Food Deserts in Context: How Site-Specific Factors Reshape Food Deserts Discussion

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June 6, 2025.

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Abstract

Research on food deserts has evolved from a narrow focus on geographical distance to a comprehensive framework considering socioeconomic, infrastructural, and cultural factors. This review synthesizes global literature to examine how local contexts reshape food desert definitions, measurement, and interventions. We find a clear shift from distance-based metrics to multidimensional analyses incorporating affordability, mobility, and local food environments. Correspondingly, interventions are diverse, spanning from supermarket investments to digital platforms, with effectiveness highly dependent on site-specific conditions like urban density or social capital. We conclude that addressing food deserts demands integrated, context-sensitive policies, as a one-size-fits-all approach is insufficient. Future research should leverage mobility data, online food access trends, and localized models to build more effective food security strategies.

Keywords: Food deserts, Food accessibility, Local context, Policy intervention

1 Introduction

"Food deserts," conventionally defined as geographic areas with limited access to affordable and nutritious food, have been a significant subject of study in public health and urban planning. The concept gained traction in the late 1990s and early 2000s, initially focusing on the lack of access to food retailers in disadvantaged urban areas [1, 2]. Seminal studies from this period highlighted issues such as 'supermarket redlining' [3] and disparities in the availability and price of food in poor neighborhoods [4]. Early definitions and research often emphasized geographic distance to supermarkets and the characteristics of the local food environment [2, 5–8]. By the mid-2000s, research frequently employed threshold-based

measures (e.g., one-mile urban or ten-mile rural cutoffs) to map these areas and identify spatial disparities in supermarket distribution, which disproportionately affected low-income and minority neighborhoods, particularly in North American cities [9–11]. These studies underscored racial and economic inequities in food access, forming a basis for initial policy responses focused on retail expansion [8, 12].

Research emerging in the mid-to-late 2000s and beyond began to systematically challenge the assumption that physical proximity alone determines food accessibility. Studies increasingly found that food affordability and quality were equally, if not more, important than mere store location [13–16]. The role of transportation in food access also gained significant attention, with findings suggesting that individuals without private vehicles, or those reliant on limited public transit, faced substantial barriers in reaching supermarkets, even if stores were geographically relatively close [17, 18]. Additionally, sociocultural factors, including dietary preferences, food purchasing habits, and the broader neighborhood context influencing everyday mobility, were identified as critical determinants of actual food access and consumption patterns [19, 20].

Despite growing research, much of the literature continues to generalize food deserts, assuming that similar factors contribute to food inaccessibility across diverse contexts [2, 21]. However, this one-size-fits-all approach has proven inadequate, as food access challenges are fundamentally shaped by local contextual factors. Interventions that succeed in urban settings may not be applicable in rural areas due to differences in population density and infrastructure [5, 17, 22].

Additionally, individual affordability [4, 15, 23] and dietary behavior [19, 24] vary considerably across regions, necessitating more tailored approaches that reflect these contextual and behavioral differences. These observations suggest that the conceptualization and measurement of food deserts must be adapted to local conditions, as the factors influencing food accessibility vary widely by region and individual circumstances [25, 26].

To address this gap in understanding *regional variations*, this review examines how food desert research varies across geographic regions with diverse contexts. Unlike previous research, we take a comprehensive look at the evolution of food desert definitions and focus on how these concepts manifest differently across countries and continents. Using a dataset of scholarly articles from the Web of Science database, we identified research sites, categorizing them by city, country, and continent. This analysis enables an exploration of how local conditions influence the conceptualization, measurement, and proposed interventions to food deserts.

2 Methods

This study employs a systematic literature review approach to investigate the multifaceted discussions surrounding food deserts across various global regions. The methodology encompasses a structured literature search, a meticulous filtering process, data extraction assisted by Large Language Models (LLMs), and a thematic synthesis of the selected articles.

2.1 Literature Search Strategy

A comprehensive literature search was conducted using the Web of Science (WoS) Core Collection database. The search query was designed to capture relevant studies focusing on food deserts, utilizing the following keyword string: `'food (NEAR/2) desert' OR 'food (NEAR/2) deserts'`. The `NEAR/2` operator ensures that the terms 'food' and 'desert' (or 'deserts') appear within two words of each other, accommodating variations in phrasing. This initial search yielded a total of 1,044 articles. No specific date restrictions were applied to ensure a comprehensive historical overview of the research landscape.

2.2 Study Selection and Eligibility Criteria

The initial pool of 1,044 articles underwent a rigorous screening process to identify studies directly relevant to the research questions. This multi-stage filtering was based on the articles' titles, keywords, and abstracts. The primary inclusion criterion was a clear focus on the concept of food deserts, including their definition, identification, impacts, or proposed solutions. Articles were excluded if they were deemed irrelevant to the core topic of food deserts upon examination of their title, abstract, and keywords (e.g., studies focusing purely on agricultural deserts without a food access component, or metaphorical uses of the term unrelated to food environments). This screening process resulted in a final selection of 884 articles for in-depth review and analysis.

2.3 Study Site Identification

For each of the 884 selected articles, key information was extracted to facilitate the review. This included standard bibliometric data (authors, publication year, journal) and, critically, the geographical research site(s) of the study. The resulting distribution of these studies by country is illustrated in Figure 1. Recognizing the time-intensive nature of manually identifying research locations from extensive textual content, we employed an LLM, specifically GPT-4o-mini, to assist in this process. The model was tasked with analyzing the title, keywords, and abstract of each article to identify and extract the primary country or region(s) investigated. We then manually verified the geographic sites of each literature for consistency.

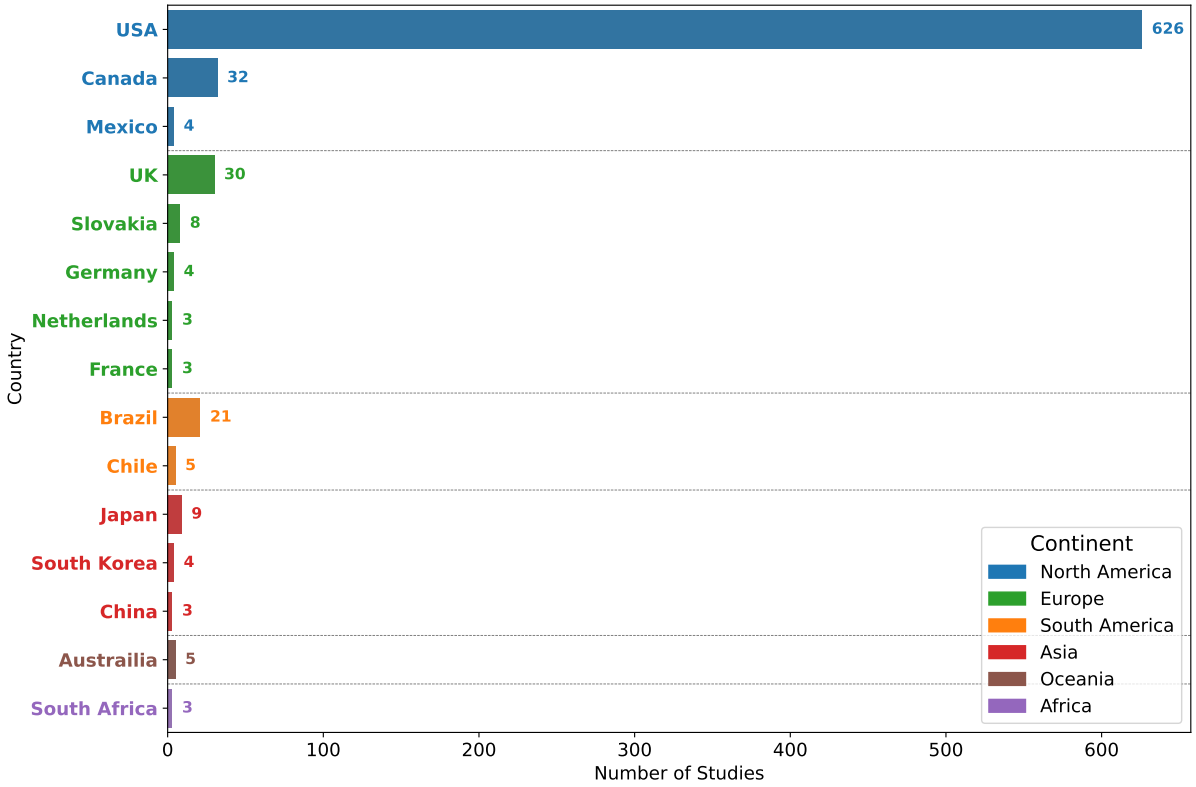

Fig. 1: Distribution of Reviewed Food Desert Studies by Country within Each Continent. This horizontal bar chart illustrates the number of academic studies on food deserts included in this review, categorized by country within each continent. The United States accounts for the vast majority of the research, followed by Canada, in North America. The chart highlights the geographical concentration of existing food desert literature within the reviewed corpus.

Beyond the geographical distribution by country, the dataset also reveals distinct temporal trends in research output when analyzed by continent, as illustrated in Figure 2. Europe, including the United Kingdom, made major contributions to the research on food deserts in the early 2000s. North America has consistently dominated the research landscape, exhibiting several peaks in publication activity since 2010. Other regions, such as Asia, were also focused on the number of studies, particularly in the last decade. Contributions from Africa, Oceania, and South America remain relatively low in volume throughout the period, though some show sporadic increases or slight upward trajectories in more recent years. Studies categorized under 'Multiple continents' demonstrate comparative studies over time.

2.4 Thematic Analysis and Synthesis

The core of this review involved a thematic analysis of the selected literature to understand how discussions on food deserts have evolved and varied across diverse contexts. The 884 articles were reviewed to identify and categorize key themes related to three primary perspectives:

1. **Social Impacts and Issues:** Investigating the social, economic, health, and equity consequences associated with food deserts.

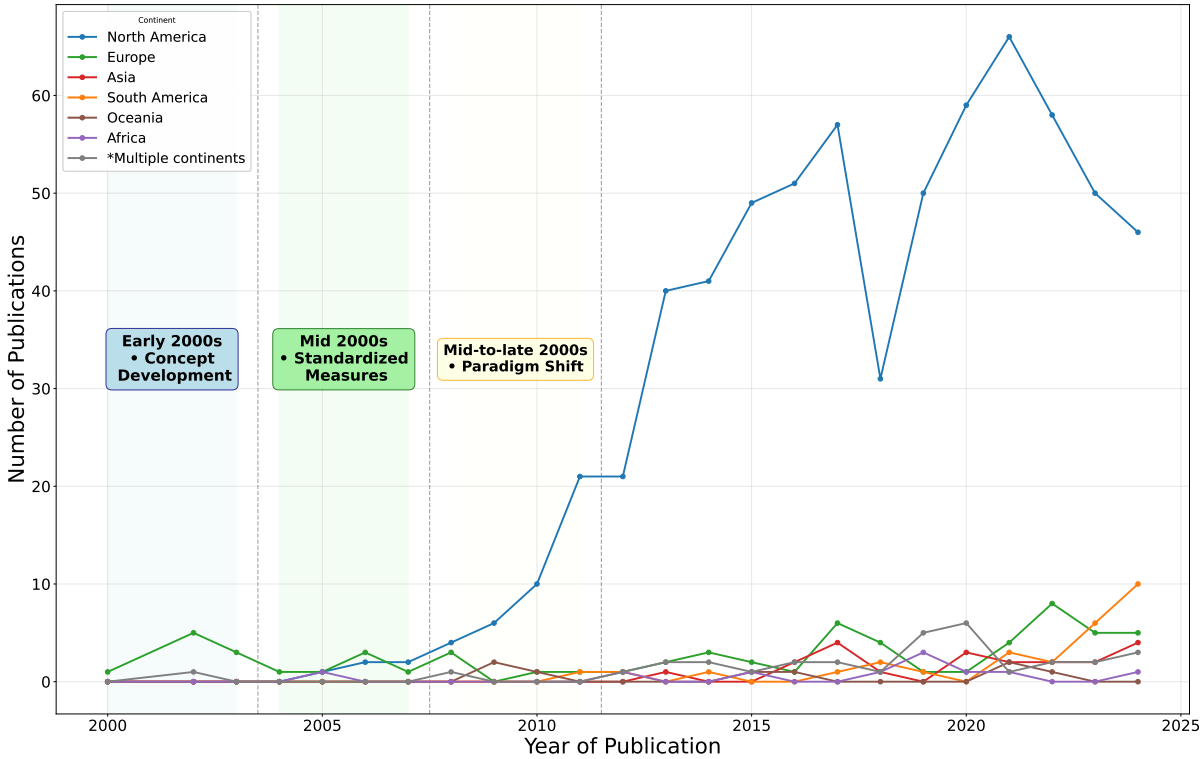

Fig. 2: Temporal Trends in Food Desert Research Output by Continent Group (2000-2024). North America consistently represents the largest volume of publications, exhibiting distinct periods of increased research activity. While other regions contribute fewer studies overall, several show a discernible upward trend in research output in more recent years.

2. **Policy and Interventions:** Examining strategies, programs, and policy measures proposed or implemented to address food deserts.
3. **Methodologies for Assessment:** Analyzing the diverse quantitative and qualitative methods used to define, measure, and analyze food deserts.

3 Impacts of Food Deserts in Regional Contexts

The consequences of limited food access, commonly termed food deserts, are not uniform globally. Instead, they are profoundly shaped by the interplay of local site conditions, including sociodemographic inequality (**SI**), spatial dynamics (**SD**), economy (**EC**), retail environments (**RE**), policy and governance (**PG**), public health landscapes (**HE**), mobility and transportation (**MT**), the extent of digital transformation (**DT**), and other unique contextual elements (**OT**). These varying conditions lead to distinct manifestations of food deserts, different primary concerns in research, and diverse challenges faced by affected populations.

Table 1 provides a structured, comparative overview of the key focus areas and primary challenges as they are discussed in the literature across major global regions, utilizing the standardized thematic abbreviations detailed in the table's note. The following subsections examine the evolving understanding of these impacts and explore specific regional divergences.

Table 1: Comparative overview of key focus areas and challenges in food desert research across global regions. This table summarizes the distinct topics identified in the literature concerning food deserts, categorized by geographical region.

Region	Key Focus Areas	Primary Challenges
North America	• **SI:** Emphasis on socioeconomic and racial inequalities. • **SD:** Impact of suburban sprawl and residential segregation. • **RE:** Role of large supermarkets versus smaller stores. • **MT:** High car dependency.	• **EC:** Financial burden on low-income and minority communities [9]. • **HE:** Significant diet-related health disparities (e.g., obesity [6]). • **OT:** Limited impact of proximity-only solutions (intervention effectiveness) [27].
Europe	• **EC:** Food affordability. • **RE:** Retail restructuring and store closures (especially in rural areas). • **PG:** Role of welfare systems and urban planning policies. • **MT:** Importance of public transport access.	• **EC:** Persistent financial barriers despite physical store availability [15]. • **MT:** Increased travel distances, particularly for rural elderly [28]. • **MT:** Growing car dependency in rural settings [29].
South America	• **SI:** Socioeconomic and structural inequalities as primary drivers. • **SD:** Focus on urban peripheries. • **RE:** Significance of informal markets and prevalence of *food swamps*. • **MT:** Notable infrastructure deficits.	• **SI:** Pronounced racial disparities in food access [30]. • **EC:** Higher food costs due to poor transportation infrastructure [31]. • **RE:** Overabundance of unhealthy food options contributing to poor food environment quality [32]. • **HE:** Negative maternal and child health outcomes linked to poor access [33].
Asia	• **SI:** Issues related to aging populations and social isolation. • **SD:** Challenges from rapid urbanization. • **PG:** Influence of government food programs. • **DT:** Development and role of technology (e-commerce, delivery).	• **SI:** Inequality in access between urban core and peri-urban areas [34]. • **SI:** Social isolation exacerbating access issues for the elderly [35]. • **DT:** Urban-rural digital divide impacting online food access [36]. • **OT:** Food access disruptions post-disaster (environmental/external factor) [37].

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Region	Key Focus Areas	Primary Challenges
Oceania / Africa	• **SD:** Predominance of rural access challenges. • **RE:** Role of local agriculture and informal economies. • **MT:** Severe limitations due to road and transport infrastructure. • **MT:** Long travel distances to food sources.	• **EC:** High transport costs significantly inflating food prices [38]. • **RE:** Critical reliance on non-supermarket and informal food sources [39]. • **OT:** High vulnerability of food access to climate and weather disruptions (environmental/external factor) [40].

Notes: Category Abbreviation: Sociodemographic inequality **(SI)** Spatial dynamics **(SD)** Economy **(EC)** Retail environment **(RE)** Policy & government **(PG)** Health **(HE)** Mobility and transportation **(MT)** Digital transformation **(DT)** Others **(OT)**

3.1 Evolving Perspectives on Spatial Inequality and Vulnerable Populations

Mid 2000s research on food deserts primarily highlighted spatial inequalities that disproportionately affected low-income and minority populations, especially in North America [9–12]. Findings indicated that many disadvantaged neighborhoods had fewer supermarkets or only small corner stores offering lower-quality products at higher prices [4, 7]. This environment exacerbated dietary risks and contributed to poorer health outcomes, including higher rates of obesity and chronic disease [41]. Analysis in U.S. cities also revealed that predominantly African American neighborhoods were often situated farther from supermarkets or had fewer chain grocery outlets, heightening the economic burden on residents [9, 11].

Beyond the United States, similar patterns emerged in Canada and parts of the United Kingdom, where low-socioeconomic status urban districts were found to exhibit limited access to nutritious food [8, 12, 15]. Studies focused on London, Ontario, and inner-city neighborhoods in Leeds documented a growing disparity in store locations, illustrating how retail transformations could entrench or worsen food access gaps [12, 42].

3.2 Expanding Perspectives on Multifactorial Influences

Although initial research emphasized geographic distance, subsequent studies demonstrated that food deserts are also shaped by social and economic forces [14–16, 43]. Factors such as purchasing power, cultural food preferences, and community-level attitudes can mitigate or amplify the effects of limited retail outlets [19, 43]. Investigations showed that physical proximity alone did not necessarily result in healthier diets, especially when affordability, quality, and the social acceptability of available foods remained barriers [14, 16]. Research in Montréal offered evidence that some neighborhoods had adequate supermarket coverage yet continued to exhibit poor dietary outcomes due to economic and cultural

obstacles [14]. Meanwhile, findings in rural areas revealed that some low-income communities actually enjoyed better spatial access to stores but lacked the resources to purchase healthier items, highlighting the relationship between location and socioeconomic factors [17].

3.3 Divergent Discussion by Site Conditions

A substantial body of work in the United States has examined the direct health impacts of living in a food desert. Lack of supermarket access has been linked to lower fruit and vegetable consumption and higher rates of obesity and diet-related illnesses [6, 44]. Studies using national health surveys in the United States have observed that when supermarket availability increases, fruit and vegetable intake tends to rise, especially among residents in historically marginalized communities [7, 45]. Investigations into maternal health have also found that pregnant women living far from full-service grocery stores face higher risks of poor diet quality, revealing deeper vulnerabilities in low-access areas [46, 47]. In addition, there is growing recognition that the abundance of unhealthy food options is closely linked to negative health outcomes. Research has shown that the proximity of convenience stores and fast-food restaurants is strongly associated with higher obesity prevalence, underscoring how the broader food environment shapes dietary behavior [11, 48].

In European nations, the impacts of food deserts manifest differently due to distinct welfare systems, urban planning paradigms, and infrastructural conditions. Early research in the United Kingdom revealed that while introducing a large supermarket could reduce travel distances and slightly improve dietary choices, entrenched economic barriers continued to restrict benefits for lower-income households [15, 42]. In Germany, rural regions experienced significant store closures, partially driven by retail chains requiring a minimum population threshold for profitability [29]. This transformation left some villages or small towns with minimal or no grocery options, forcing residents to rely heavily on private cars to access food [28]. Further analyses indicated that road infrastructure, spatial development policies, and local economic viability each shaped the severity of food deserts in these areas [49].

Studies in Brazil demonstrated how socioeconomic and structural inequalities intensify the effects of food deserts. Neighborhoods with high poverty rates, lower literacy levels, and inadequate infrastructure showed higher concentrations of limited-service stores and an overabundance of ultra-processed foods [32, 50]. Research in Porto Alegre and Recife confirmed that peripheral neighborhoods often lacked reliable transport and saw more pronounced racial disparities, with Black, Brown, and Indigenous populations experiencing even greater restrictions on healthy food access [30, 31, 51]. Evidence indicated that these disparities negatively influenced maternal and child health, including elevated risks of adverse birth outcomes related to poor diets [33]. Importantly, structural inequalities were especially evident in rural regions, where limited road connectivity compounded the situation by inflating transportation costs, thereby raising retail prices and further constraining food options [31].

Asian contexts illustrate how demographic changes and rapid urbanization create unique food desert impacts. In China, research on metropolitan regions found that equitable distribution of retail outlets was crucial, yet significant inequalities persisted between core urban areas and peri-urban or rural districts [34, 52, 53]. Further evidence suggested that online food delivery systems can broaden access, but digital platforms often concentrate services in profitable zones, thereby intensifying the urban-rural divide [36]. Investigations into government-subsidized affordable food shops revealed that merely offering discounted goods did not fully overcome socioeconomic barriers, indicating that deeper structural measures are needed to close gaps in food availability [54]. In Japan, the phenomenon of *kaimono-nanmin* (shopping refugees) has drawn attention to how population aging and weak community ties can exacerbate food insecurity, even in neighborhoods containing adequate physical infrastructure [35, 55]. Studies showed that limited mobility and social isolation among seniors contributed to *food access deserts* rooted not only in geography but also in social and cultural dimensions [56]. Additional challenges were observed following the Great East Japan Earthquake, where damaged infrastructure and displacement magnified existing inequalities in vulnerable areas [37].

In nearly every context, food deserts stem from interrelated factors that extend beyond store location. Limited purchasing power, systemic racial inequities, inadequate transportation, and insufficient public infrastructure frequently coincide to produce severe nutritional and health consequences [13, 57]. Studies in both developed and developing countries indicate that once supermarket or grocery options are removed from a neighborhood, residents often face higher prices and fewer healthy foods, leading to a detrimental cycle of poor diet and exacerbated health risks [7, 9]. Rural areas in Africa, Asia, and **red**South America exhibit additional complexities involving long travel distances, lower retail density, and underdeveloped road networks, creating a distinct set of challenges for already vulnerable groups [31, 39, 58–60].

4 Policy and Intervention Strategies Across Diverse Contexts

Addressing food deserts requires a multifaceted approach, integrating public policies, community-driven initiatives, and private sector innovations to enhance food access. A variety of strategies have been developed and implemented globally, each with distinct objectives, mechanisms, and varying degrees of success and inherent challenges depending on the local context. Table 2 provides a summary of common intervention types—ranging from retail and financing strategies to community-based, mobility-focused, and technology-driven solutions—outlining their primary goals alongside a synopsis of their typical effectiveness and associated difficulties as documented in the literature. This section will explore these key approaches in greater detail, examining specific examples and the contextual factors that influence their outcomes.

Table 2: Summary of common interventions to mitigate food deserts, their objectives, effectiveness, and challenges. This table categorizes various strategies aimed at addressing food deserts, outlining the primary objective of each intervention type.

Intervention	Primary Objective	Effectiveness and Challenges
Retail	Increase the physical supply and availability of healthy food retailers in underserved areas.	**Effectiveness:** • Can increase store numbers [61]. **Challenges:** • Store presence does not guarantee dietary change [27]. • Risk of 'supermarket redlining' [3]. • Small store initiatives, while potentially cost-effective, face sustainability challenges [62].
Financing	Improve economic access by increasing purchasing power for nutritious foods.	**Effectiveness:** • Directly addresses food affordability. **Challenges:** • Effectiveness is often limited by the local availability of healthy options. • May not overcome deeper structural economic issues [63]. • Program reach and uptake can vary significantly.
Community	Increase local access (especially to fresh produce); Empower communities; Foster social cohesion; Provide culturally appropriate foods.	**Effectiveness:** • Can fill gaps where large-scale retail is absent or fails [64]. • Mobile markets offer flexibility in reaching underserved areas [65]. **Challenges:** • Often reliant on grants/volunteers, leading to sustainability concerns [66]. • May inadvertently cluster in more affluent or organized areas [67]. • Participation levels and community awareness can be low [68].
Mobility	Reduce physical barriers related to distance and mobility, especially for those without personal vehicles.	**Effectiveness:** • Can improve physical connectivity to existing food stores. **Challenges:** • Requires significant financial investment for infrastructure or services. • Effects can differ substantially between urban and rural settings [69]. • Public transit schedules may not align with residents' shopping needs.

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Intervention	Primary Objective	Effectiveness and Challenges
Technology	Overcome physical distance barriers; Increase convenience in food procurement; Potentially lower last-mile delivery costs.	**Effectiveness:** • Broadens food access reach, especially beneficial for individuals with limited mobility [36]. **Challenges:** • Digital divide (issues of access to devices/internet, and digital literacy [70]). • Minimum order values or delivery fees can exclude low-income users [71]. • Limitations in rural coverage for delivery services [72]. • Infrastructure requirements for emerging technologies (e.g., autonomous delivery robots - ADRs).

4.1 Encouraging Food Retailers in Underserved Areas

Relocation of supermarkets away from low-income zones has nevertheless persisted in some regions. This phenomenon is sometimes referred to as *supermarket redlining*, where major chains avoid or leave neighborhoods perceived as unprofitable due to crime rates or lower spending power [3]. Studies in Hartford, Connecticut, revealed that supermarket closures and relocations disproportionately affected vulnerable communities, underscoring the need for retention policies alongside new developments [73, 74].

The development of new supermarkets in low-income neighborhoods has been promoted through financial incentives and public-private partnerships. In the United States, the Pennsylvania Fresh Food Financing Initiative (FFFI) is a frequently cited program that provides grants and loans to grocery retailers willing to locate in underserved areas [75]. FFFI reportedly used $30 million in state funds and $90 million from The Reinvestment Fund (TRF) to support 58 stores and generate 1.4 million square feet of retail space [61]. Similar models have been proposed in Illinois and New York [76, 77].

But they do not always lead to improved dietary behaviors or health outcomes, despite increasing the number of supermarkets. [27, 78]. Moreover, they may unintentionally disrupt the existing retail environment by displacing small local food retailers [79]. As an alternative, enhancing the quality of food in existing outlets has emerged as a more immediate and cost-effective strategy.

Results from the Healthy Bodega Initiative in New York City indicated that reorganizing store layouts and increasing fresh produce items boosted sales of fruits, vegetables, and low-fat milk in underserved neighborhoods [80–82]. Authorities in other municipalities have similarly aimed to modernize corner shops or small grocers by offering training, price subsidies, and promotional campaigns for healthier food items [62, 83].

4.2 Nutrition Assistance and Financing Programs

Government-led efforts to address food deserts frequently include direct financial assistance and policy incentives. In the United States, the Supplemental Nutrition Assistance Program (SNAP) supports food purchases for low-income families, targeting the affordability dimension of food insecurity [84, 85]. The Healthy Food Financing Initiative (HFFI) delivers grants or loans to supermarkets and grocery stores, often focusing on neighborhoods that overlap with high SNAP usage [79].

Outside the United States, other countries implement comparable approaches. The United Kingdom utilizes Healthy Start Vouchers to subsidize fruits, vegetables, and milk, supplemented by broader town center retail policies [86, 87]. Canada's Nutrition North program addresses food costs in remote northern regions, while organizations like FoodShare Toronto promote community-led food cooperatives [88]. In Japan, municipal authorities combine mobile grocery stores with children's cafeteria programs, known as *Kodomo Shokudo*, to support both rural and urban populations, reflecting the nation's mobility and demographic challenges [56, 89, 90].

Although financing programs and subsidies can mitigate some barriers, disparities often persist if deeper structural problems remain unresolved. For example, while SNAP increases purchasing power, it does not guarantee access to fresh produce if local stores lack quality offerings or even no more stores [91, 92]. These shortfalls have led many experts to argue that more holistic policies—encompassing decent wage structures, affordable housing, and robust public transport—are fundamental for any long-term solution [27].

4.3 Community-Led Interventions

Farmers' markets and mobile markets often arise where large-scale retail investments are lacking. Research in rural Vermont showed that farmers' markets reduced travel distances and increased access to produce [64]. However, another study noted that farmers' markets can inadvertently cluster in affluent areas, failing to reach the neighborhoods most in need [67]. By contrast, mobile markets have proven more flexible because they can travel directly to senior centers, low-income housing complexes, and other high-need locations [65]. Despite short-term gains in dietary quality, many mobile market programs rely heavily on external funding, which raises concerns about long-term sustainability [66].

Community gardens are frequently cited as holistic interventions that can foster social interaction while improving food access. Their impact, however, can be limited in practice. An evaluation of gardens in Phoenix, Arizona, showed that local awareness remained low, and participation rates were limited [68]. A study of community gardens in another U.S. city found that they were more likely to be located in areas already well-served by supermarkets, thus failing to address entrenched inequalities in under-resourced neighborhoods [93]. Even where gardens do operate, extreme climates, lack of gardening knowledge, and time constraints often deter consistent participation [94, 95]. These challenges suggest that community

gardens may complement broader strategies but cannot independently resolve the structural barriers associated with food deserts.

4.4 Transportation and Infrastructure Interventions

Analyses using simulation frameworks have indicated that expanding public transit routes and improving pedestrian infrastructure can raise the likelihood of accessing healthy food outlets in underserved neighborhoods [96]. A study of five major U.S. cities revealed that transit-based interventions, including new bus stops and modified routes, successfully enhanced grocery store connectivity in specific food deserts [97]. Research on the Critical Closeness Accessibility (CCA) model showed that identifying essential roads for food access investments can improve planning efficiency by prioritizing infrastructure repairs where low-income populations are most affected [98].

In sub-Saharan Africa, investigations have highlighted the influence of regional infrastructure projects, such as the Trans-Gambia Bridge and the Nigeria-Cameroon Multinational Highway, in reducing transport costs and narrowing food accessibility gaps [99]. Another study in Kisumu, Kenya, found that deteriorating roads along food corridors increased prices due to high logistical costs, which particularly impacted vulnerable households [38, 100]. These examples underline the importance of linking targeted transportation measures to food availability initiatives, especially in rural and peri-urban locales.

Improving roads, public transit, and pedestrian pathways can have different impacts in rural versus urban settings. While urban centers may benefit from short-distance transit solutions and multi-modal systems, rural areas often require broader infrastructural upgrades that address long travel distances and sparse populations [69]. In many African nations, rural townships also rely on unpaved roads, which can be disrupted by weather conditions, further complicating food delivery and access [40].

4.5 Advanced Logistics and Technological Solutions

The increasing availability of e-commerce and online grocery platforms has introduced new means of accessing healthy food, alongside emerging forms of inequality. In Great Britain, research showed that while urban residents frequently benefit from diverse online delivery services, rural communities face limited coverage, higher fees, and fewer retailer options [71]. Another study employed the Store Food Desert Index (SFDI) and Online Food Desert Index (OFDI) to reveal that 23% of residents in England and Wales experience inadequate access to both physical and online grocery services [72].

In China, a framework that integrates onsite and online food services was proposed to capture the complex interplay between offline grocery stores and food-delivery platforms [36]. While online channels broaden overall reach, rural and semi-urban zones continue to experience reduced service coverage,

resulting in a digital divide that mirrors traditional food deserts [101, 102]. Moreover, digital illiteracy, broadband access, and minimum-order requirements remain major barriers for older adults and low-income households [70].

To address the barriers faced by rural communities and regions often referred to as *online food deserts*, innovative logistics models have emerged to reduce costs and expand service coverage. Delivery pooling, for instance, consolidates orders at local pick-up points, eliminating high minimum-order totals for individual shoppers [103]. Crowdshipping, whereby in-store customers deliver groceries along their homeward route, has been trialed by large U.S. retailers and third-party platforms in parts of Europe, potentially improving service availability in rural or exurban locations [104]. Autonomous Delivery Robots (ADRs) have also been explored in some pilot projects. E-commerce providers are testing ADRs to determine whether they can extend grocery delivery at lower cost to disadvantaged neighborhoods, although widespread adoption may require additional community education and infrastructure development [105].

5 Measuring Food Deserts

The methods used to define and measure food deserts have evolved considerably since the concept first gained prominence. Initial approaches often relied on relatively simple spatial metrics, but a growing understanding of the multifaceted nature of food access has led to the development of more sophisticated and multidimensional methodologies. Accurately identifying areas of concern and formulating effective interventions depends critically on the chosen measurement framework. Table 3 provides a comparative analysis of common methodologies employed in food desert research, detailing their typical key variables and summarizing their principal strengths and limitations as documented in the literature. The following subsections trace this evolution, from early spatial conceptualizations to more integrated approaches that consider a broader range of influencing factors.

5.1 From Spatial Inequality to Multidimensional Definitions

The term *food desert* first emerged in the 1990s to describe areas where residents struggle to obtain healthy, affordable food due to geographic barriers [2, 21]. Early research concentrated on physical distance to supermarkets, highlighting significant inequalities tied to race, income, and urban-rural divides [17, 106, 107]. This focus on spatial inequality fostered a perception that food deserts were primarily defined by proximity issues, largely ignoring temporal, cultural, and economic dimensions [21].

Over time, it is pointed out that distance alone cannot fully capture access challenges, since some residents bypass nearer stores to seek lower prices or better quality farther away [24]. Scholarly debates introduced terms like *food mirages* to describe areas where physical access exists but economic barriers prevent meaningful utilization [108]. Store quality also plays a crucial role. Empirical evidence also indicated that proximity to high-end outlets, rather than merely a standard supermarket, correlates

more strongly with dietary quality [109]. These findings led to broader definitions of food deserts that account for not only income disparities, but also the nutritional quality of available food options and other multidimensional factors such as transportation access and cultural preferences [26, 110, 111].

Table 3: Comparative Analysis of Methodologies for Measuring Food Deserts. This table details various approaches used to identify and analyze food deserts, outlining typical key variables and a summary of their principal strengths and limitations as discussed in existing research.

Methodology	Key Variables	Strengths & Limitations
Proximity	• Distance metrics (miles/km) • Locations of supermarkets or relevant food stores.	**Strengths:** • Simple to implement, facilitating easy initial assessment [2, 21]. **Limitations:** • Often ignores actual travel barriers (e.g., road networks, terrain). • May overlook store characteristics (e.g., type, quality, price) [12, 18].
Spatial Network Analysis	• Road network data • Transit routes and schedules (e.g., GTFS) • Travel time/speed data • Store locations	**Strengths:** • Provides a more realistic assessment of travel burden than simple buffers [14, 17]. **Limitations:** • Typically data-intensive and more complex to implement. • May still overlook non-network barriers (e.g., highway divisions, safety [98]). • Often does not directly account for food affordability.
Spatial Density Metrics	• Store location data by type (supermarket, convenience, fast food) • Store counts per unit area • Ratios of healthy to unhealthy outlets	**Strengths:** • Captures aspects of overall food environment quality. • Effective for identifying *food swamps* [112, 113]. **Limitations:** • Definitions of 'healthy'/'unhealthy' outlets can vary and be subjective. • May obscure micro-level access issues within an apparently dense food area [114].

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Methodology	Key Variables	Strengths & Limitations
Temporal Analysis	• Store operating hours • Transit schedules (e.g., GTFS) • Commuting patterns • Data for time-specific accessibility measures	**Strengths:** • Captures the dynamic and time-sensitive nature of food access. • Highlights access disparities for specific populations (e.g., shift workers) [111, 115]. **Limitations:** • Requires complex, often difficult-to-obtain, time-series data. • Can be computationally intensive to model and analyze [59, 116].
Socioeconomic Integration	• Spatial access data • Demographic data from census (income, race, etc.) • Vehicle access statistics • SNAP participation rates	**Strengths:** • Emphasizes crucial equity dimensions of food access. • Effective in identifying and prioritizing vulnerable population groups [21, 108]. **Limitations:** • Risk of ecological fallacy when interpreting area-level associations. • Defining thresholds for socioeconomic vulnerability can be arbitrary.
Integrated Approach	• Combined spatial/socioeconomic data • Survey data (cultural food preferences, shopping behaviors) • Food price data • Nutritional literacy information	**Strengths:** • Offers a more holistic and nuanced understanding of 'access.' • Considers individual agency and real-world choice environments [19, 117]. **Limitations:** • Methodologically highly complex to design and implement. • Requires integration of diverse, often disparate, datasets. • Difficult to standardize or replicate across diverse studies/contexts [118].

Initial measurements of food deserts typically relied on straight-line (Euclidean) distance or *buffer zones* around stores to define accessibility thresholds [106, 109]. For instance, some studies labeled urban districts as food deserts if supermarkets were more than 1 mile away, or rural areas if stores were more than 10 miles away [22, 119]. However, these thresholds overlooked actual travel patterns, such as road networks, public transit routes, and congestion [12, 18].

To address the oversimplifications of buffer-based approaches, researchers began employing network-based distances that more accurately reflect real-world travel [14, 17]. Using street grids and driving or walking speeds, this method reveals that some neighborhoods have longer effective travel times than

simplistic Euclidean calculations predict [12]. Even with network analysis, distance alone can still be insufficient, as it fails to account for other physical barriers—such as large highways without pedestrian crossings or neighborhoods poorly served by public transportation [98].

While distance-based approaches capture a single retailer or closest store, density metrics measure the concentration of multiple food outlets within a specified zone [113]. Tools like kernel density models incorporate the number and types of retailers, adjusting for factors such as crime rates or transit availability [120]. Typically, these methods extend beyond grocery stores to include fast-food outlets and convenience stores, enabling researchers to identify *food swamps*, where unhealthy food options overshadow healthier choices [112, 114].

The concept of food swamps extends measurement from 'lack of healthy options' to 'overabundance of unhealthy options' [112, 121]. Density-based methods reveal how a high concentration of fast-food chains or convenience stores in urban neighborhoods can override the benefits of having a supermarket within a short distance [114]. Studies in rural areas and developing countries also show that certain districts simultaneously exhibit features of both deserts and swamps, further complicating straightforward definitions [32, 122].

To better capture complex environments characterized by both limited healthy options and an overabundance of unhealthy ones, some studies employ the Modified Retail Food Environment Index (mRFEI), which calculates the ratio of healthy to unhealthy retailers in a given census tract [123–125]. This approach uses a density perspective to highlight areas with an excessive supply of less nutritious foods relative to nutritious ones, broadening the measurement paradigm beyond a single 'desert' lens [124, 126, 127].

Other studies highlight time as an essential, yet historically overlooked, dimension in food desert research. Temporal variability by store operating hours, transit schedules, and commuting patterns influences where food deserts expand or contract during hours [111]. In some low-income neighborhoods, even if a supermarket is geographically proximate, limited store hours may clash with residents' work shifts, reducing meaningful access [115]. Additionally, the absence of late-night retailers or weekday vendors in economically disadvantaged areas sometimes forces individuals to rely on pricier or less healthy options [59]. Time-dependent analyses leverage data on public transit (e.g., GTFS feeds), which allows researchers to model how travel times fluctuate across daily schedules [116].

5.2 Broadening Variables: Socioeconomic, Cultural, and Demand-Side Considerations

To capture the full complexity of food environments, many researchers augment spatial metrics with demographic data on income, race, vehicle ownership, and household composition [21, 106]. Analyses indicate that African American and Hispanic communities often endure the double burden of low retail

density and limited financial resources to purchase healthy foods, perpetuating cycles of inequality [108]. Other work highlights the role of vehicle access, showing that car ownership can transform a neighborhood widely considered a food desert into a less severe access zone, as residents can travel farther for affordable groceries [120, 128].

Food desert measurements have also expanded to incorporate cultural influences and personal agency. Studies on African refugee communities in Australia, for example, illustrate how cultural preferences and desire for traditional foods shape where people shop, sometimes overriding proximity-based metrics [129]. Similarly, research in multiple U.S. cities reveals that some low-income households drive past nearby stores to find better deals or culturally preferred products [130, 131]. Such behavior challenges assumptions that residents are bound by their immediate physical environment, underscoring the limits of purely distance-based or cost-based indices [117].

Measurement frameworks that include economic, temporal, and cultural factors have proven invaluable for assessing policy interventions like SNAP, the Healthy Food Financing Initiative (HFFI), or local farmers' market subsidies [132, 133]. Some analyses incorporate demand-side data—such as user behavior or nutritional literacy—to determine how effectively these policies improve food access beyond simple geographic metrics [91, 118]. This approach helps identify overlooked barriers, including limited public transit, cultural mismatches in product offerings, and store distribution gaps in minority neighborhoods [92, 134].

6 Discussion

From our site-specific perspective, there are opportunities to examine how food desert research can be developed comparatively across diverse contexts. Although multi-country or multi-region studies exist, they often apply uniform definitions that obscure critical nuances. There is scope for collaborative, cross-context research in which scholars systematically compare, for instance, older European welfare states with emerging Latin American economies. Such comparative designs would highlight context-specific drivers of food deserts—like government subsidies, urban sprawl, or robust social safety nets—and yield more fine-grained insights.

Innovations developed in one context—such as mobile produce markets in urban Latin America or online grocery in East Asia—could be adapted to others with similar (but not identical) constraints. Future research can pinpoint which dimensions (e.g., population density, cultural acceptance of technology, economic feasibility) foster successful adaptation of a solution from one site to another. This comparative perspective goes beyond superficial *policy transfer* to incorporate local constraints and enablers.

As the dynamics of contemporary societies continue to evolve, food desert research must also expand to reflect emerging factors and overlooked dimensions. While much of the existing literature has focused

on traditional determinants such as race, income, and the rural-urban divide, a broader, more nuanced approach is now needed. In particular, further dimensions—such as age, disability status, or immigration history—are critical in shaping how food deserts manifest in distinct places. Future research should explore how aging populations in developed East Asian countries, for instance, require different interventions than youth-dominated communities in parts of sub-Saharan Africa. Such intersectional analysis can clarify why some site-specific groups are more acutely affected by limited food access.

In some regions, climate change or natural disasters—hurricanes, floods, earthquakes—can transform local food access overnight. While research in Japan has begun examining disaster-induced 'instant food deserts,' further exploration is needed in other vulnerable areas (e.g., coastal Latin America, Southeast Asia) to understand how infrastructure resilience, social networks, and government preparedness mitigate (or exacerbate) these acute episodes.

In areas with limited formal retail——such as some rural African villages or informal Latin American neighborhoods——social capital and informal markets often play a larger role than formal supermarkets. Future directions might systematically analyze how community networks, street vendors, and bartering practices fill the gaps that official data sets overlook. This lens recognizes that 'food deserts' can look very different in highly networked or community-driven local systems.

Traditional food desert research often focuses on where access is limited in terms of geography, infrastructure, or socioeconomic constraints. However, personal preference and behavior provide critical nuance, shedding light on why individuals may or may not utilize the food resources in their local area and how they make food-related decisions. Some shoppers travel beyond closer, potentially cheaper stores to find preferred brands, culturally appropriate foods, or higher-quality produce, indicating that cultural and psychological factors can override simplistic measures of distance or cost. Future studies could explore how food identities, taste preferences, and brand loyalties vary across different racial or ethnic communities, age groups, and socioeconomic strata—even within the same neighborhood.

Incorporating behavioral economics tools and frameworks into food desert analysis can help explain why, for instance, individuals choose convenience stores over supermarkets despite comparable distances. Nudges, price promotions, and in-store marketing can shape personal decisions and thus influence local demand for certain products. Empirical research on choice architecture—such as store layout, signage, or point-of-purchase promotions—could illuminate which strategies encourage healthier consumption in low-access areas. By integrating consumer psychology with spatial metrics, researchers might better pinpoint how individual agency interacts with the built environment to shape shopping behaviors.

Personal preference often emerges from cultural norms, social networks, and family traditions, leading individuals to value certain foods over others. In many multicultural urban areas, ethnic grocery stores become essential for supplying culturally relevant staples. Similarly, strong family ties or church communities can foster collective shopping trips that affect the viability of particular retail outlets. In

future work, ethnographic methods, participatory mapping, and household-level surveys might uncover how these social and cultural factors shape shopping behaviors, especially in contexts where formal food systems overlap with informal or community-based networks.

7 Conclusion

The study reviewed the evolution of food desert research, emphasizing how conceptualizations of food access have shifted from a focus on spatial proximity to more comprehensive frameworks incorporating affordability, mobility, and sociocultural factors. Initial research primarily examined geographic barriers to food access, but later studies demonstrated that economic constraints, transportation networks, and dietary behaviors also influence food availability.

Policy responses have varied across regions, reflecting different economic structures, governance systems, and urban-rural dynamics. Supermarket expansion policies have been implemented to improve physical access, but findings suggest that these interventions alone do not resolve food insecurity. Community-based initiatives, store modifications, transportation improvements, and digital food distribution have been introduced to address food access challenges more effectively.

The study also examined different methodologies used to measure food deserts, noting that definitions and measurement techniques have evolved to reflect local conditions. The integration of spatial analysis, behavioral data, and economic indicators has improved assessments of food accessibility.

Future research should continue developing context-sensitive solutions by incorporating mobility data, digital food access trends, and socioeconomic variables. Policymakers should consider localized strategies that address both physical and economic barriers to food security, ensuring that interventions align with the needs of specific communities.

Declarations

Supplementary information. The supplementary material includes a detailed table containing the list of reviewed articles and analysis (e.g., methodology classification, identified interventions, regional context summaries) used to inform the synthesis presented in this review.

Acknowledgments. We are grateful to Center for Advanced Urban Systems (CAUS) of Korea Advanced Institute of Science and Technology (KAIST) funded by GS E&C for their financial support, which made this research possible. This work was also funded by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (RS-2023-00259550, RS-2024-00356597) and the Institute of Information & Communications Technology Planning & Evaluation (IITP) grant funded by the Korea government (MSIT) (No.2019-0-01126).

Competing interests. All authors declare no financial or non-financial competing interests.

Ethics approval. Not applicable

Consent to participate. Not applicable

Consent for publication. Not applicable

Availability of data and materials. The datasets generated and/or analysed during the current study are available in Food Desert Review Repository, https://github.com/youngjour/fooddesert_review.

Authors' contributions. Y.P. conceptualized the study and wrote the initial draft. J.N. and K.J. conducted the literature search and data extraction. D.L., C.K., and Y.Y. reviewed and edited the manuscript. All authors read and approved the final manuscript.

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