, and food transfers including gifts (Turner *et al.*, 2018).

There is strong evidence that despite the rising number of supermarkets worldwide, traditional markets are notably still the dominant source of FV. As shown in Figure 7, estimates suggest that 90 percent of FV are sourced in traditional markets in Kenya, Zambia, and Nicaragua (Gómez and Ricketts, 2013). Even in countries such as Thailand or Mexico, which have higher rates of supermarket penetration, the primary source for FV remains the traditional market (Gómez and Ricketts, 2013).

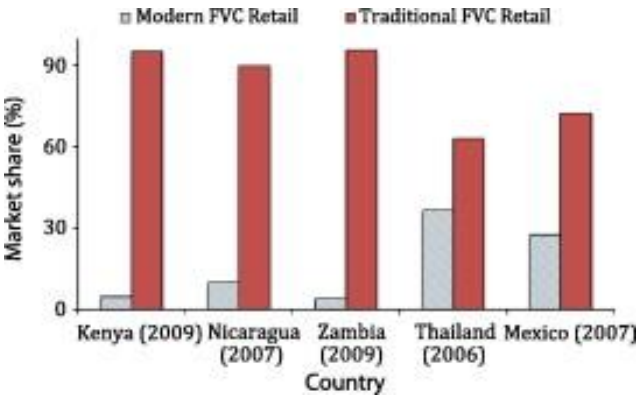

Figure 7. Fresh fruits and vegetables market share of modern and traditional FVC (Food Value Chain) retail sales (Gómez and Ricketts, 2013).

Marketing and regulation/ Promotion, advertising and information

Commercial campaigns for FV are not thought to be common in LMIC, although data is lacking. In high-income countries, FV are underpromoted compared to other (processed) foods in commercial campaigns (Chandon, 2014). While promotion can have an effect on consumption of foods, the FV sector in LMIC, usually made up of farmers selling directly to markets, does not possess a marketing budget like international companies. In the absence of such capacity, national policies can be a tool in LMIC to provide information on a healthy diet and the consumption of FV. Thirty-one percent of health and nutrition policies in LMIC include promoting FV consumption as a goal (Lachat *et al.*, 2013). Promotion of school gardening, home gardening, and urban agriculture are the main actions included to ensure availability and accessibility of FV in those countries (Lachat *et al.*, 2013). The enforcement of the policies in the form of promotion is organized by government bodies, e.g. through health counselling or communication about food-based dietary guidelines. Food-based dietary guidelines are not widely available in all LMIC, however, as noted earlier in Section 4.1. Health counselling is only available for limited segments of the population, primarily taking place around pregnancy and childbirth, with limited opportunity for sharing information on healthy diets (Kavle and Landry, 2018), let alone FV consumption for the general population.

Personal food environment

Physical access (proximity)

Accessibility factors such as physical distance, mode of transport, and time to reach points of sale are important factors in the food environment (ANH Academy, 2017), eventually leading to purchase and consumption. Spatial distribution of small points of sale for vegetables and proximity to them have been shown to be positive determinants of vegetables intake in the US (Nicholas Bodor *et al.*, no date). Other studies found price, rather than physical proximity of supermarkets, to be associated with higher FV intake in the US (Aggarwal *et al.*, 2014). Limited evidence on this subject is available from LMIC, though physical access might play a different role in LMIC as cold storage facilities (refrigeration and electricity) and ownership of transport is less common for low-income consumers. In urban areas, shopping outside the residential area, but closer to the workplace, is common, as has been observed in South African townships, for example (Ligthelm, 2008). Further research is needed to understand the association between physical determinants in the personal food environment and FV intake in LMIC, both in urban and rural areas, where market access and shopping patterns differ.

Markets are not the only way consumers access food in LMIC, however. Street food consumption provides adults in LMIC 13 to 50 percent of their energy (Steyn *et al.*, 2014). With such a large proportion of foods consumed outside the home, street foods are an important vehicle for FV consumption. The proportion of fruits and vegetables consumed out of home is unknown in LMIC, however, and might differ for urban and rural populations as urbanization is thought to drive out-of-home consumption (Steyn *et al.*, 2014).

Economic access - Affordability

Income and education are associated with FV consumption, as noted in Section 5.1. Gender, age and urbanization are not universal predictors of FV consumption in the adult population, although this can differ from country to country.

As reported throughout many studies, the proportion of household income spent on food is higher for low-income households than for high-income households. For example, Miller et al. find the percentage of monthly household income spent on food to be higher in those countries with a lower gross national income ranking (Miller *et al.*, 2016). Zooming in on the price of vegetables, they found the absolute cost of one serving of vegetables to be cheapest in low-income countries. In contrast, the absolute cost of fruits was highest in low-income countries (Miller *et al.*, 2016). However when looking into the cost of one serving relative to income, it is observed that the cost of a portion of vegetables is 19 times higher in low-income countries than in high-income countries (Miller *et al.*, 2016). For fruits, the cost is 50

times higher. Subsequently, a large proportion (57 percent) of the population in low-income countries cannot afford the recommended five servings of FV per day (Miller *et al.*, 2016).

Stark differences in affordability of FV are seen between rural and urban communities, especially in low-income countries, where the cost relative to income and the proportion of those unable to afford five servings per day is even higher in rural communities (Miller *et al.*, 2016). Similar findings are observed for the EAT-Lancet diet, which includes large amounts of FV, and is estimated to be unaffordable for most low-income people worldwide (Hirvonen *et al.*, 2019). The FV food group accounts for the highest cost (31.2 percent) globally among the foods included in the EAT-Lancet diet (Hirvonen *et al.*, 2019).

Convenience

Low-income consumers in LMIC have a high workload, which limits their time available for food acquisition and preparation. Women's time is particularly highly constrained worldwide (Herforth and Ahmed, 2015). As a result, for some, convenience may be more important than the monetary cost of food (Herforth and Ahmed, 2015). For example, in urban Nigeria, convenience was a main barrier for vegetables intake (Raaijmakers *et al.*, 2018), while research in rural Vietnam shows that 75 percent of the respondents indicated that choices for shopping sites are convenience-driven (Wertheim-Heck, Spaargaren and Vellema, 2014). How convenience impacts FV acquisition and consumption in LMIC has not been studied widely and need further study.

Desirability

The interaction between food preferences and the environment in which those preferences are formed is thought to play a central role in determining food choice (Hawkes *et al.*, 2015). While the key driver for eating is considered hunger, food choices are not determined solely by physiological or nutritional needs (EUFIC, 2006). Factors determining food choice include:

- Biological determinants such as hunger, appetite, and taste
- Economic determinants such as cost, income, and availability
- Physical determinants such as access, education, skills (e.g., cooking), and time
- Social determinants such as culture, family, peers, and meal patterns
- Psychological determinants such as mood, stress, and guilt
- Attitudes, beliefs, and knowledge about food

The above list is not exhaustive (EUFIC, 2006), and might especially not give full coverage to the factors determining food choice in LMIC. While determinants of FV choice have been studied widely in HIC (Kamphuis *et al.*, 2006; Guillaumie, Godin and Vézina-Im, 2010; Di Noia and Byrd-Bredbenner, 2014), evidence from LMIC is more scarce (Ruel, Minot and Smith, 2005). As the food environment looks very different in LMIC compared to HIC, it is necessary to also study determinants in LMIC. We will elaborate on the social and psychological determinants, as well as attitudes, beliefs, and knowledge, here.

Gender dynamics are thought to play a major role in food choice in LMIC, where women are the main caretakers and responsible for most of the food preparation. However, decision making around what to grow, trade, purchase and cook is influenced by other household members, including the (often) male household head. Moreover, FV preparation in the household does not guarantee all members of the household are consuming them. Intra-household distribution of food can depend on gender roles and cause women to eat less or lower-quality food (Harris-Fry *et al.*, 2017; Coates *et al.*, 2018). Gender roles and intra-household distribution of FV consumption are not known and need to be studied at the local level to understand these dynamics.

As hunger is the main driver of food choice, many diets in LMIC include a large staple food component, such as rice. This could cause vegetables and fruits to play a minor role in the diet in LMIC. Vegetables might even be seen as a condiment and not as a major constituent of a meal, as for example in Nigeria, tomatoes and onions were considered spices, rather than vegetables (Raaijmakers *et al.*, 2018). Research on food motives regarding vegetables consumption in urban Nigeria shows motives Health, Mood, Natural and Weight control to be considered the most important motives in making food choices, while ethical concern was considered least important (Raaijmakers *et al.*, 2018). More research is needed

on how choices are made, including the perception of the role of FV in the diet in LMIC and how this perception impacts consumption.

Beliefs can encourage or reduce consumption of FV. Food taboos are handed over from one generation to another, along with other cultural elements (Iradukunda, 2019), and are especially found in LMIC around pregnancy, lactation and illness. Food taboos around pregnancy can involve limiting consumption of certain FV (Iradukunda, 2019). Another belief present around FV is the perception of them as a "poor man's crop." This is especially the case for indigenous vegetables, which are sometimes considered a "low status" food (Keatinge *et al.*, 2015)(Keding *et al.*, 2017). The magnitude of the occurrence of these beliefs and their impact on (indigenous) FV consumption in LMIC is unknown, but important for future study.

There are high levels of concern about food safety in LMIC (Grace, 2015). If vegetables regularly contain pathogens or exceed maximum pesticide residue limits, consumers begin to associate fresh vegetables with health risks rather than health benefits and reduce consumption (Schreinemachers, Simmons and Wopereis, 2018). A study in Vietnam shows food safety to be the most important factor in food choice (Meldrum *et al.*, 2019). Food safety concerns, their relation to actual contamination, and the impact on FV consumption needs further study in LMIC. Similarly, results from HIC show an association between knowledge and consumption of FV (Guillaumie, Godin and Vézina-Im, 2010), but reviews from LMIC are lacking and needed to confirm these findings.

7. Sustainability

Dietary choices play a major role in human health, but also in environmental sustainability (Clark, Hill and Tilman, 2018). The amount of vegetables and fruits in the diet and the interchangeability with other food groups can determine the footprint of the diet. Plant-based foods, including FV, cause fewer adverse environmental effects than animal source foods across various environmental indicators, see Figure 8 (Willett *et al.*, 2019).

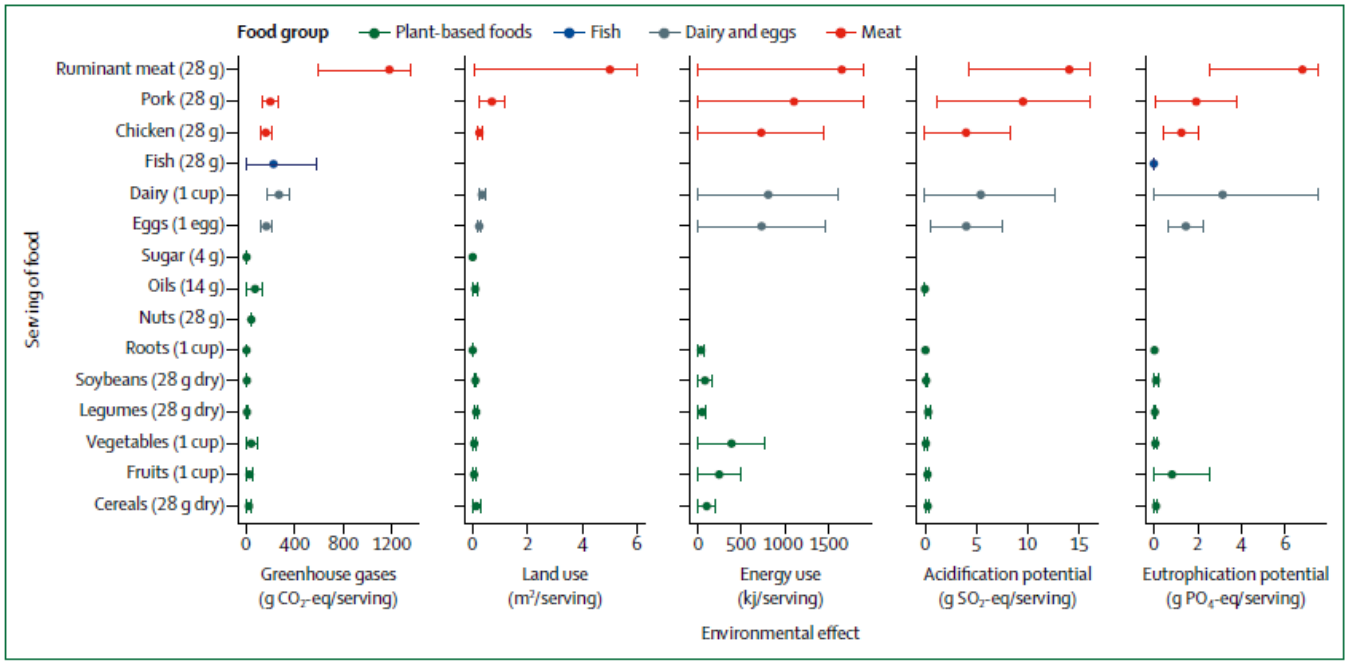

Figure 8. Environmental effects per serving of food produced (Willett *et al.*, 2019). *Bars are mean (SD). CO_2=carbon dioxide. Eq=equivalent. O_4=phosphate. SO_2=sulphur dioxide.*

The environmental effects of FV are determined by different aspects in the value chain, including amongst others input use, heated green houses, and transport. The health and environmental impacts can collide as FV are grown in greenhouses or imported by air (Michalský and Hooda, 2015).

While LMIC may have lower FV import rates than HIC, they do export increasing amounts of FV (Figure 9) (Feyaerts, Van den Broeck and Maertens, 2020). While this likely has some local environmental consequences, the global environmental effect of import and export of FV in LMIC is unknown.

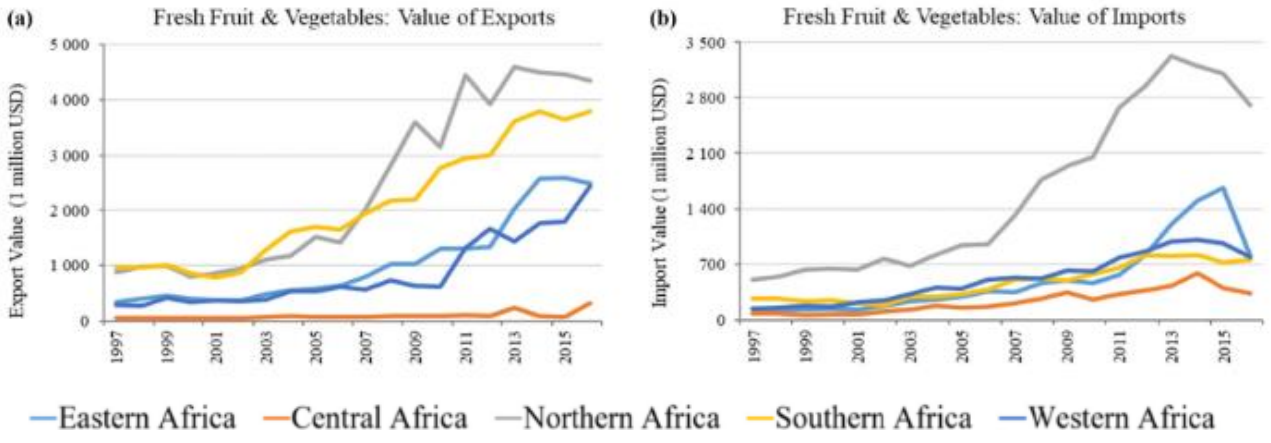

Figure 9. Evolution of exports and imports in real value (1 million USD) by crop category and subregion over the period 1997-2016 (Feyaerts, Van den Broeck and Maertens, 2020).

Despite favorable weather conditions for FV production in LMIC, the environmental impact of that production can be higher than in Europe, as shown by Perrin et al., who studied the environmental impact of urban tomato garden systems in Benin (Perrin *et al.*, 2017). The impacts of urban garden systems is estimated to be 10 times higher than for tomato production in Europe (Perrin *et al.*, 2017). Factors contributing to this were fuel consumption for irrigation, organic fertilizer use, and insecticide application (Perrin *et al.*, 2017). Environmental impacts of FV value chains should be studied in LMIC to better understand the contributing factors.

Increasing the intake of vegetables, fruits and nuts to national dietary recommendations will likely result in an increase in greenhouse gas (GHG) emissions, eutrophication and land use for most countries (Behrens *et al.*, 2017). Figure 10 shows the absolute environmental impacts of average diets for different national income groups per person (A) and the differences in environmental impacts between average and recommended diets per person (B) (Behrens *et al.*, 2017). However, if increased FV consumption replaces other food groups, the net impact can still be significantly lower in comparison with the current environmental impact. For example, 20 servings of vegetables still have less GHG emissions than one serving of beef (Tilman and Clark, 2014).

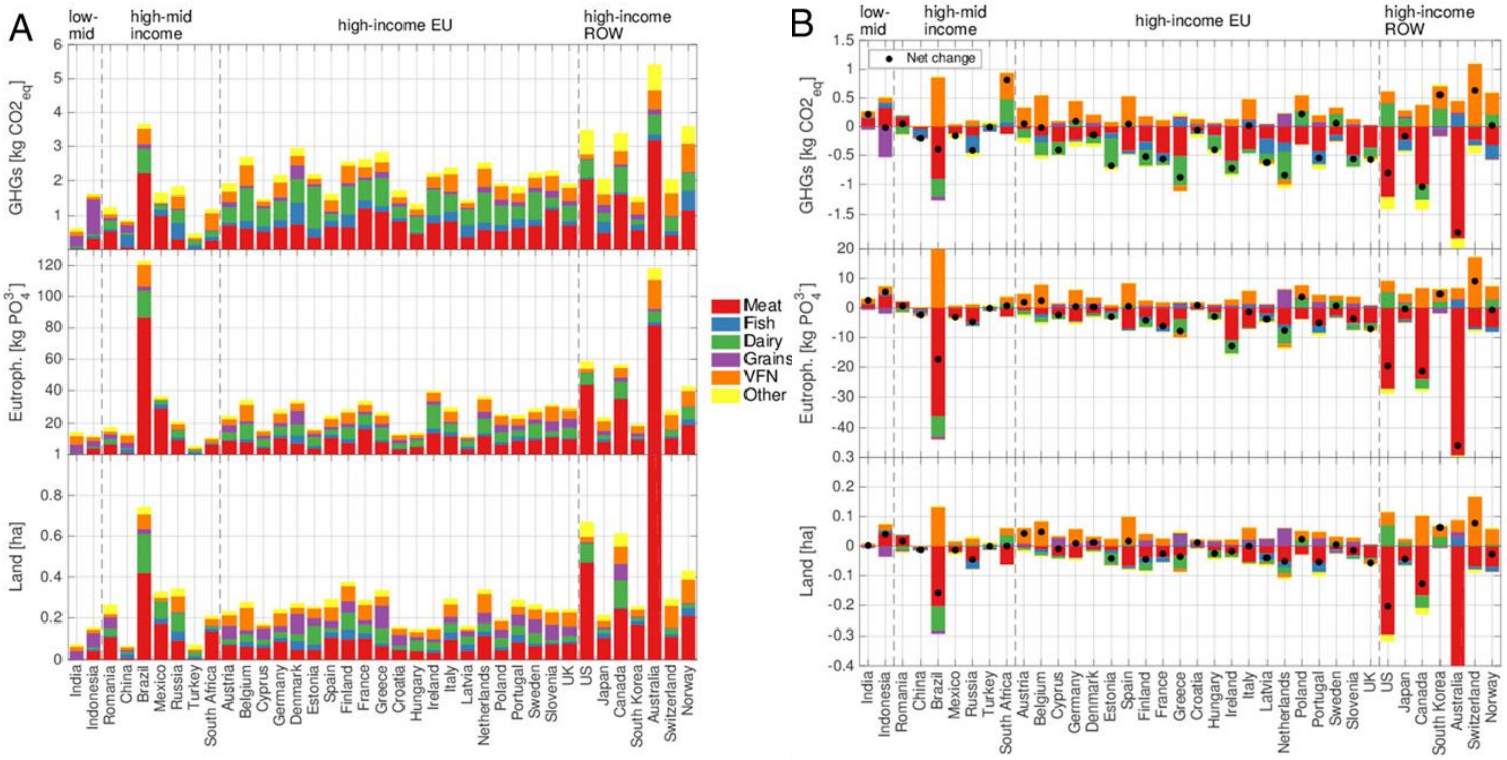

Figure 10. (A) Absolute environmental impacts of average diets for different national income groups per person. (B) Differences in environmental impacts between average and recommended diets per person. Net change and change by food group are shown. VFN= Vegetables, Fruits and Nuts (Behrens *et al.*, 2017). Both panels give GHG and eutrophication emissions in terms of per day and land use in ongoing, yearly requirement. Land use in Australia has been truncated in both panels for ease of visualization (in A, total Australian land use is 3.3 ha; in B the change is a reduction of 1.0 ha).

To study the sustainability of the diet, and FV in particular, it is important to understand the environmental impact of different crops. In HIC, a large part of the diet's environmental impact comes from animal source foods, but this is not the case in most LMIC. Diets in LMIC have a lower environmental impact than HIC diets to begin with, and more animal source foods should actually be consumed to fulfill nutrient requirements (Adesogan *et al.*, 2019). An increase in FV consumption will likely not lead to a reduction of "high-impact" food groups, as the consumption of those food groups in LMIC is already low. As diets are changing worldwide due to the nutrition transition, it is important to

monitor the sustainability of diets worldwide and in LMIC related to FV consumption. Fruits and vegetables value chains in LMIC should be studied to understand their environmental impact and how this can be improved.

Food-based dietary guidelines

As noted in Section 4, FBDGs are an important tool for providing nutritional advice. Only four countries worldwide mention sustainability factors in their FBDG, and none of them are LMIC (Behrens *et al.*, 2017). The EAT-Lancet Commission recommends a range of 100 to 300g of fruits and 200 to 600g of vegetables per day to ensure human health, taking into account the planetary boundaries for food production to ensure a stable earth system (Willett *et al.*, 2019). These boundaries take the safe operating space into account to ensure both human health and environmental sustainability (Willett *et al.*, 2019), and are sufficient to meet recommendations. However, the applicability of this diet has been questioned as it has been estimated to be unaffordable for LMIC consumers (Hirvonen *et al.*, 2019). Sustainability aspects should be part of FBDG promotion of FV consumption, but need to take local food system considerations into account.

8. Implementation and research gaps related to fruits and vegetables consumption worldwide and in LMIC

Guided by the High Level Panel of Experts (HLPE) framework of food systems and healthy diets, the comprehensive literature review resulted in a wealth of information on the fruits and vegetables consumption worldwide and especially in low- and middle-income countries related to the drivers, food system components and food system outcomes. This review also showed the implementation and research gaps that will be highlighted in this section, arranged per chapter.

Chapter 3. Health and Nutrition

1. The magnitude of foodborne disease caused by FV in LMIC is not known across countries. This relates to Section 6.14 and can limit consumption.
2. Upper threshold based on dose-response relationship for NCD's ranges from 300-800g. Lack of clarity exists if "the more the better" holds and if thresholds are applicable in LMIC as evidence comes from HIC and is based on NCDs rather than micronutrient deficiencies. See also Section 4: Recommendations worldwide and in LMIC.
3. Data on cooking and processing habits and the consequences on the quality of FV in LMIC is lacking and needs further investigation.
4. Although FV are known to be a rich source of micronutrients, the contribution of this food group to intake and adequacy of micronutrients in the diet in LMIC is largely unstudied to our knowledge.
5. Even though fibre is considered an important nutrient, global and LMIC data on fibre consumption and the contribution of FV to it are missing.
6. Although the health burden of micronutrient deficiencies is studied widely, the contribution of inadequate FV intake to the health burden of micronutrients deficiencies is unknown to our knowledge.
7. Considering the high prevalence of micronutrient deficiencies in LMIC and the mitigating effect of fruits and vegetables consumption, the association between consumption and disease or all-cause mortality is possibly different in LMIC compared to HIC. It is not known whether and how the underlying highly prevalent micronutrient deficiencies and undernutrition may affect the association of FV intake with NCDs on the one hand, and on the other, limiting the applicability of the existing evidence in LMIC.

Chapter 4. Recommendations worldwide and in LMIC

1. Currently, scientists use different measures, and inclusion of foods in food groups are not standardised. It is advised to come up with international standards to improve comparability of the literature in the future.
2. No differentiation between cooked and raw is made in the 400g daily consumption recommendation by WHO, making it unclear if the recommendation is the amount that goes into a dish raw or if it is the final weight after cooking. The recommended amount and the differentiation between raw and cooked depends on the epidemiological evidence that feeds into the recommendation. As studies do not specify the quantities as cooked, raw, or a mix, conclusions on the quantities to be consumed remain vague. As current dietary guidelines do not differentiate between raw and cooked vegetables intake, and guidelines are mostly based on European and US data, the recommendations might not apply to other regions in the world (Miller *et al.*, 2017).
3. It is uncertain if we are using the right methods to estimate the recommended quantity of FV as there are many different recommendations, and evidence from epidemiological studies ranges from 300-800g/d (see Section 3.5). As the WHO recommendation is from 2003 and refers to even earlier recommendations (WHO/FAO, 2003b), recent evidence is not included. Recommendations for different age groups are especially lacking.

4. Evidence on the utilization of FBDG by the general public is scarce (Brown *et al.*, 2011), and the effect of FBDG on FV consumption is unstudied to our knowledge.
5. In Africa, the number of countries with FBDG is particularly limited: only seven out of 54 African countries have FBDG (Herforth *et al.*, 2019). Efforts should be made to develop FBDGs for every country.
6. Even though the method of preparation greatly impacts the nutritional quality of FV, WHO dietary recommendations do not get specific on the form of consumption. Although the magnitude and consequences of overcooking are not studied widely, changing consumer behavior around cooking habits should be an important aspect of nutrition programs and guidelines to decrease nutrient loss and improve nutritional status.

Chapter 5. Current consumption patterns worldwide and in LMIC

1. There is a need for disaggregated FV intake data for wealth quintiles and income levels across LMIC.
2. Further study is necessary to understand FV consumption patterns in urban and rural areas in LMIC.
3. Global demographic trends such as rising incomes and rates of urbanization should be further studied to predict effects on the demand for FV.
4. Global data on consumption of FV in children age two to 13 years does not exist.
5. Data on the quality of produce consumed globally, and particularly in LMIC, is limited. We are unaware if the FV consumed have been peeled, cooked, processed, etc. Nutrient content can thus differ depending on local practices, however, we are not in the possession of this consumption data.
6. Reports from the data sources presented in Section 5.1 do not detail species consumed. This is important for future interventions and policy.
7. Availability of global datasets containing representative and recent country estimates of dietary intake data is limited. The limited availability of regularly updated data constrains the interpretation and monitoring possibilities of FV intake globally, in LMIC and in-country.
8. Underutilised local species of FV need further nutritional analysis and attention as they can be rich sources of nutrients.

Chapter 6. Determinants of consumption in the food system worldwide and in LMIC

1. No "general" reviews were found on determinants of FV consumption in adults in LMIC.
2. Although home production is thought to be an important source of FV in LMIC, it is unknown, to our knowledge, what percentage of produce is sourced from home gardens or own production. Differences in sources of acquisition (own production vs sale) are expected for urban and rural consumers, but data here is also lacking.
3. It is unknown how much the current supply of FV contributes to micronutrient adequacy in LMIC.
4. During storage, transport, and retail, fresh FV are exposed to heat and bruising, impacting the shelf life and nutritional quality. High levels of this kind of impact can be an important determinant of availability.
5. As noted in Section 6.1, the supply of FV in LMIC is insufficient to meet WHO recommendations. Next to low availability, diversity of FV available for sale is also observed to be lower than in high-income countries, with rural areas being worse off than urban (Miller *et al.*, 2016).
6. Although the impact of seasons on FV availability and consumption is often assumed, this has not been studied widely across LMIC to our knowledge.
7. Data on the prevalence of consumers experiencing limited availability of FV and the association with consumption (quantity, diversity etc.) is unknown.

8. The association between physical determinants in the personal food environment and FV intake in LMIC, both in urban and rural areas where market access and shopping patterns differ, needs to be studied.
9. The proportion of FV consumed outside the home is unknown and might differ for urban and rural populations. As out-of-home consumption is common in LMIC, this is an important research area.
10. How convenience impacts FV acquisition and consumption in LMIC has not been studied widely.
11. While determinants of choice for FV have been studied widely in HIC, evidence from LMIC is more scarce. As the food environment looks very different in LMIC compared to HIC, it is necessary to study determinants in LMIC.
12. Gender roles and intra-household distribution of FV consumption need to be studied to understand these dynamics at the local level.
13. The magnitude and frequency of the occurrence of food taboos and beliefs and impacts on (indigenous) FV consumption in LMIC is unknown.
14. Food safety concerns, their relation to actual contamination, and the impact on FV consumption in LMIC needs to be studied. Research is needed on the perception of the role of FV in the diet in LMIC and how this perception impacts consumption.
15. Results from HIC show an association between knowledge and consumption of FV, but reviews from LMIC are lacking to confirm these findings in those countries.

Chapter 7. Sustainability

1. The environmental effect of import and export of FV in LMIC is unknown to our knowledge.
2. Environmental impacts of FV value chains in LMIC should be studied to understand the contributing factors.
3. As diets are changing worldwide due to the nutrition transition, it is important to monitor the sustainability of diets worldwide, and in LMIC in particular, related to FV consumption.
4. Different FV value chains in LMIC should be studied to understand their environmental impact and how this can be improved.
5. To study the sustainability of the diet, and FV in particular, it is important to understand the environmental impact of different crops.
6. Sustainability aspects should be part of FBDG promoting FV but need to take local food system aspects in LMIC into account.

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