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Article

Access to fresh food in vulnerable urban areas: a classification study of the favelas and formal establishments in São Paulo

André Luís de Castro Moura Duarte [1]
Vinicius Picanço Rodrigues [1 2]
Raquel Carolinne Freitas Alves [1]
Gustavo Magalhães de Oliveira [3]

[1] Insper Instituto de Ensino e Pesquisa, São Paulo / SP – Brazil
[2] University of Strathclyde / Department of Design, Manufacturing and Engineering Management, Glasgow – United Kingdom
[3] University of Bonn / Institute for Food and Resource Economics, Bonn – Germany

The environment significantly influences individuals' food choices. Vulnerable urban areas, such as favelas, can have a decisive impact on discouraging the consumption of fresh, nutritionally rich foods. This issue is exacerbated by the urban infrastructure required to deliver fresh foods to these locations. Therefore, it is essential to understand the context of the favelas in the municipality of São Paulo in terms of the food environment and infrastructure to support the design of public policies that enhance the presence of minimally processed foods in these areas. We applied the k-means clustering method to two datasets: the food environment of favelas, characterized by food establishments, and the urban infrastructure of the favelas in the municipality of São Paulo. Of the city's 1,701 favelas, only 271 have formally registered food establishments. Larger favelas with better urban infrastructure generally exhibited a food environment with greater access to fresh foods. The results suggest that investing in urban infrastructure can increase access to fresh foods in these areas. It is also necessary to consider local specificities to find effective solutions that increase the availability of minimally processed foods, thereby improving the population's quality of life and health.
Keywords: urban food environment; food supply chain; fresh food chain; urban infrastructure; São Paulo favelas.

Acesso a alimentos frescos em áreas urbanas vulneráveis: um estudo classificatório das favelas e dos estabelecimentos formais de São Paulo

O ambiente influência nas escolhas alimentares dos indivíduos. Áreas urbanas vulneráveis, como favelas, podem ter um efeito decisivo em desestimular o consumo de alimentos frescos, com alto poder nutritivo. Essa questão é ampliada pela infraestrutura urbana necessária para que os alimentos frescos cheguem a esses locais. Assim, é essencial entender o contexto das áreas de favela do município de São Paulo em termos de ambiente alimentar e infraestrutura para apoiar o desenho de políticas públicas que aumentem a presença de alimentos minimamente processados nesses locais. Para isso, aplicamos o método de clusterização *k-means* com dois conjuntos de dados:

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ambiente alimentar das áreas de favela, caracterizado por estabelecimentos de alimentos, e infraestrutura urbana das favelas do município de São Paulo. Das 1.701 favelas da cidade, apenas 271 têm estabelecimentos alimentares formalmente cadastrados. As favelas maiores e com melhor infraestrutura urbana apresentaram, em geral, um ambiente alimentar com maior acesso a alimentos frescos. Os resultados sugerem que investir em infraestrutura urbana pode ter um efeito positivo sobre o acesso a alimentos frescos nessas áreas. É necessário ainda considerar as especificidades locais para encontrar soluções eficazes que aumentem a disponibilidade de alimentos minimamente processados, melhorando a qualidade de vida e a saúde da população.
Palavras-chave: ambiente alimentar urbano; cadeia de suprimentos alimentar; cadeia de alimentos frescos; infraestrutura urbana; favelas de São Paulo.

Acceso a alimentos frescos en áreas urbanas vulnerables: un estudio clasificatorio de las favelas y establecimientos formales en São Paulo

El entorno influye significativamente en las elecciones alimentarias de los individuos. Las áreas urbanas vulnerables, como las favelas, pueden tener un impacto decisivo en desalentar el consumo de alimentos frescos, ricos en nutrientes. Este problema se agrava por la infraestructura urbana necesaria para que los alimentos frescos lleguen a estos lugares. Por lo tanto, es esencial comprender el contexto de las áreas de favela en el municipio de São Paulo en cuanto al entorno alimentario e infraestructura para apoyar el diseño de políticas públicas que aumenten la presencia de alimentos mínimamente procesados en estos lugares. Para ello, aplicamos el método de agrupamiento k-means a dos conjuntos de datos: el entorno alimentario de las áreas de favela, caracterizado por establecimientos de alimentos, y la infraestructura urbana de las favelas en el municipio de São Paulo. De las 1.701 favelas de la ciudad, solo 271 tienen establecimientos de alimentos registrados formalmente. Las favelas más grandes y con una mejor infraestructura urbana generalmente presentaron un entorno alimentario con un mayor acceso a alimentos frescos. Los resultados sugieren que invertir en infraestructura urbana puede tener un efecto positivo en el acceso a alimentos frescos en estas áreas. También es necesario considerar las especificidades locales para encontrar soluciones efectivas que aumenten la disponibilidad de alimentos mínimamente procesados, mejorando así la calidad de vida y la salud de la población.
Palabras clave: entorno alimentario urbano; cadena de suministro alimentaria; cadena de alimentos frescos; infraestructura urbana; favelas de São Paulo.

1. INTRODUCTION

What features of vulnerable urban areas either promote or obstruct the development of food environments with high nutritional quality? This question is relevant when considering a major, current, and extensively debated issue highlighted in the 2020 report by the Global Panel on Agriculture and Food Systems for Nutrition: around 3 billion people globally are affected by a diet lacking in nutrients, which is linked to 11 million deaths each year. Vulnerable urban regions often have food environments of low nutritional quality, which play a role in one of the most significant challenges facing humanity today, namely, diseases related to diet (Zenk et al., 2005).

The connection between the food environment, infrastructure, and public health is well documented and recognized. Studies show that urban infrastructure features, such as the presence of supermarkets, exercise facilities, safety, and aesthetic considerations, significantly affect the health of disadvantaged and vulnerable populations, especially in terms of obesity and physical activity (Gordon-Larsen et al., 2006; Lovasi et al., 2009). Disadvantaged groups often live in areas with limited access to healthy food choices and inadequate physical activity facilities, leading to health inequalities. Altering the built environment infrastructure to encourage physical activity and healthy eating is a proven method to address obesity (Lovasi et al., 2009).

Obesity, being overweight, and diet-related chronic diseases, such as type 2 diabetes and hypertension, are increasing in low- and middle-income countries (Global Panel on Agriculture and Food Systems for Nutrition, 2020). Addressing this issue is a multidisciplinary challenge of increasing global importance, especially in developing countries (Turner et al., 2019). To ensure the entire population has access to nutritionally high-quality diets, it is crucial to comprehend the infrastructure of the built environment, local food systems, and supply chains, and then to redesign them accordingly.

Infrastructure also has implications for cardiac function and the risk of heart failure. Research has examined the relationships between neighborhood infrastructure, such as food facilities and opportunities for physical activity, and cardiac function. The connections between the built environment and subclinical cardiac dysfunction offer vital evidence on the mechanisms that increase the risk of heart failure (Patel et al., 2020).

The connection between urban infrastructure and public health is not limited to physical wellbeing, but also includes mental health. The state of the built environment can affect community mental health outcomes, and these effects vary across different metropolitan areas (Mukherjee et al., 2021). While the links between the characteristics of the built environment and physical activity are well documented, the influence of urban infrastructure on eating habits is less clear (Murphy et al., 2016). Nevertheless, studies have shown that aspects of the food environment, such as the density and accessibility of food outlets, can shape dietary habits, especially in terms of fruit and vegetable intake (Jaime et al., 2011). Additionally, a higher density of parks and public sports facilities has been associated with a lower incidence of overweight individuals, and vice versa. These insights highlight the importance of integrating urban infrastructure into strategies to promote healthy eating and combat obesity (Jaime et al., 2011).

There is a growing body of evidence that demonstrates a link between the food and built environments and public health. Urban infrastructure has a considerable influence on obesity rates, levels of physical activity, cardiovascular health, mental wellbeing, and dietary habits. Strategies to improve public health should include interventions that alter urban infrastructure to promote healthy behaviors, such as access to nutritious food, physical activity facilities, safety, and aesthetic improvements (Lovasi et al., 2009). By recognizing and addressing the effects of urban infrastructure, policymakers and urban planners can help reduce health disparities and enhance public health.

This study suggests that consuming fruits, vegetables, and greens is a key indicator of a healthy diet. Research has explored how the food environment affects people's access to these types of food (Robinson, 2013). Outlets such as farmers' markets, produce stands, bulk food stores, and supermarkets are considered to support a balanced diet by offering foods that are minimally processed. In contrast, small shops and convenience stores tend to sell ultra-processed items, which are viewed as unhealthy and diminish the nutritional value of the local food environment (Franco et al., 2008; Larson et al., 2009; Romão, 2018).

Urban environments have been associated with improved wellbeing and easy access to goods and services. However, rapid urbanization can lead to increased poverty, higher land costs, informal living and working conditions, and significant disparities in access to fresh food (Fraine et al., 2015; Walker et al., 2010). Romão's (2018) research shows that adolescents who live near farmers' markets or come from wealthier families tend to eat more fruits and vegetables. Living close to outlets selling ultra-processed food is linked to a higher prevalence of overweight individuals. Therefore, while food environments influence diet-related health outcomes, certain vulnerable groups may face risks because of unequal access to fresh food (Wang & Qiu, 2016).

In this context, less affluent and vulnerable areas on the outskirts of major cities do not present commercial appeal for fresh produce retailers to set up their businesses, because of market considerations or local infrastructure challenges (Borges et al., 2018). This situation affects consumer options regarding where to buy and what to eat. Inadequate infrastructure can obstruct the accessibility and development of businesses in low-income neighborhoods (Frayne & McCordic, 2015). For example, with fresh foods, power outages can interfere with product storage, increase perishability, and lead local retailers to prefer selling ultra-processed foods instead.

Limited access to private transportation leads to a dependence on local markets, restricting residents of low-income areas to the products available nearby (Morland et al. 2002). The connection between the food environment and local infrastructure has not been thoroughly researched, and this study seeks to improve our knowledge of this relationship. Wang and Qiu (2016) suggest that such research can identify underserved populations and help in developing policies to improve access to fresh food in low-income neighborhoods.

This study examines the food environment in low-income neighborhoods of São Paulo, especially the favelas, which show differences in urban infrastructure and availability of food stores. São Paulo includes 1,729 favelas within its 96 districts (Habitasampa, 2022), characterized by intricate infrastructure problems, access difficulties, and diverse food environments. The varied nature of the favelas in São Paulo is important from a public health and policy standpoint, necessitating customized supply chain solutions to properly serve the city's most disadvantaged communities. The findings could be applicable to other areas around the world that share similar complexity and diversity.

This study seeks to offer a classification for the favelas in São Paulo by examining the presence of officially registered food businesses and the urban infrastructure available in these areas. We consider only those food establishments that are registered with the Federal Revenue Service, confirming their inclusion in official databases according to the National Classification of Economic Activities (CNAE), the mandatory code for all legal entities used by the Brazilian government. As a result, the study does not include informal trading activities.

During the initial phase, we classified favela areas according to the presence of food establishments, dividing them into three groups: those offering unprocessed foods, those with ultra-processed foods, and those providing a mix of both. In the second phase, we further categorized the favelas based on their local infrastructure, which included elements such as water supply, sanitary sewage systems, household electrical grids, street lighting, and paved roads. To accomplish our goals, we performed cluster analyses using the k-means method to organize and categorize favela areas according to the presence of food establishments and the state of local infrastructure. Additionally, we cross-referenced the two sets of classifications to gain a deeper understanding and to propose tailored strategies for food access in different types of favelas.

2. BRIEF THEORETICAL FRAMEWORK

A significant body of research emphasizes the importance of the food environment in shaping the dietary decisions of a particular neighborhood or community, whether those choices are healthy or not (Bogard et al., 2021). The "food environment" is defined as the setting in which people interact with the food system to acquire and eat food (Turner et al., 2020). In general, the food environment is described as the combined physical, economic, political, and sociocultural context that offers opportunities and conditions that affect the dietary preferences of the population (Swinburn et al., 2013).

According to these definitions, poor dietary habits and the prevalence of obesity are not solely explained by individual determinants, but also by social and built environments that affect individual access to healthy and nutritious foods (Glanz et al., 2005). Borges et al. (2018) clarify that environmental factors associated with consuming a balanced diet include the presence of establishments that offer access to less processed foods, the variety of food outlets in a region, the quality and availability of food-retailing stores, their accessibility (operating hours), pricing, and the placement of products on shelves.

Food environments differ significantly based on context (Grace, 2016). In urban settings, they may be expansive and varied, providing a broad range of options, prices, and places to purchase food, or they may be limited, offering a narrow selection of food items. Consequently, urban food environments can either restrict or encourage dietary choices.

Over 55% of the world's population lives in urban areas (United Nations, 2018). The growing population in the megacities of developing countries poses challenges in distributing food to small retailers. Navarro (2020) shows that low-income areas encounter additional difficulties, such as inadequate infrastructure, limited public and private services, and increased crime rates.

The relationship between the availability of fresh food and neighborhood traits received significant attention in the literature review by Walker et al. (2010), and it continues to draw substantial interest from both policymakers and the public. The concept of "access" encompasses various aspects. Access to fresh food might relate to the presence of stores that sell fresh produce, the closeness and ease of reaching these venues, the prices of the items, their suitability, and the capacity to satisfy the requirements of the local population.

According to Glanz et al. (2005), the presence of unhealthy food outlets, such as convenience stores and fast-food restaurants, near homes and workplaces can obstruct access to a balanced diet. The study shows that the nature of the establishment and the type of food offered can serve as obstacles for vulnerable populations in obtaining a balanced diet. Castro (2018) and Duran (2013) argue that supply structures shape the conditions for food access, with factors such as cost, composition, and quality being heavily influenced by production and distribution methods.

Published evidence suggests that in low- and middle-income countries, food sales mainly take place in small to medium-sized markets (Turner et al., 2020). Retail operations in low-income areas are distinct from those in major retail chains found in higher-income regions. Typically, the distribution of products is more intricate, involving many delivery points and a small drop size because of the limited storage space (Blanco & Fransoo, 2013).

In the context of perishable foods, the complexity increases, requiring suitable infrastructure for refrigeration and storage. Furthermore, access to retailers in low-income neighborhoods may be impeded by substandard pavement quality and elevated crime rates. These precautions raise the operational costs for retailers and their supply chains, resulting in higher-priced products, a reduced selection of fresh foods, and compromised quality.

In favela areas, Duarte et al. (2019) emphasize the challenges of last-mile delivery due to inadequate urban logistics. These challenges include problems with finding addresses on streets that lack names and numbers, dealing with narrow or steep roads that may also include staircases, and the absence of lighting, paving, or sanitation. Additionally, there is a high risk of natural disasters such as floods and landslides, as well as the potential for restrictions caused by criminal activity. Duarte et al. (2019) conclude that the effectiveness of last-mile delivery logistics in favelas depends on the specific local access and infrastructure.

Zmitrowicz and De Angelis (1997) explains that urban infrastructure is composed of various subsystems designed to facilitate services that bolster productive activities, such as the production, distribution, and sale of goods and services. Subsystems that the author identifies include water supply, energy, sewage, and transportation systems. When these subsystems are present and functioning effectively, logistics, distribution, and delivery operations are likely to run smoothly. This ensures that the population has access to goods and services. Consequently, it is crucial to prioritize investment in infrastructure that enables the production, storage, and transportation of these goods as a public strategy (Global Panel on Agriculture and Food Systems for Nutrition, 2016).

In addition to the state of infrastructure and environmental aspects of the food environment in favelas, the purchasing power of the resident families and their eating habits play a crucial role in determining food security. Many studies highlight that favelas are areas characterized by class solidarity, strong community bonds, and industrious residents (Khan, 2020). These communities are also recognized for their creativity and innovation, which can create a positive image with commercial appeal. Initiatives have been launched to integrate favelas into the smart city concept by capitalizing on their creative industries and cultural assets to boost economic prospects (Portugal et al., 2021).

The uneven distribution of resources, along with challenges such as limited infrastructure, informal labor markets, and violence, indicates that the purchasing power of individuals in favelas is often limited (Coutinho, 2014). The lack of basic services, such as access to clean water, sanitation, and reliable electricity, can impede economic development and restrict purchasing power. It is important to note that individual experiences and purchasing power within favelas can differ greatly. While some individuals may be employed in the formal sector, have access to income-generating activities, or receive benefits from government programs designed to alleviate poverty (Gonçalves & Malfitano, 2020), others may face substantial obstacles to economic empowerment and struggle to satisfy their basic needs.

Urban collectives, social movements, and emerging associations in favelas play a crucial role in providing essential services for the community's wellbeing, especially when comprehensive public policies are lacking. They operate on the principle of self-reliance (Fleury, 2023). The importance and effectiveness of these groups became more evident during the pandemic, because they were instrumental in ensuring access to food and preventing hunger among the extremely vulnerable. These solidarity initiatives and collective organizations often pursue political agendas that go beyond immediate crises, such as pandemics, focusing on broader issues including food security, anti-racism, feminism, and the fight against inequality (Abers & Von Bülow, 2021).

3. RESEARCH METHODOLOGY

This quantitative study examines the food environment and urban infrastructure in low-income areas. The empirical analysis uses data from the Brazilian Federal Revenue (2021) and Geosampa (2021) to classify favela regions within the São Paulo municipality. Initially, it is crucial to classify favela areas based on food environments and urban infrastructure. To achieve this, we employed the clustering method, which groups similar objects into distinct clusters. This method partitions the data set into subgroups that meet specific criteria for distance and similarity (Omran et al., 2007).

Distinct groups were identified using a k-means cluster analysis, which determines the center of each cluster by calculating the mean. The Euclidean distance served as the dissimilarity measure. To decide on the number of clusters, the Calinski-Harabasz pseudo-F statistic was employed, calculated as the ratio of the sum of squares between clusters to the sum of squares within clusters. The objective was to divide the sample into groups that are internally consistent, yet distinct from each other. The k-means algorithm calculation is shown in Equation 1:

$$S\left(\{G_j\}_{j=1}^{K}\right) = \sum_{j=1}^{K} \sum_{x \in G_j} \left\|x - c_j\right\|_1$$

Here, given a set of x data points, *K* centroids must be selected to minimize the sum of the distances (S) from each data point x to its nearest centroid, based on the group's mean . To obtain the results, we perform two cluster analyses:

1) We categorize environmental food classifications in favelas by clustering the number of establishments that sell raw, mixed, and ultra-processed foods. Out of 1,704 favelas in the sample, only 271 have at least one of these establishments. The analysis includes the total number of households in each favela, as reported by Geosampa (2021), to represent the size of the favela and indicate the concentration of food establishments in each area.
2) We cluster infrastructure variables in favela territories. Only 1,660 favelas provide information on their infrastructure. The data used for this analysis included elements such as water supply, sanitary sewage, household electrical grid, street lighting, and paved roads.

All clustering was performed in the Stata software using the "cluster" package and the k-means algorithm.

3.1. Search variables

3.1.1. Variables related to the food environment

The NOVA food classification system developed by Monteiro et al. (2016) categorizes foods into four groups: unprocessed or minimally processed, processed culinary ingredients, processed food and ultra-processed, based on the industrial methods used to preserve, extract, modify, or produce them.

This study categorizes establishments according to the type of food they market, following the classification system by Monteiro et al. (2016). The classifications are based on the CNAE codes (Box 1) associated with businesses located in the favela regions of São Paulo's districts. This information was obtained from the 2021 data of the Brazilian Federal Revenue. The methodology for clustering these establishments is in line with the "Mapping Food Deserts in Brazil" technical study conducted by the Interministerial Chamber of Food and Nutritional Security (Câmera Interministerial de Segurança Alimentar e Nutricional [Caisan], 2018, pp. 17-18).

BOX 1 CNAE LIST AND ESTABLISHMENT CLASSIFICATION

Unprocessed food establishments	Mixed food establishments	Ultra-processed food establishments
CNAE 47.22-9/01: Butcher shops	CNAE 47.11-3/01: Hypermarkets	SIC 47.21-1/03: Retailers of dairy and deli products
CNAE 47.22-9/02: Fishmongers	CNAE 47.11-3/02: Supermarkets	CNAE 47.21-1/04: Retailers of confectionery, candies, chocolates, and similar products
CNAE 47.24-5/00: Retailers of fruits and vegetables	CNAE 47.12-1/00: Mini-markets, grocery stores, and warehouses	CNAE 47.29-6/02: Convenience stores
	NACE 47.21-1/02: Bakeries and pastry shops	CNAE 56.11-2/03: Snack bars and tea houses, juice bars and similar establishments
	SIC 47.29-6/99: General food product retailers	CNAE 56.20-1/03: Private dining and catering services
	CNAE 56.11-2/01: Restaurants and similar establishments	
	CNAE 56.12-1/00: Mobile food services	
	CNAE 56.20-1/04: Provision of prepared foods for home consumption	

Source: Elaborated by the authors and based on the Caisan report. (2018).

Following the classification system by Monteiro et al. (2016), the study adopted the number of establishments in favela areas based on the aggregation of CNAE types. The use of absolute numbers, rather than proportions or densities, is because of the typically low count of establishments in these areas. To represent the size of each favela, we use the variable "number of households" for the favelas under examination.

3.1.2. Infrastructure-related variables

The infrastructure variables for favela areas were obtained from GeoSampa (2021). Following the conceptual framework established by Zmitrowicz and De Angelis (1997), the analyzed variables, all represented as percentages, consist of water supply, sanitary sewage, household electrical grid, street lighting, and paved roads.

4. RESULTS

4.1. Descriptive Analysis of Districts Regarding the Food Environment in São Paulo's Favelas

Table 1 displays the distribution of food establishments by food group within the favelas of São Paulo municipality.

TABLE 1 DESCRIPTIVE VALUES OF FOOD ENVIRONMENT VARIABLES

	Type of food environment	No. observations	Average	Standard deviation	Minimum	Maximum
Favelas with food establishments	Unprocessed	271	1.25	5.46	0	75
	Mixed	271	11.81	42.81	0	566
	Ultra-processed	271	2.38	8.46	0	106
Favelas lacking food establishments		1433				

Source: Elaborated by the authors based on data from the Federal Revenue Service (2021).

Table 1 clearly shows that only about 16% of the favelas in the São Paulo municipality (271 in total) have at least one kind of establishment (i.e., unprocessed, mixed, or ultra-processed). On average, there are 1.25 stores selling unprocessed foods. The average number of stores primarily selling ultra-processed food is about twice as high as those selling unprocessed foods, at 2.38, while establishments offering a mix of foods are more common, with an average of around 12 stores. The standard deviation indicates a significant heterogeneity in access to food within the favelas, even though food establishments are present.

The heterogeneity within favela infrastructure is clear from the data presented in Table 2. It shows that the average availability of sanitary sewage services, at 30%, is lower than that of other utilities. In contrast, services such as water supply, electrical grid, public lighting, and paved roads have an average availability of around 50%. The standard deviation is consistent across all five variables.

TABLE 2 DESCRIPTIVE ANALYSIS OF INFRASTRUCTURE VARIABLES IN SÃO PAULO'S FAVELAS

Variable	Number of observations	Average	Standard deviation	Minimum	Maximum
% Water supply	1660	582	370	0	1
% Sanitary sewage	1660	305	359	0	1
% Electrical grid	1660	500	396	0	1
% Street lighting	1660	494	383	0	1
% Paved roads	1660	556	408	0	1

Source: Elaborated by the authors based on data from Geosampa (2021).

4.2. Clustering and classification of food environments in favela areas

A cluster analysis shows that the food environments in São Paulo's favelas are significantly different. Of the total, 1,433 favelas lack food establishments, while the remaining 271 have a wide range of characteristics. Table 3 presents the results of the k-means algorithm applied to cluster the environmental food variables.

TABLE 3 SUMMARY OF THE NUMBER OF FAVELAS, AVERAGE VALUES, AND STANDARD DEVIATION PER CLUSTER

	Favela Counts	Average number of unprocessed food establishments per favela	Average number of mixed food establishments per favela	Average number of ultra-processed food establishments per favela	Average Number of households per favela
Cluster 1: Environment with relative access to mixed food establishments and a higher number of households	39	769 -959	11.48 (11.07)	1.89 (2.28)	1,062.87 (213.53)
Cluster 2: Environment with moderate access to food establishments in general	14	3 (3.42)	29.35 (28.44)	5.92 (8.87)	2,366.07 (662.45)

Continua

	Favela Counts	Average number of unprocessed food establishments per favela	Average number of mixed food establishments per favela	Average number of ultra-processed food establishments per favela	Average Number of households per favela
Cluster 3: Environment with limited access to food establishments, in general	134	0.64 (1.54)	4.90 (6.95)	1.18 (1.73)	160.14 (92.28)
Cluster 4: Environment with relative access to mixed food establishments and fewer households	82	0.76 (1.75)	8.84 (9.95)	1.75 (2.57)	509.10 (124.82)
Cluster 5: Environment with greater access to food establishments in general	2	59 (22.62)	480.5 (120.91)	93 (18.38)	16,501 -930,553
Favelas with food establishments (Clusters 1, 2, 3, 4, 5)	271	1.25 (5.46)	11.81 (42.81)	2.38 (8.46)	630.20 -1484,18
Favelas lacking food establishments	1391				149.22 (231.56)

Source: Elaborated by the authors using data from the Federal Revenue Service.

The clusters described in Table 3 have the following characteristics:

a) Cluster 1 consists of 39 favelas and is marked by a moderate number of mixed food establishments, which is less than those found in clusters 2 and 5. Additionally, this cluster has a relatively large number of households, yet these households have limited access to establishments selling unprocessed and ultra-processed foods.
b) Cluster 2 includes 14 favelas and features an average household density along with a moderate number of different food establishments. It ranks slightly below Cluster 5, which is made up of two favelas.
c) Cluster 3 is characterized by a significant presence of favelas, totaling 134, and has the fewest fresh food outlets, mixed food services, and ultra-processed food establishments. Additionally, this cluster has the smallest number of households.

d) Cluster 4 is distinguished by its relatively easy access to various food establishments and a lower number of households. As the second-largest group, with 82 favelas, it features a low average number of three distinct types of food commerce locations. Among these, only the mixed diet category showed a minimal result.
e) Cluster 5 consists of only two favelas, Heliópolis and Paraisópolis, which are characterized by a high density of various types of food retailers and a significant number of households.

4.3. Clustering and classification of favela areas in districts based on infrastructure

Considering only the favelas that have formal establishments, the classification related to infrastructure suggests that areas with very poor infrastructure can still support food establishments. On average, the infrastructure in favelas with food establishments does not significantly differ from those without them, as shown in Table 4.

TABLE 4 SUMMARY OF THE COUNT OF FAVELAS, AVERAGE VALUES AND STANDARD DEVIATION PER CLUSTER

	Total number of Favelas	Water supply	Sanity sewage	Electrical grid	Paved roads	Street lighting
Cluster 1 - Higher infrastructure levels	132	0.81 (0.19)	0.54 (0.32)	0.74 (0.26)	0.80 (0.22)	0.71 (0.28)
Cluster 2 - Lower infrastructure levels	136	0.36 (0.26)	0.13 (0.20)	0.21 (0.26)	0.26 (0.29)	0.29 (0.26)
Favelas with food establishments	268	0.58 (0.32)	0.33 (0.34)	0.47 (0.37)	0.53 (0.37)	0.50 (0.34)
Favelas lacking food establishments	1392	0.58 (0.37)	0.29 (0.36)	0.50 (0.40)	0.56 (0.41)	0.49 (0.39)

Note: The differences in the number of observations between Tables 4 and 5 are because of missing values in some variables.

Source: Elaborated by the authors based on data from Geosampa (2021).

The classification of favelas in São Paulo's districts into two clusters is possible by examining the urban infrastructure variables outlined in Table 4. Cluster 1 represents favelas with higher average infrastructure values, whereas Cluster 2 consists of favelas with lower infrastructure values.

a) Cluster 1 comprises 132 favelas and exhibits higher values for all analyzed infrastructure variables. Notably, the rates of water supply and paved roads are impressive, with average values exceeding 80%. Conversely, the sewage infrastructure is notably deficient.

b) Cluster 2 encompasses 136 favelas characterized by regions with inadequate infrastructure in all aspects. Note the particularly low average values for sanitary sewage and the household electrical grid.

4.4. Unified classification of favela areas of districts: food and infrastructure environment

This section seeks to interpret the relationships between the two classifications based on clustering analyses of the food environment and urban infrastructure in São Paulo's favelas.

Table 5 presents the cross-classification of food environment and infrastructure, while Table 6 details the comparison of infrastructure parameters across clusters. As expected, favelas with higher infrastructure levels show better facilities in all assessed criteria. There is a higher standard deviation in infrastructure within favelas that lack food establishments, indicating greater variability. Notably, Cluster 5, which includes mega-slums, does not contain any areas classified as having low levels of infrastructure.

Table 5 shows that the distribution of observations is uniform across both the environmental and the infrastructure categories. A significant difference is observed in Cluster 1, where most observations (26) are categorized as having lower-level infrastructure, and only 30% (11) are associated with better infrastructure. Although these are medium-sized favelas, with more than a thousand households and some food establishments, they typically have the poorest infrastructure compared to other clusters, as shown in Table 6.

Cluster 2 includes only 13 favelas, which make up 4.85% of the total, and are primarily medium to large in size, with more than 2,000 households each. These favelas have significantly better infrastructure than those in Cluster 1, with a higher proportion of sewage systems, water supply, and paved roads compared to Clusters 2 and 3. This improved infrastructure likely explains the increased number of food establishments found within these favelas.

Clusters 3 and 4 comprise 80% of São Paulo's favelas, which are relatively small, with fewer than 600 households as shown in Table 3, and possess, on average, moderate infrastructure. These favelas often benefit from the nutritional environment of nearby areas because they host a limited number of food establishments. The level of infrastructure in these favelas is comparable to that in even smaller favelas that do not have food establishments.

Finally, Cluster 5 includes the two largest favelas in São Paulo, which are considered mega-slums, with an average of over 16,000 households each. The food environment in these areas is plentiful with various establishments, but it displays a trend where there are nearly twice as many businesses primarily selling ultra-processed foods as there are those providing unprocessed foods. Additionally, these two favelas possess infrastructure that is significantly more developed than that of other favelas.

The infrastructure coverage in Heliópolis and Paraisópolis is very good, including paved roads, electrical grids, and water supply systems that support distribution operations. In these areas, coverage for these three factors is nearly or above 80%, while in other clusters, the maximum coverage for this parameter is only 60%. This trend is expected because it relates to well-established favelas that are increasingly the focus of state investments and enhancements for the benefit of the residents.

TABLE 5 DISTRIBUTION AND CLASSIFICATION OF FAVELAS IN SÃO PAULO MUNICIPALITY BY FOOD ENVIRONMENT AND INFRASTRUCTURE

		Infrastructure (number of observations)		
		Highest level infrastructure	Lower level infrastructure	Total per item
FOOD ENVIRONMENT	Cluster 1: Environment with relative access to mixed food establishments and a higher number of households	11 -4,10%	26 (9.70%)	37 (13.80%)
	Cluster 2: Environment with moderate access to food establishments in general	7 (2.61%)	6 (2.24%)	13 (4.85%)
	Cluster 3: Environment with limited access to food establishments in general	70 (26.12%)	64 (23.88%)	134 (50.00%)
	Cluster 4: Environment with relative access to mixed food establishments and fewer households	42 (15.67%)	40 (14.93%)	82 (30.60%)
	Cluster 5: Environment with greater access to food establishments in general	2 (0.75%)	0 (0.00%)	2 (0.75%)
	Favelas with food establishments (clusters 1, 2, 3, 4, 5)	132 (49.25%)	136 (50.75%)	268 -100%
	Favelas lacking food establishments	732 (52.59%)	660 (47.41%)	1392 -100%

Source: Elaborated by the authors.

TABLE 6 RELATIONSHIP BETWEEN FOOD ENVIRONMENT AND INFRASTRUCTURE VARIABLES IN FAVELAS IN THE SÃO PAULO MUNICIPALITY

		Highest level infrastructure	Lower-level infrastructure	Total per item
Cluster 1: Environment with relative access to mixed food establishments and more households	Water supply	0.72 (0.17)	0.27 (0.25)	0.40 (0.30)
	Sanitary sewage	0.50 (0.31)	0.13 (0.16)	0.24 (0.27)
	Home electrical grid	0.70 (0.21)	0.20 (0.23)	0.35 (0.32)
	Paved roads	0.78 (0.18)	0.28 (0.28)	0.43 (0.34)
	Street lighting	0.65 (0.25)	0.35 (0.27)	0.44 (0.30)

Continue

		Highest level infrastructure	Lower-level infrastructure	Total per item
Cluster 2: Environment with moderate access to food establishments in general	Water supply	0.72 (0.20)	0.50 (0.31	0.62 (0.27)
	Sanitary sewage	0.66 (0.26)	0.23 (0.16)	0.46 (0.30)
	Home electrical grid	0.69 (0.18)	0.11 (0.18)	0.42 (0.34)
	Paved roads	0.77 (0.23)	0.51 (0.28)	0.65 (0.28)
	Street lighting	0.58 (0.26)	0.25 (0.14)	0.43 (0.27)
Cluster 3: Environment with limited access to food establishments in general	Water supply	0.81 (0.21)	0.38 (0.28)	0.61 (0.33)
	Sanitary sewage	0.52 (0.36)	0.14 (0.25)	0.34 (0.36)
	Home electrical grid	0.72 (0.29)	0.20 (0.27)	0.47 (0.38)
	Paved roads	0.84 (0.22)	0.21 (0.29)	0.54 (0.40)
	Street lighting	0.76 (0.27)	0.27 (0.27)	0.52 (0.36)
Cluster 4: Environment with relative access to mixed food establishments and fewer households	Water supply	0.84 (0.17)	0.37 (0.22)	0.61 (0.31)
	Sanitary sewage	0.56 (0.27)	0.08 (0.13)	0.33 (0.32)
	Home electrical grid	0.79 (0.21)	0.24 (0.27)	0.52 (0.36)
	Paved roads	0.75 (0.24)	0.29 (0.28)	0.52 (0.34)
	Street lighting	0.67 (0.29)	0.30 (0.23)	0.49 (0.32)
Cluster 5: Environment with greater access to food establishments in general	Water supply	0.81 (0.02)	-	0.81 (0.02)
	Sanitary sewage	0.61 (0.01)	-	0.61 (0.01)
	Home electrical grid	0.77 (0.24)	-	0.77 (0.24)
	Paved roads	0.88 (0.12)	-	0.88 (0.12)
	Street lighting	0.58 (0.02)	-	0.58 (0.02)

Continue

		Highest level infrastructure	Lower-level infrastructure	Total per item
Favelas with food establishments (clusters 1, 2, 3, 4, and 5)	Water supply	0.81 (0.19)	0.36 (0.26)	0.58 (0.32)
	Sanitary sewage	0.54 (0.32)	0.13 (0.20)	0.33 (0.34)
	Home electrical grid	0.74 (0.25)	0.21 (0.26)	0.47 (0.37)
	Paved roads	0.80 (0.22)	0.26 (0.29)	0.53 (0.37)
	Street lighting	0.71 (0.28)	0.29 (0.25)	0.50 (0.34)
Favelas lacking food establishments	Water supply	0.83 (0.22)	0.30 (0.31)	0.58 (0.37)
	Sanitary sewage	0.48 (0.38)	0.09 (0.17)	0.29 (0.36)
	Home electrical grid	0.79 (0.25)	0.18 (0.26)	0.50 (0.40)
	Paved roads	0.81 (0.28)	0.28 (0.35)	0.56 (0.41)
	Street lighting	0.72 (0.31)	0.23 (0.29)	0.49 (0.39)

Source: Elaborated by the authors.

5. CONCLUSION

A healthy diet, which emphasizes fresh and minimally processed foods, goes beyond social considerations, and is influenced by public policy and economic factors. There is a link between poor dietary habits and a higher risk of diseases, such as diabetes and obesity. Stores that sell fruits, vegetables, and legumes are linked to higher consumption of these items (Gordon-Larsen et al., 2006; Lovasi et al., 2009), yet these stores are often found in wealthier neighborhoods (Morland et al., 2002). In low-income urban areas, like the favelas of São Paulo, the limited availability of fresh food is a pressing issue that deserves attention because it contributes to diet-related diseases (Zenk et al., 2005).

Ensuring the availability of these foods in certain areas poses a challenge for the food supply chain. It is essential to consider the unique characteristics of these foods during logistical planning and to address the political and social issues caused by inadequate or nonexistent urban infrastructure in these areas. The lack of road paving, public lighting, household electrical grids, water supply, sewage systems, garbage collection, and stormwater drainage makes it difficult to provide services and supply food to the population in these regions.

This study aimed to contribute to effective solutions for the challenges faced by categorizing urban areas based on their food environment and infrastructure, to better understand the heterogeneity within São Paulo's favelas. Note that favelas show considerable heterogeneity in size and infrastructure, as demonstrated by Duarte et al. (2019). The research indicates that this diversity is not limited to these aspects, but also includes the variety found in the formal food environment.

Most favelas in São Paulo (84%) do not have any formal food establishments, even those with less precarious infrastructure. This finding supports the challenges and complexities in supplying retailers in low-income areas, as identified by Blanco and Fransoo (2013).

A notable characteristic of favelas without formal food establishments is their small number of households. Smaller favelas may not generate enough demand to support these businesses financially. In these cases, the nearby area becomes important, because it is probable that many food purchases take place in adjacent neighborhoods. While this study does not specifically concentrate on this aspect, the availability of public transportation infrastructure can be crucial in providing an appropriate food environment for these communities.

A notable discovery is that in favelas with established food outlets, which constitute 16% of the total, the number of stores selling ultra-processed foods is almost double the number of those offering unprocessed foods. Drawing on Franco et al. (2008), Larson et al. (2009), and Romão (2018), who propose that the built environment influences the nutritional quality of a community's diet, it is evident that the vulnerable populations in favelas are also exposed to diets of low nutritional value. These individuals face limited access to fresh foods and encounter a high prevalence of ultra-processed foods, increasing the risk of diet-related health issues.

In the context of infrastructure, the analysis revealed that most clusters have a similar count of favelas with formal food establishments, regardless of the local infrastructure's quality. The favelas' size was the primary factor influencing the quantity of food establishments. Nevertheless, this does not lessen the importance of infrastructure for the existence of these shops, especially those focusing on selling fresh, unprocessed food. Larger favelas exhibited better infrastructure in almost all areas studied, with a notably higher number of such shops. This suggests that a fundamental level of infrastructure is necessary for retailers to successfully set up in these areas, as noted by Frayne and McCordic (2015).

The objective of this study was to highlight the varied characteristics of favelas across multiple dimensions and to stress the significance of acknowledging these distinctions when addressing the issue of poor nutrition in low-income neighborhoods. Successful public policies should consider the unique needs and preferences of each area, pursuing tailored and context-specific strategies. This requires involving the local community in the decision-making process to create solutions that are both socially relevant and economically feasible, with the goal of improving food quality in vulnerable communities.

The challenge involves creating sensitive and adaptable public policies that address the disparities in favelas. It is crucial to consider the socioeconomic, cultural, and environmental diversity of each area to promote healthy and accessible nutrition for everyone. Recognizing the unique characteristics and aspirations of each community allows for the development of effective interventions tailored to meet the specific needs of the favelas, thus improving nutritional quality.

This study has a limitation in that it only considered formal establishments when assessing the diversity of food environments. Informal settings, such as home-based sales or street vending, were not included. Moreover, it is possible that residents of a particular region may consume food bought from sales outlets and businesses in adjacent districts, an aspect that this study did not explore.

This study's limitations, which also suggest avenues for future research, include the lack of scientific literature on Brazil's food environment, especially in low-income urban areas. Most existing research on this subject comes from developed countries. Our study adds to the body of knowledge by categorizing the favelas of São Paulo based on their food environment and urban infrastructure.

The analysis of conditions reveals opportunities in public policy, mobility, urban logistics, and supply chain management that are applicable to low-income urban areas, considering their distinct context. To explore these opportunities, a deeper understanding of these locations is necessary. It is recommended to carry out qualitative studies in these areas to map potential informal trade and community-led solutions in the favelas that offer minimally processed foods. Furthermore, investigating additional formal or informal infrastructures could provide additional insights.

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André Luís de Castro Moura Duarte

Master and PhD in Business Administration from Fundação Getulio Vargas (FGV EAESP); Senior Teaching Fellow at Insper Institute for Teaching and Research. E-mail: andre.duarte@insper.edu.br

Vinicius Picanço Rodrigues

Master in Operations Research from the Federal University of São Carlos (UFSCar); Ph.D. in Engineering from the Technical University of Denmark (DTU); Assistant Professor at Insper Institute of Education and Research. E-mail: vinicius.picanco@insper.edu.br

Raquel Carolinne Freitas Alves

Master in Business Administration from Insper Institute of Education and Research.
E-mail: raquelcfa@al.insper.edu.br

Gustavo Magalhães de Oliveira

Master's and Doctorate in Business Administration from the University of São Paulo (FEA-USP).
E-mail: gusmoliv@uni-bonn.de

AUTHOR'S CONTRIBUTION

André Luís de Castro Moura Duarte: Conceptualization (Lead); Data curation (Equal); Formal Analysis (Lead); Funding acquisition (Lead); Investigation (Lead); Methodology (Supporting); Project administration (Lead); Resources (Equal); Supervision (Lead); Validation (Supporting); Visualization (Supporting); Writing - original draft (Equal); Writing - review & editing (Equal).

Vinicius Picanço Rodrigues: Conceptualization (Lead); Data curation (Equal); Formal Analysis (Lead); Funding acquisition (Lead); Investigation (Lead); Methodology (Supporting); Project administration (Supporting); Resources (Equal); Supervision (Supporting); Validation (Supporting); Visualization (Supporting); Writing - original draft (Equal); Writing - review & editing (Equal).

Raquel Carolinne Freitas Alves: Conceptualization (Equal); Data curation (Equal); Formal Analysis (Equal); Investigation (Equal); Methodology (Equal); Project administration (Equal); Visualization (Supporting); Writing - original draft (Lead).

Gustavo Magalhães de Oliveira: Conceptualization (Equal); Data curation (Lead); Formal Analysis (Equal); Investigation (Equal); Methodology (Supporting); Supervision (Supporting); Validation (Supporting); Visualization (Support); Writing - original draft (Supporting); Writing - review & editing (Supporting).

DATA AVAILABILITY

The entire data set supporting the results of this study is available on Dropbox: https://www.dropbox.com/scl/fi/ux4awc57dnqhdbtoc3q7p/RawData_Clusters-VF.xls?rlkey=a0m0hprr659fqiwtd1n1quj2q&dl=0. If necessary, consult the author André Luís de Castro Moura Duarte (andrelcmd@insper.edu.br).

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