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Global Food Security

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

The association of dimensions of fruit and vegetable access in the retail food environment with consumption; a systematic review

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ARTICLE INFO

Keywords:

Retail food environment
Fruit
Vegetable
Diet
Access
Consumption
Adults

ABSTRACT

The consumption of fruit and vegetables (F&V) is important for human health to protect against non-communicable disease and micronutrient deficiency. Increasing consumption of F&V may also benefit planetary health if these foods are substituted for foods with higher environmental footprints such as red meat or dairy. The retail food environment (RFE) is an influential junction between the food system and individual diets as it drives access to F&V through external (physical access) and personal (availability, affordability, acceptability) domains. We performed a systematic search of six literature databases (January 2021) for studies assessing access to F&V in the RFE and its association with F&V consumption in adults in high- and upper-middle income countries. 36 studies were identified and categorised by dimensions of food access – accessibility, affordability, acceptability, availability and accommodation. More than half of the studies ($n = 20$) were based in the USA. F&V accessibility was the most commonly reported dimension ($n = 29$); no study reported on accommodation. 6 studies were rated to be high quality. A positive association of increased availability of F&V options in the RFE with intake was identified in 9 of 15 studies. Associations in both acceptability and accessibility dimensions were inconsistent. No association was observed between F&V affordability and consumption although available data were limited. Many challenges exist to building a robust evidence base within food environment research including conceptual, definitional and methodological heterogeneity and measurement standardisation. Future food policies should consider multi-dimensional interventions to promote access to F&V in the RFE across all domains.

1. Introduction

Fruit and vegetables (F&V) are an important component of diets due to the multitude of health benefits and potential to reduce the risk of non-communicable diseases (WHO, 2016). The EAT-Lancet Commission highlights the general need to reduce intake of red meat and animal sourced foods in higher-income countries and that a diet high in plant-based foods may be beneficial for both human and planetary health (Willett et al., 2019). Emerging analyses of dietary targets indicate that global F&V intake is required to more than double whilst intake of ‘less healthy’ high sugar, calorie-dense foods must halve to prevent a possible 11 million annual adult deaths (Willett et al., 2019). Global F&V intake has been classified as sub-optimal as F&V consumption was approximately 150g/day less than the optimal threshold of 250g/d fruit; 360g/d vegetables (GBD 2017 Diet Collaborators, 2019). The WHO

recommend a minimum consumption of 400g/day of F&V to improve overall health and reduce risk of non-communicable disease. This global target has been estimated to save nearly 2.7 million lives annually; however many individuals in higher-income settings continue to have an inadequate intake (WHO, 2016). This may be due to poor availability of F&V; as only half the global population met the WHO minimum target in 2015 for F&V availability (Mason-D’Cruz et al., 2019). Future F&V projections, assuming food waste of 33% and current socio-economic trends, indicate an average global shortage and suggest 1.5 billion people will have an inadequate supply by 2050 compared to a 0% waste scenario (Mason-D’Cruz et al., 2019). Under a more optimistic waste scenario of 15%, 4 regions (Europe, Former Soviet Union, Latin America & Caribbean and Sub-Saharan Africa) remain below recommended levels by 2050. Furthermore, on average as global F&V prices increase relative individual consumption decreases (Miller et al., 2016). There are key

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<https://doi.org/10.1016/j.gfs.2021.100528>

Received 6 August 2020; Received in revised form 29 January 2021; Accepted 4 March 2021

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social, economic and environmental predictors of F&V consumption, individual dietary behaviours and overall health.

Many individual factors are involved in dietary intake including personal choice, health status and income but external environmental factors are also important (Kearney, 2010). The food environment is classified as the “collective physical, economic, policy and sociocultural surroundings, opportunities and conditions that influence people’s food and beverage choices and nutritional status” (Hawkesworth et al., 2017). Exposure to a limited food environment may amplify individual and community risk factors associated with poor diets (Macintyre, 2007). Almost all consumers interact with the Retail Food Environment (RFE) making it a conceptually important link for accessing healthy diets and optimising health (Turner et al., 2019). Food access in the RFE is described as “a multifaceted determinant of food acquisition” and is categorised into dimensions of access (Turner et al., 2018). The specified dimensions are *accessibility (location and distance to food outlets)*, *affordability (food price and consumer perception of worth)*, *availability (adequacy of supply of food outlets or presence of food in outlet)*, *acceptability (consumer’s personal attitudes to attributes of produce)* and *accommodation (community requirements; opening hours, payment method)* (Caspi et al., 2012b).

Relationships between food access in the RFE and dietary outcomes are inconsistent. A review of the local food environment and obesity identified no association (Cobb et al., 2015). However, links have been made between F&V consumption and multiple dimensions of the RFE (Caspi et al., 2012b). The availability of healthy foods in various food outlets has been associated with improved diet quality, and increased price and reduced availability of F&V was associated with decreased intake (Black and Macinko, 2008; Miller et al., 2016; Rose et al., 2009). The RFE may therefore be a pivotal driver of F&V access and consumption. A systematic review published in 2012 analysing the whole local food environment and multiple dietary components was the first to review the RFE by “dimensions of access”, concluding a tentative link but called for further RFE research (Caspi et al., 2012b). Additionally, reviews have analysed the RFE and child dietary outcomes highlighting moderate associations between some dimensions of access; availability (Yang et al., 2020) and accessibility (da Costa Peres et al., 2020). No reviews to-date have analysed F&V access in the RFE specifically in higher- and upper-middle income settings and this review aims to build on previous evidence (Caspi et al., 2012b).

Here we report a systematic review of the published evidence assessing the dimensions of access to F&V in the RFE and their association with consumption of F&V among adults in high- and upper-middle-income countries. We chose to limit the review setting to capture the socio-economic, environmental and cultural contexts; and aimed to examine how multiple access dimensions influence consumption in more developed RFEs as non-retail availability of F&V is a key component of LMIC consumption. We also sought to review the methodologies used to capture the RFE.

2. Methods

2.1. Search strategy

This review is aligned with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (supplementary material S6). A literature search was conducted in January 2021 to identify all studies that assessed at least one dimension of F&V access in the RFE in a higher- or upper-middle-income country with at least one F&V consumption outcome measure. The search sought to identify papers published between the beginning of 2012 to January 2021 (January 13, 2021 to update the evidence from a previous systematic review published in 2012 (Caspi et al., 2012b)). The following six electronic databases were searched systematically: Global Health, PsychINFO, EMBASE, PubMed, Scopus and Web of Science as well as Google Scholar. The reference sections of identified articles were hand-searched for

additional relevant papers. 2 authors were contacted if the full text was not available; both responded with texts. The strategy was first developed in Scopus and adjusted to the other databases (Table 1; full search strategy supplementary material S1).

2.2. Selection criteria

Titles and abstracts were screened by a single reviewer (GT). Inclusion and exclusion criteria were followed rigorously - full-text papers were checked by a second reviewer (RG).

The following inclusion criteria were followed during study selection for the review:

Population:

- Adults aged 18 years and older.

Setting:

- RFE defined as any food retail outlet, shop, supermarket or store that accommodates purchasing of produce
- Higher- and upper-middle income countries only as defined by the World Bank (World Bank, 2020).
- Single country studies.

Exposure:

- Access to F&V in the RFE
- Access defined under five dimensions of access: accessibility (location or distance of retail food outlets), affordability (price or perceived worth of produce), acceptability (consumer’s personal attitudes or perceptions of produce), availability (presence of produce), accommodation (measure of food outlet adaptation to local resident requirements). Further description of measures in supplementary material S2

Outcomes:

- Reported measures of intake or purchase of any fresh, frozen, canned, dried or 100% juiced F&V including potatoes and starchy tubers as typically situated within F&V section of RFE

Table 1

Summary of terms used in each database search – terms used were adapted for each specific database (supplementary material S1).

Theme	Search Terms
Food Environment	Food environment, retail food environment, supermarket*, superstore*, hypermarket, convenience store*, market, food mart, retail food store, corner store, grocery store, greengrocers, food store, food outlet, urban, local, shop, corner shop, co-op, department store, neighbourhood, community, foodscape, nutrition environment, store
Access	Availability, availab*, physical proximity, physical access, accessibility, access*, accessible, affordability, afford*, perceived cost, perceived price, price, value, proximity, convenience, distance, culture, accommodation, acceptability, acceptable, presence, cost, purchase, density, location, select, taste, perception
F&V	Fruit*, vegetable*, fruit and vegetable, veg, leafy, green, leafy green vegetables, berries, citrus*, root, salad, legumes, pulses, root vegetables, plants, plant-based, plant-based foods, healthy foods, fresh, frozen, canned, preserved, purchase, conserved
Intake	Consumption, intake, consumption of fruit and vegetable intake, consume, consumption of fruit and vegetable, fruit consumption, vegetable consumption, fruit and vegetable consumption, intake, purchase, consumed, increased intake, decreased intake, consumed fruit, consumed vegetable, consumed fruit
Setting	High-income setting, high-income country, upper-middle income, affluent setting (full country list included)
Population	Adults

- Published in English only
- Observational studies only

Relevant information extracted from the papers were as follows: study authors and publication year; sample population and study characteristics; data analysis methods; exposure and outcome validity measures; F&V access measures; F&V consumption and purchase data; confounding and adjusted variables; key study findings.

2.3. Study quality

Due to this review only identifying observational studies, the tool selected to measure study reporting quality was the “Methods for the development of NICE public-health Guidance” (NICE, 2006). Each study was assessed using the quality appraisal checklist for quantitative studies reporting correlations and associations. The checklist appraised internal and external validity through assessing the following components: participant characteristics, enrolment criteria, exposure variable definitions, outcome measures and analysis methods and each component was scored. Each criterion was provided with a quality score of either high, moderate or low quality and an average was taken to allocate a final quality rating (supplementary material S3).

2.4. Data analysis

Quantitative synthesis was not possible as the exposure and outcome measures were highly heterogeneous, therefore, a narrative synthesis was performed with extracted data being tabulated. Where possible outcome summary effect sizes were compared if similarities in access measures and consistencies of methods and data analysis could be identified. Multiple exposure measures were used in each study to measure the five domains of F&V access which are shown in Table 2. Outcome measures were F&V servings/day, number of F&V purchased, and independent fruit/vegetable variables. All key summary findings were mapped against specific dimensions of F&V access in the RFE to illustrate the relationship with F&V consumption.

3. Results

The initial database search identified 12130 citations. After the removal of duplicates and screening by title and abstract, 91 studies remained. Hand-searching of reference lists and other review papers identified an additional 1 paper for full text screening. Of the 91 potentially relevant studies, 56 were excluded during full text screening. A total of 36 papers reporting at least one measure of F&V access in the RFE and F&V consumption were included in the final review (Fig. 1). Of the 56 excluded papers, 26 failed to meet the exposure definition criteria, 10 were intervention, reviews or qualitative studies, 16 were not specific to the outcome of interest, 2 analysed specific population groups e.g., children and 2 focused on settings out of the scope of this review.

3.1. Study characteristics and methods

The 36 studies included in the review varied in setting, study sample size, sample characteristics, dimension of access measured, and exposure methods used (Table 2; full summary in supplementary material S4).

The measures used to capture F&V access in the included studies varied with some studies assessing access using a single dimension measure or multiple (Table 2). All papers in this review were cross-sectional in study design. Accessibility was the most frequently used measure (n = 29) and 13 studies measured multiple dimensions of access to the RFE. No studies chose to measure F&V access in the RFE by accommodation parameters. USA (n = 20) and Brazil (n = 5) had the highest number of national or regional studies. Studies conducted in UK

(n = 3) and Japan (n = 2) both quantified access across multiple towns/municipalities whilst all 3 Australian studies reported F&V access in Melbourne only. Additionally, studies assessed F&V access and consumption in Hong Kong (n = 1), Canada (n = 1) and Netherlands (n = 1).

The methods used to measure the specific dimensions of access were heterogeneous. 21 studies used Geographical Information Systems (GIS) to measure accessibility to the RFE by set Euclidean distance, radial buffers or Kernel density measures to food outlets and geocoding resident homes. Two studies developed a Retail Food Environment Index – a measure of the density of unhealthy to health food outlets (n = 3). Self-report survey measures of access was used by 18 studies. Three compared subjective and objective measures of accessibility to the RFE on F&V consumption. Store auditing tools were used to quantify F&V availability, affordability and acceptability in the RFE (n = 8) and most scored food stores using the Nutrition Environment Measures Survey (NEMS-S) (n = 4). One study used a pre-validated audit tool specific to the Brazilian RFE due to the high volume of fresh produce markets.

Definitions of F&V within the RFE varied across the included studies in this review (Table 3). Definitions referenced F&V as fresh (n = 36), 100% juiced (n = 14), frozen (n = 11), canned (n = 11) and dried (n = 3). Only 9 of the 36 studies excluded potatoes as a fruit or vegetable in their definition, despite the fact that these would usually be classified separately from F&V nutritionally. All studies quantified consumption through self-reported dietary surveys. Two studies quantified F&V intake both by self-report survey and objectively by measuring skin carotenoids concentration (Jilcott Pitts et al., 2017; McGuirt et al., 2018).

3.2. Study quality & bias

All 36 studies were evaluated for reporting quality under 5 indicators; representation of source population, selection method of exposure, outcome measures, analysis strategy, internal and external validity (Table 2; supplementary material S4; S5). Six studies were rated high quality (Alber et al., 2018; Chor et al., 2016; Flint et al., 2013; Gustafson et al., 2013b; McGuirt et al., 2018; Yamaguchi et al., 2019) and the remaining studies were scored at moderate quality with conclusions unlikely to be subject to change. No study was excluded from the review due to study reporting quality.

3.3. Dimensions of access

In studies measuring F&V accessibility (Table 4) by geographical distance between residency and RFE, the majority (n = 15) reported no influence or a negative association of distance with F&V consumption or purchasing; ; (Aggarwal et al., 2014; Caspi et al., 2012a; Curl et al., 2013; Drisdelle et al., 2020; Hattori et al., 2013; Hawkesworth et al., 2017; Jack et al., 2013; Liese et al., 2013; Mason et al., 2013; Mejia et al., 2015; Murphy et al., 2017; Ollberding et al., 2012; Reitzel et al., 2016; Thornton et al., 2013; Yamaguchi et al., 2019). 7 studies reported a positive association between shorter distance or increased density/convenience to food stores and higher F&V consumption when measured using a geographical information system (GIS) tool (Clary et al., 2016; Curioni et al., 2020; Duran et al., 2016; McGuirt et al., 2018; Pessoa et al., 2015; Thornton et al., 2012; Zhang and Huang, 2018) and 1 Australian study identified a positive association of food store density with vegetable consumption only (Thornton et al., 2013). A study conducting field audits of healthy food outlets found that neighbourhoods with more healthy food outlets had a 26% lower odds of healthier food purchasing (Mason et al., 2013). When observing F&V accessibility through participant perceptions of convenience to the RFE or density of food outlets, mixed results were reported with 6 studies identifying a positive association (Blitstein et al., 2012; Caspi et al., 2012a; Lucan and Mitra, 2012; McGuirt et al., 2018; Nakamura et al., 2017; Yamaguchi et al., 2019) and 5 reporting null or negative findings (Aggarwal et al., 2014; Drisdelle et al., 2020; Gustafson et al., 2013b; Lenk et al., 2018;

Table 2
 Characteristics of included studies; setting, access dimensions, measure of access method, study quality.

Country & Region			Access Dimension					Access Measure		Used	Study Quality
			Accessibility	Availability	Affordability	Acceptability	Accommodation	GIS	Store Audit tool	Not used	
										Used	
Mason et al., 2013 (Mason et al., 2013)	Australia	Melbourne	█	█	█	█	█	█	█	█	
Murphy et al., 2017 (Murphy et al., 2017)		Melbourne	█	█	█	█	█	█	█	█	
Thornton et al., 2013 (Thornton et al., 2013)		Melbourne	█	█	█	█	█	█	█	█	
Chor et al., 2016 (Chor et al., 2016)	Brazil	6 Cities*	█	█	█	█	█	█	█	█	
Curioni et al., 2020 (Curioni et al., 2020)		Rio de Janeiro	█	█	█	█	█	█	█	█	
Duran et al., 2016 (Duran et al., 2016)		Sao Paulo	█	█	█	█	█	█	█	█	
Menezes et al., 2018 (Menezes et al., 2018)		Belo Horizonte	█	█	█	█	█	█	█	█	
Pessoa et al., 2015 (Pessoa et al., 2015)		Belo Horizonte	█	█	█	█	█	█	█	█	
Drisdelle et al., 2020 (Drisdelle et al., 2020)	Canada	Montreal	█	█	█	█	█	█	█	█	
Zhang et al., 2018 (Zhang and Huang, 2018)	Hong Kong	Hong Kong	█	█	█	█	█	█	█	█	
Nakamura et al., 2017 (Nakamura et al., 2017)	Japan	31 Municipalities	█	█	█	█	█	█	█	█	
Yamaguchi et al., 2019 (Yamaguchi et al., 2019)		31 Municipalities	█	█	█	█	█	█	█	█	
Tak et al., 2012 (Tak et al., 2012)	Netherlands	Eindhoven	█	█	█	█	█	█	█	█	
Clary et al., 2016 (Clary et al., 2016)	UK	London	█	█	█	█	█	█	█	█	
Hawkesworth et al., 2017 (Hawkesworth et al., 2017)		20 UK towns	█	█	█	█	█	█	█	█	
Thornton et al., 2012 (Thornton et al., 2012)		Glasgow	█	█	█	█	█	█	█	█	
Alber et al., 2018 (Alber et al., 2018)	USA	Philadelphia	█	█	█	█	█	█	█	█	
Aggarwal et al., 2014 (Aggarwal et al., 2014)		Seattle, Washington	█	█	█	█	█	█	█	█	
Blitstein et al., 2012 (Blitstein et al., 2012)		Chicago, Illinois	█	█	█	█	█	█	█	█	
Caspi et al., 2012 (Caspi et al., 2012a)		Boston, Massachusetts	█	█	█	█	█	█	█	█	
Curl et al., 2013 (Curl et al., 2013)		6 cities**	█	█	█	█	█	█	█	█	
Flint et al., 2013 (Flint et al., 2013)		Philadelphia, PA	█	█	█	█	█	█	█	█	
Gustafson et al., 2013a (Gustafson et al., 2013a)		Kentucky	█	█	█	█	█	█	█	█	
Gustafson et al., 2013b (Gustafson et al., 2013b)		Kentucky	█	█	█	█	█	█	█	█	
Hattori et al., 2013 (Hattori et al., 2013)		California	█	█	█	█	█	█	█	█	
Jack et al., 2013 (Jack et al., 2013)		New York, NY	█	█	█	█	█	█	█	█	
Jilcott Pitts et al., 2017 (Jilcott Pitts et al., 2017)		North Carolina	█	█	█	█	█	█	█	█	
Lenk et al., 2018 (Lenk et al., 2018)		Minnesota	█	█	█	█	█	█	█	█	
Liese et al., 2014 (Liese et al., 2013)		South Carolina	█	█	█	█	█	█	█	█	
Lucan et al., 2012 (Lucan and Mitra, 2012)		Philadelphia, PA	█	█	█	█	█	█	█	█	
Lucan et al., 2014 (Lucan et al., 2014)		Philadelphia, PA	█	█	█	█	█	█	█	█	
Martin et al., 2012 (Martin et al., 2012)		Connecticut	█	█	█	█	█	█	█	█	
McGuirt et al., 2018 (McGuirt et al., 2018)		North Carolina	█	█	█	█	█	█	█	█	
Mejia et al., 2015 (Mejia et al., 2015)		California	█	█	█	█	█	█	█	█	
Ollberding et al., 2012 (Ollberding et al., 2012)		Hawaii	█	█	█	█	█	█	█	█	
Reitzel et al., 2016 (Reitzel et al., 2016)		Texas	█	█	█	█	█	█	█	█	
Total: 36			29	15	8	9	0	21	8	18	

* Rio de Janeiro, São Paulo, Vitória, Belo Horizonte, Bahia and Porto Alegre. ** Baltimore City and Baltimore County, Maryland; Chicago, Illinois; Forsyth County, North Carolina; Los Angeles County, California; New York, New York; and St. Paul, Minnesota

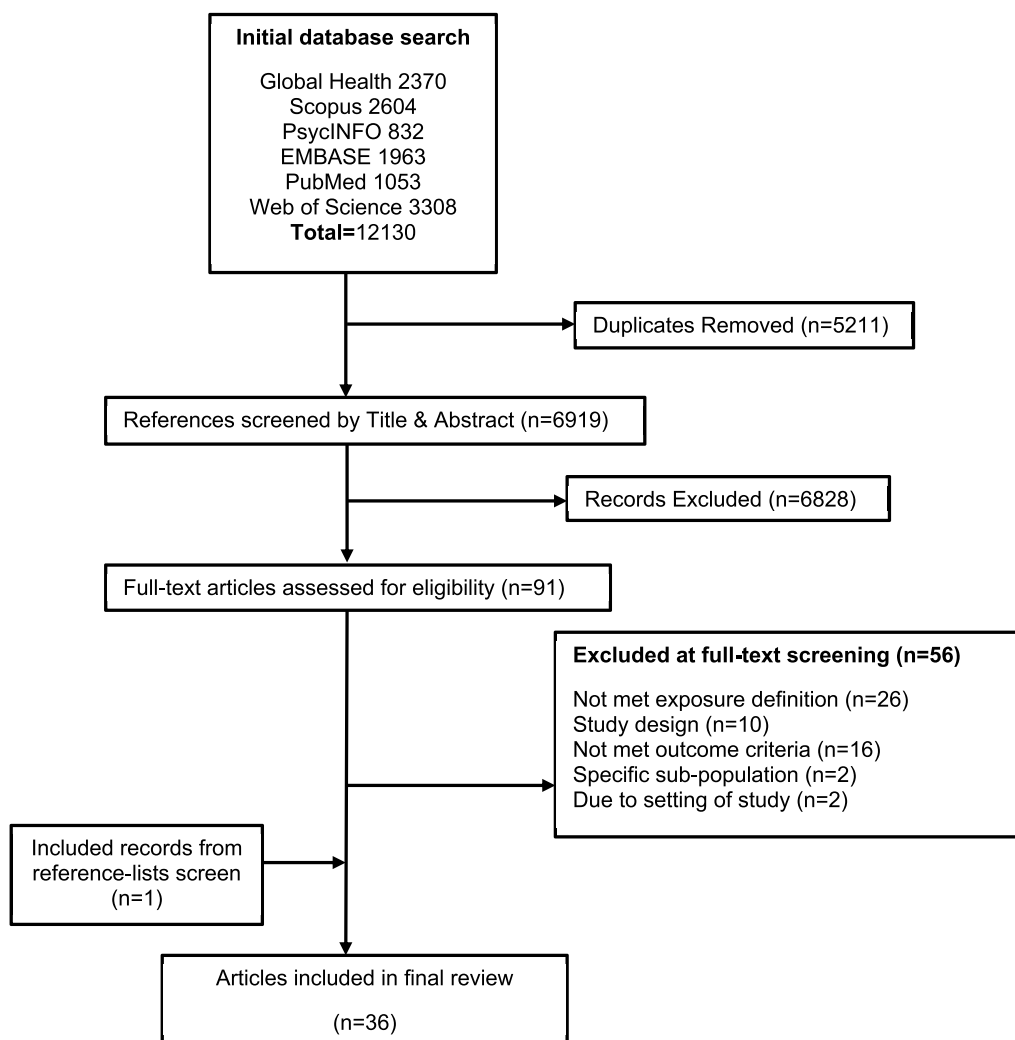


Fig. 1. PRISMA chart showing study number at each search stage.

Tak et al., 2012).

Affordability was measured in these 3 studies by survey responses (Duran et al., 2013; Gustafson et al., 2013a; Jilcott Pitts et al., 2017) and survey responses (n = 5) (Aggarwal et al., 2014; Alber et al., 2018; Blitstein et al., 2012; Drisdelle et al., 2020; Flint et al., 2013). Two studies averaged and categorised the price of a selection of F&V (Aggarwal et al., 2014; Duran et al., 2013). Three studies used NEMS-S and embedded F&V prices into aggregate scores of overall consumer access to F&V (availability, price, quality score) (Alber et al., 2018; Gustafson et al., 2013a; Jilcott Pitts et al., 2017). Survey responses to F&V affordability were measures of agreement with statements such as “F&V in my neighbourhood are [expensive/affordable]” and the responses were coded. Of the 8 studies that assessed affordability, two US studies found an association of increased consumption of F&V daily with increased affordability of F&V (Aggarwal et al., 2014; Gustafson et al., 2013a). Neither study specifically measured affordability, which was aggregated with other access dimensions as an overall measure of F&V in the RFE.

The dimension of availability was quantified by the presence of F&V in food stores measured by perception surveys and store audit methods (n = 15) (Alber et al., 2018; Blitstein et al., 2012; Chor et al., 2016; Curl et al., 2013; Drisdelle et al., 2020; Duran et al., 2016; Gustafson et al., 2013a,b; Jilcott Pitts et al., 2017; Liese et al., 2013; Lucan et al., 2014; Lucan and Mitra, 2012; Martin et al., 2012; Menezes et al., 2018; Flint et al., 2013). 9 of the 15 studies identified a relationship between

increased availability of F&V in the food outlet and a higher daily consumption of F&V (n = 9) (Blitstein et al., 2012; Chor et al., 2016; Curl et al., 2013; ; Duran et al., 2016; Gustafson et al., 2013b; Liese et al., 2013; Lucan and Mitra, 2012; Martin et al., 2012; Menezes et al., 2018). One study reported possible bias due to high collinearity between the availability and variety of F&V in the RFE (Duran et al., 2016).

Nine studies measured the acceptability of F&V by freshness, quality or variety in the RFE and were embedded in other scoring measures (e.g. NEMS-S) and findings were inconsistent. Four papers identified positive associations of perceived F&V quality with F&V intake (Alber et al., 2018; Blitstein et al., 2012; Gustafson et al., 2013b; Lucan and Mitra, 2012). A single negative association was identified in a Brazilian study where F&V intake was higher when individuals lived nearer to supermarkets with low quality, fresh produce (Duran et al., 2016). All other studies reported null findings between F&V acceptability and intake (Drisdelle et al., 2020; Flint et al., 2013; Jilcott Pitts et al., 2017; Lucan et al., 2014).

Accommodation parameters were not reported in any study included in this review.

Some studies assessed multiple dimensions of access to F&V in the RFE (n = 13) (Aggarwal et al., 2016; Alber et al., 2018; Blitstein et al., 2012; Curl et al., 2013; Drisdelle et al., 2020; Duran et al., 2016; Flint et al., 2013; Gustafson et al., 2013a, 2013b; Jilcott Pitts et al., 2017; Liese et al., 2013; Lucan et al., 2014; Lucan and Mitra, 2012). The most common combination of measures were availability, affordability and

Table 3

Variation of fruit and vegetable definition within included studies in review; form of fruit and vegetable (fresh, frozen, canned, juiced, dried), cooked or uncooked and exclusions to study definition of fruit and vegetables. Green indicates confirmation of inclusion in definition.

Study	Country (region)	Fruit and Vegetable type definition								
		Type of F&V					Cooked		Other	
		Fresh	Frozen	Canned	Juiced 100%	Dried	Cooked	Uncooked	Exclusions	Comments
Mason et al., 2013 (Mason et al., 2013)	Australia	Melbourne								
Murphy et al., 2017 (Murphy et al., 2017)		Melbourne								
Thornton et al., 2013 (Thornton et al., 2013)		Melbourne								
Chor et al., 2016 (Chor et al., 2016)	Brazil	6 Cities*							Potatoes and root tubers	
Curioni et al., 2020 (Curioni et al., 2020)		Rio de Janeiro								Leafy vegetables only
Duran et al., 2016 (Duran et al., 2016)		Sao Paulo								
Menezes et al., 2018 (Menezes et al., 2018)		Belo Horizonte								
Pessoa et al., 2015 (Pessoa et al., 2015)		Belo Horizonte								
Drisdelle et al., 2020 (Drisdelle et al., 2020)	Canada	Montreal							Fried potatoes	
Zhang et al., 2018 (Zhang and Huang, 2018)	Hong Kong	Hong Kong								No specific definition
Nakamura et al., 2017 (Nakamura et al., 2017)	Japan	31 Municipalities								
Yamaguchi et al., 2019 (Yamaguchi et al., 2019)		31 Municipalities								
Tak et al., 2012 (Tak et al., 2012)	Netherlands	Eindhoven							Vegetables	
Clary et al., 2016 (Clary et al., 2016)	UK	London							Potatoes	
Hawkesworth et al., 2017 (Hawkesworth et al., 2017)		20 UK towns								
Thornton et al., 2012 (Thornton et al., 2012)		Glasgow							Potatoes	
Alber et al., 2018 (Alber et al., 2018)	USA	Philadelphia, PA							Potatoes	10 fruits, 10 vegetables
Aggarwal et al., 2014 (Aggarwal et al., 2014)		Seattle, Washington								
Blitstein et al., 2012 (Blitstein et al., 2012)		Chicago, Illinois								
Caspi et al., 2012 (Caspi et al., 2012a)		Boston, Massachusetts								
Curl et al., 2013 (Curl et al., 2013)		6 cities**								Organically grown vs. not
Flint et al., 2013 (Flint et al., 2013)		Philadelphia, PA							Potatoes	10 fruits, 12 veg
Gustafson et al., 2013a (Gustafson et al., 2013a)		Kentucky							Potatoes, cooked dried beans	
Gustafson et al., 2013b (Gustafson et al., 2013b)		Kentucky								No specific definition
Hattori et al., 2013 (Hattori et al., 2013)		California							Exclude juice, fried potatoes	
Jack et al., 2013 (Jack et al., 2013)		New York, NY								No specific definition
Jilcott Pitts et al., 2017 (Jilcott Pitts et al., 2017)		North Carolina								Include tomato sauce, vegetable mixtures
Lenk et al., 2018 (Lenk et al., 2018)		Minnesota							Fried potatoes or savoury snacks	
Liese et al., 2014 (Liese et al., 2013)		South Carolina								
Lucan et al., 2012 (Lucan and Mitra, 2012)		Philadelphia, PA								
Lucan et al., 2014 (Lucan et al., 2014)		Philadelphia, PA								
Martin et al., 2012 (Martin et al., 2012)		Connecticut								
McGuirt et al., 2018 (McGuirt et al., 2018)		North Carolina								Include tomato sauce, potatoes & dried beans
Mejia et al., 2015 (Mejia et al., 2015)	California									
Oilberding et al., 2012 (Oilberding et al., 2012)	Hawaii								Include fried potato, tomato sauce	
Reitzel et al., 2016 (Reitzel et al., 2016)	Texas							Fried potatoes, fibre		
Total			36	11	11	14	3	7	32	

* Rio de Janeiro, São Paulo, Vitória, Belo Horizonte, Bahia and Porto Alegre. ** Baltimore City and Baltimore County, Maryland; Chicago, Illinois; Forsyth County, North Carolina; Los Angeles County, California; New York, New York; and St. Paul, Minnesota

Table 4
 Overview of reported associations between dimensions of access to F&V in the retail food environment and F&V consumption. Relationships qualified as statistically significant at the 5% level. Relationship: P=Positive, N=Negative, X = Null. Quality: = low, + = moderate, ++ = high

Study (Quality)	Country & Region	Dimensions of Access			
		Accessibility	Affordability	Availability	Acceptability
Mason et al., 2013 (+) (Mason et al., 2013)	Australia	Melbourne	N*5-7 stores		
		Melbourne	X*>8 stores		
Murphy et al., 2017 (+) (Murphy et al., 2017)		Melbourne	X		
Thornton et al., 2013 (+) (Thornton et al., 2013)		Melbourne	P*veg(2km)		
			X*fruit		
Chor et al., 2016 (++) (Chor et al., 2016)		6 Cities ^a		P	
Curioni et al., 2020 (+) (Curioni et al., 2020)		Rio de Janeiro	P*markets		
			N*supermarkets		
Duran et al., 2016 (+) (Duran et al., 2016)	Brazil	Sao Paulo	P	X	P
Menezes et al., 2018 (+) (Menezes et al., 2018)		Belo Horizonte		P	
Pessoa et al., 2015 (+) (Pessoa et al., 2015)		Belo Horizonte	P		
Drisdelle et al., 2020 (+) (Drisdelle et al., 2020)	Canada	Montreal	X*GIS	X*survey	X*survey
			X*survey		X*survey
Zhang et al., 2018 (+) (Zhang and Huang, 2018)	Hong Kong	Hong Kong	P		
Nakamura et al., 2017 (+) (Nakamura et al., 2017)	Japan	31 Municipalities	P		
Yamaguchi et al., 2019 (++) (Yamaguchi et al., 2019)		31 Municipalities	N*GIS		
			P*survey		
Tak et al., 2012 (+) (Tak et al., 2012)	Netherlands	Eindhoven	X		
Clary et al., 2016 (+) (Clary et al., 2016)	UK	London	P		
Hawkesworth et al., 2017 (+) (Hawkesworth et al., 2017)		20 UK towns	X		
Thornton et al., 2012 (+) (Thornton et al., 2012)		Glasgow	P		
Alber et al., 2018 (++) (Alber et al., 2018)		Philadelphia, PA		X	N
Aggarwal et al., 2014 (+) (Aggarwal et al., 2014)		Seattle, Washington	X	P	
Blitstein et al., 2012 (+) (Blitstein et al., 2012)		Chicago, Illinois	P	X	P
Caspi et al., 2012 (+) (Caspi et al., 2012a)		Boston, Massachusetts	X*GIS		
			P*Survey		
			N*supermarkets		
Curl et al., 2013 (+) (Curl et al., 2013)		6 cities ^b	X*GIS	P*Survey	
Flint et al., 2013 (++) (Flint et al., 2013)		Philadelphia, PA		X	X
Gustafson et al., 2013a (+) (Gustafson et al., 2013a)		Kentucky	X		X
Gustafson et al., 2013b (++) (Gustafson et al., 2013b)		Kentucky		P*veg (0.5km)	P*veg (0.5km)
			X*fruit (0.5km)/F&V (1km)	X*fruit (0.5km)/ F&V (1km)	X*fruit (0.5km)/F&V (1km)
Hattori et al., 2013 (+)		California	X		
Jack et al., 2013 (+) (Jack et al., 2013)	USA	New York, NY	X		
Jilcott Pitts et al., 2017 (+) (Jilcott Pitts et al., 2017)		North Carolina		X	X
Lenk et al., 2018 (+) (Lenk et al., 2018)		Minnesota	N		
Liese et al., 2014 (+) (Liese et al., 2013)		South Carolina	X		P
Lucan et al., 2012 (+) (Lucan and Mitra, 2012)		Philadelphia, PA	P		P
Lucan et al., 2014 (+) (Lucan et al., 2014)		Philadelphia, PA	X		X
Martin et al., 2012 (+) (Martin et al., 2012)		Connecticut			P
McGuirt et al., 2018 (++) (McGuirt et al., 2018)		North Carolina	P*mRFEI & 10mile road network (GIS)		
			P*survey		
Mejia et al., 2015 (Mejia et al., 2015)		California	X		
Ollberding et al., 2012 (+) (Ollberding et al., 2012)		Hawaii	X		
Reitzel et al., 2016 (+) (Reitzel et al., 2016)		Texas	X*grocery stores		

*Differing measures/parameters within singular dimension of access

^a Rio de Janeiro, São Paulo, Vitória, Belo Horizonte, Bahia and Porto Alegre

^b Baltimore City and Baltimore County, Maryland; Chicago, Illinois; Forsyth County, North Carolina; Los Angeles County, California; New York, New York; and St. Paul, Minnesota

acceptability (Alber et al., 2018; Flint et al., 2013; Gustafson et al., 2013b; Jilcott Pitts et al., 2017). 4 studies assessed both the external (accessibility, availability) and personal (affordability, acceptability) food environment domains (Aggarwal et al., 2016; Drisdelle et al., 2020; Lucan et al., 2014; Lucan and Mitra, 2012). Two studies used all four dimensions of access and both reported positive associations of F&V accessibility or availability with F&V consumption but mixed findings for acceptability and affordability (Blitstein et al., 2012; Duran et al., 2016). In studies examining more than one dimension, there was a positive association of F&V with intake in 6 studies and a negative association in one study.

4. Discussion

To our knowledge this is the first systematic review of the available published evidence assessing the association of dimensions of F&V access in the RFE with F&V consumption among adults in higher- and upper-middle income countries. Heterogeneity in methodology within and between dimensions of access prevents direct comparisons and firm conclusions but our review suggests there is a growing body of evidence of a positive association of F&V access in the RFE with F&V intake. In particular, this review presents suggestive evidence of an association of increased F&V availability in the RFE with increased consumption. F&V accessibility and acceptability in the RFE were inconsistently associated with F&V consumption. This review finds there to be currently no good evidence in the published literature of an association of F&V affordability with consumption in higher income settings although the evidence base is scant. The review confirms a link between F&V access in the RFE and F&V intake, but demonstrates that there are parameter and methodological disparities.

The inconsistencies in access identified in this review are aligned with previous systematic reviews, which suggest modest associations between the food environment and dietary and health outcomes (Caspi et al., 2012b; Engler-Stringer et al., 2014; Yang et al., 2020). Conceptually, the relationship between the RFE and F&V intake should be strong as the RFE is the intersection for consumer dietary access, however measuring the RFE is challenging. The inconsistencies in this review can, in part, be attributed to the range of definitions, the heterogeneity of methodological approaches, study quality and complexities of the RFE. Furthermore, how studies defined F&V varied in this review which inherently will influence the findings as customers consider types of F&V differently e.g. fresh versus frozen. Only a third of papers excluded potatoes which aligns with the WHO F&V definition (WHO, 2016) however, across countries, definitions differ by botanical, culinary or nutritional classification. The inclusion of root vegetables in definitions may be because they are situated next to the 'real' F&V in food outlets.

Accessibility of food outlets was the most frequently used measure of the RFE however, study findings reporting F&V accessibility were mixed. This review suggests a possible association within Asian and UK contexts, but the study sample size is small, and no association was identified in the US. Other reviews of the food environment and dietary outcomes in both children and adults report mixed findings (Caspi et al., 2012b; Engler-Stringer et al., 2014; Yang et al., 2020). This is likely due to F&V shopping being ubiquitous therefore, measuring the proximity or density of food stores by set distances to resident addresses is unlikely to capture where all F&V purchases occur (Bivoltsis et al., 2018; Yang et al., 2020). Furthermore, inconsistencies may reflect psychometric attributes such as safety of routes, mobility constraints and public transport which influence resident views of accessibility (Yang et al., 2020). The type or introduction of supermarkets and car ownership may influence perceptions of accessibility as residents report no access to supermarkets even when food stores are directly opposite the home (Hawkesworth et al., 2017). To measure how the accessibility to the RFE impacts F&V dietary behaviours, factors such as car ownership, safety perceptions and retail typology are important to consider.

Availability refers to the presence of F&V in the RFE captured using store-auditing or self-report measures. This review presents a modest association between increased availability of F&V and increased intake. Global literature agrees as consistently increased availability of F&V is linked with increased consumption (Bodor et al., 2008; Ding et al., 2012; Turner et al., 2019). Conceptually, it would be expected that when more healthy options are available in food stores that F&V consumption increases. However, a possible reason for this modest association is that individuals with diets high in F&V may choose to shop in stores where F&V are more widely available raising concerns of reverse causality – a common issue with cross-sectional study designs. In HIC, RFEs are relatively stable with less fluctuation in the availability of F&V as issues of seasonality or reliance on domestic agriculture are less of a concern (Turner et al., 2018). Comparatively, in LMIC contexts food availability is more variable, with seasonal cycles and non-retail supplies driving the availability of different F&V types. Stable global F&V availability is important for the RFE and consumer and is dependent on a resilient food system. F&V shortages in the RFE were reported during the Covid-19 pandemic (Shanks et al., 2020) because of 'volume-purchasing' and distribution disruptions which exposed the fragility of some national food systems (OECD, 2020; Richards and Rickard, 2020). F&V availability is a likely important predictor for F&V intake but is co-dependent on other parameters such as the acceptability, affordability and demand.

The concept of F&V acceptability is relatively novel. In this review, studies measuring F&V acceptability reported inconsistent associations with F&V intake likely due to acceptability or desirability measures aggregated as overall healthy-food scores (e.g. NEMS-S). Other reviews report conflicting findings however they note evidence paucity and the complexity of defining food 'acceptability' (Caspi et al., 2012b; Turner et al., 2019). Evidence from low-income neighbourhoods indicated that poor-quality produce was more expensive when compared to higher-income areas which raises issues of equity (Gosliner et al., 2018). The current conceptualisation of F&V acceptability requires development beyond food quality to include cultural and contextual relevance (Caspi et al., 2012b). To be considered of 'good quality' and appeal to consumers, F&V are required to appear fresh; however, many F&Vs typically have a short shelf-life. Strategies aiming to reduce food waste, particularly spoilage, may have a positive impact on F&V quality and acceptability (Bajželj et al., 2020). The conceptualisation of acceptability in RFE is emerging in the literature as a potentially important parameter of F&V acquisition (Turner et al., 2018).

Affordability is a well-reported aspect of food environments. In this review, no association was identified between F&V affordability and intake, contradicting existing literature (Caspi et al., 2012b; Engler-Stringer et al., 2014; Mah et al., 2019; Turner et al., 2019). Geographical limits may explain these findings as most studies were Northern American where RFEs are typically described as 'food deserts' (Karpyn et al., 2019). If a RFE has few healthy food outlets, F&V affordability will not be accurately measured as the dimension of access which is limiting is F&V availability. Using singular measures of F&V affordability e.g., price audits will unlikely illustrate an association between affordability and consumption due to confounders such as personal choice and F&V availability. The range of affordability measures vary in their intended outcome as self-reported perceptions of what is 'expensive' or 'affordable' will differ from store audits of food prices. A mixed-method approach may be necessary to measure food affordability. Food affordability fluctuations relate to F&V price spikes meaning for some consumers, F&V are unaffordable and less prioritised in the diet (Herforth and Ahmed, 2015). In some HIC, the most optimal healthy diet was twice the price of the least healthy diet and therefore, we would expect to see an association between F&V affordability and dietary intake (Headey and Alderman, 2019; Herforth and Ahmed, 2015). However, this review may evidence Engel's law as individual incomes rise, their proportional share of expenditure on food decreases which may mean wealthier consumers are less price sensitive to F&V fluctuations. Whilst no association was reported in this review, the price of F&V is known to

be high and policies should target the RFE to make F&V more affordable.

4.1. Strengths & limitations

Key strengths of this review include rigidly following PRISMA-guidelines, searching 6 databases for peer-reviewed references and conducting assessments of study reporting quality. Furthermore, no other study has aimed to capture how the RFE interacts with F&V access and how this influences consumption.

The methodological heterogeneity in this review can be argued as both a strength and limitation. The different exposure and outcome measures in this review highlight how complex and context-specific this topic is and therefore, is necessary to use multiple parameters to capture the community and consumer food environment. However, as this review follows a robust systematic review method, the heterogeneity allowed only for a narrative analysis by sub-categorisation of access measures. Consequently, it could be argued that the measures used in RFE literature are not limiting but that systematic review methods prevent appropriate synthesis of such a diverse evidence base. Other reviews cite a limitation to be a lack of standardised RFE measures and indicators (Turner et al, 2018, 2019). By establishing standardised measures, perhaps more cohesive conclusions can be made. Additionally, few studies disaggregated F&V by type which limits the understanding of the potential differential impacts on dietary intake. The study quality criteria used in this review are not specific to food environment research as no such assessment criteria exist, thus scoring was challenging. Publication bias may be present due to most studies presenting at least 1 significant association. A final limitation of this review is the narrow geographical coverage. Although this review includes studies conducted in multiple RFEs across eight higher- and upper-middle income countries, most were in the USA and Brazil, with a paucity of evidence from European and Asian contexts. As might be expected from detailed studies of RFEs, most studies focus on individual cities or local, urban contexts and are therefore limited in the extent of their representation of their country context. This disparity in both between and within country representation limits generalisability of the reported results all higher- and upper-middle income settings.

5. Conclusion

This is the first systematic review of evidence exploring dimensions of access to F&V in the RFE and the impact on consumption and builds on the evidence base initially described by Caspi et al. (2012). By synthesising the available evidence, we have identified a relationship between the dimensions of access to F&V in the RFE and an influence on F&V consumption. The availability of F&V is demonstrated in this review to be a potentially more important component of the retail food environment than parameters such as the proximity or density of food stores. Whilst physical access and the acceptability of F&V are likely to have some effect on consumption, this review highlights that this association is unclear. Furthermore, F&V affordability was not identified to be associated with dietary F&V intake however, this is likely due to methodological heterogeneities, geographical limits and scant evidence. The dimensions of access require further development to conceptually broaden their scope beyond the current definition to better represent the overall RFE. Additionally, this review highlights gaps as cultural and personal preferences, psychometric attributes and accommodation measures also influence consumer interaction in the RFE. This review unveiled RFE research complexities regarding methodological heterogeneity which challenges the relationship between access to F&V and consumption. Policy-makers should consider multi-dimensional strategies that target promoting F&V in both the external and personal dimensions of access to the RFE to drive F&V consumption.

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.

Acknowledgements

This study forms part of the Sustainable and Healthy Food Systems (SHEFS) programme supported by the Wellcome Trust's Our Planet, Our Health programme [grant number: 205200/Z/16/Z]. The research was part-funded by the National Institute for Health Research (NIHR) Health Protection Research Unit in Environmental Change and Health at the London School of Hygiene and Tropical Medicine in partnership with Public Health England, Met Office and University College London [grant number: PHSEZT6210]. The views expressed are those of the author(s) and not necessarily those of the NHS, the NIHR, the Department of Health and Social Care or PHE.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.gfs.2021.100528>.

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