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Raquel Canuto, Giovani Longo Rosa, Lauren Yurgel da Silva, Dafne Pavão Schattschneider, Fernanda Bortolaz Pivetta, Willian Luiz da Conceição, Júlio Celso Borello Vargas, Marcos Fanton

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Raquel Canuto [1,2] https://orcid.org/0000-0002-4042-1913
Giovani Longo Rosa [3] https://orcid.org/0000-0002-7947-7180
Lauren Yurgel da Silva [1] https://orcid.org/0000-0002-5907-566X
Dafne Pavão Schattschneider [1,2] https://orcid.org/0000-0002-0201-206X
Fernanda Bortolaz Pivetta [1] https://orcid.org/0009-0007-2349-4890
Willian Luiz da Conceição [4] https://orcid.org/0000-0003-0100-0080
Marcos Fanton [5] https://orcid.org/0000-0001-5360-3647
Júlio Celso Borello Vargas [3] - https://orcid.org/0000-0001-8321-5362

1 Postgraduate Program in Food, Nutrition and Health, Universidade Federal do Rio Grande do Sul, Rua Ramiro Barcelos, 2400, Porto Alegre, RS 90035-003, Brazil
2 Postgraduate Program in Epidemiology, Universidade Federal do Rio Grande do Sul, Rua Ramiro Barcelos, 2400, Porto Alegre, RS 90035-003, Brazil

3 Postgraduate Program in Urban and Regional Planning, Universidade Federal do Rio Grande do Sul, Rua Sarmento Leite, 320, Porto Alegre, RS 90050-170, Brazil

4 Postdoctoral researcher in Global Labor History in the Graduate Program in History, Universidade Federal de Santa Catarina, Campus Universitário Reitor João David Ferreira Lima, Trindade, s/nº, Florianópolis, SC, 88035-972, Brazil.

5 Postgraduate Program in Philosophy, Universidade Federal de Santa Maria, Av. Roraima, 1000, Camobi, Santa Maria, RS 97105-900, Brazil

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Abstract

Food deserts represent a critical dimension of food insecurity and health, yet their relationship with racial spatial segregation remains understudied in Global South contexts. This study examines the relationship between racial spatial segregation and the presence of food deserts across 319 Brazilian cities with more than 100,000 inhabitants. Using data from the 2022 Census, we calculated the proportion of Black residents in 231,901 census tracts and classified food retail availability based on the Locais–Nova classification of food establishments. Food deserts were defined as tracts with a density of healthy food outlets below the 25th percentile. Racial spatial segregation was assessed using Local Indicators of Spatial Association to identify local patterns of racial concentration and contrast. More than 77% of Brazilian urban census tracts were classified as food deserts, with high prevalence in the North and Northeast regions. Poisson models showed that racial spatial segregation remained significantly associated with the prevalence of food deserts after adjustment for income: High–High clusters, areas where Black populations are spatially grouped with similar neighboring tracts, had 30% (95% CI: 1.29–1.32) higher probability to be a food desert when compared with compared to Low-Low clusters, those tracts with a predominance of White residents in predominantly White surroundings. These findings demonstrate that racial spatial segregation independently contributes to unequal access to healthy food retail, reinforcing structural disadvantages faced by Afro-Brazilian communities.

Keywords: racism, racial segregation, spatial segregation, food environment

Introduction

The food environment has become an increasingly critical focus in the study of social and structural determinants of health, particularly due to its role in shaping dietary behaviors, food security, and nutrition-related health [1]. From an ecological perspective, community food environments influence eating patterns and health outcomes through the quantity and quality of food retail options, such as supermarkets, restaurants, and grocery stores, within a specific neighborhood. The spatial distribution of these establishments determines the accessibility and availability of healthy and affordable food choices and habits [2,3]. Food environments are the result of intertwined historical, political, and economic processes driven by various actors, including the private food industry, government, and society. These complex dynamics give rise to distinct and unequal patterns of food environments that shape how individuals and groups interact with the food system. This is particularly evident in neighborhoods already burdened by other dimensions of structural injustice, such as residential segregation, environmental pollution, inadequate public services and safety. Within this broader landscape of structural and social determinants, inequitable food environments do not emerge in isolation; they reflect and reinforce long-standing economic and racial or ethnic hierarchies. Emerging from these inequities is the concept of the food desert, defined as socioeconomically vulnerable areas where individuals have little or no access to healthy foods [4].

A systematic review and meta-analysis demonstrated that ethnic-racial minoritized populations, especially Black, Latinos and Indigenous, are disproportionately exposed to unhealthy food environments. Ethnic-racial minoritized groups are 70% more likely to live in food deserts than other racial, and ethnic groups. This review also revealed a striking geographical gap in the literature: over 88% of included studies were carried out in the U.S., with limited empirical research addressing the food environments of racially minoritized groups in Global South contexts [5].

Despite the overwhelming predominance of U.S.-based studies, Brazil is consistently represented in recent studies on food environment disparities [6–8]. However, empirical research primarily utilizes measures of racial concentration (i.e., the percentage of Black or Brown residents), and none of these studies have employed explicit spatial measures of segregation [5,9]. This analytical gap represents a significant limitation to a comprehensive understanding of how race, space, and access to food interact in Global South contexts.

Broadly speaking, segregation describes how different social groups become unevenly arranged at multiple spatial and structural levels, such as neighborhoods, schools, hospitals, or communities, and how they interact socially within these structures [10]. Segregation has been understood as a structural determinant of health, since opportunities, public services, and social institutions are unequally distributed across geographic areas, often reflecting the economic and social composition of each neighborhood or community. When these resources are concentrated in certain locations and scarce in others, the spatial arrangement of social groups determines how individuals will gain access and interact with them [11,12].

Racial spatial segregation refers to the physical and geographic separation of people into different neighborhoods or areas based on race or ethnicity [13]. This phenomenon often results from a combination of historical, political, economic, and social processes, including discriminatory housing policies, real estate practices, income inequality, and institutional racism, that shape where people live [14,15]. Thus, racial spatial segregation goes beyond simple inequality in population distribution, configuring itself as an active mechanism for the production and reproduction of social and racial hierarchies and subordination in urban space. It is important to note that quantitative studies on racial segregation and health outcomes in Brazil remain very limited [11], and existing patterns of segregation may exacerbate food insecurity, restrict access to healthy and culturally appropriate foods, and contribute to higher rates of diet-related diseases among Black Brazilians. Therefore, this study aims to examine the relationship between racial spatial segregation and the presence of food deserts in major Brazilian cities.

Methods

Study Design and Population

This is an ecological study whose units of analysis are the urban census tracts of 319 Brazilian municipalities with more than 100,000 inhabitants in 2022. Brazil is a federative republic divided into five official macro-regions (North, Northeast, Southeast, South, and Center-West), which group states according to geographic, cultural, and socioeconomic characteristics. The country is also composed of 26 states and one Federal District, together encompassing 5,570 municipalities. Approximately 50% of Brazilians (115 million) live in the 319 cities with more than 100,000 inhabitants [16].

Data Collection and Assessment

Community Food Environment: Food deserts

The community food environment was assessed according to the availability of retail food. Food retail data from all 2022 census tracts were extracted from the Annual Report of Social Information (RAIS). The Secretary of Labour of the Brazilian Ministry of Economy requests the information from legal entities and other employers annually to standardize the classification of companies according to their main economic activities, which allows the identification of the type of establishment (e.g., supermarket, fruit and vegetable market, canteen). This database provides data on the type of establishment and its location based on the postal address code.

Two geoprocessing stages were conducted to obtain geographic coordinates for food establishments, using ZIP code centroids of the census tracts as the inclusion criterion. Initially, 483,998 food establishments located in municipalities with at least 100,000 inhabitants were considered. In the first stage, 447,781 establishments were successfully georeferenced using the geocodebr R package [17], based on the ZIP code field. Records that could not be matched by ZIP code were reprocessed in a second stage using the Google Maps API via Awesome Table. After data cleaning and the exclusion of establishments returned only as municipality centroids or with invalid information, a total of 470,405 establishments (97.2%) were successfully georeferenced and included in the analysis. These losses were likely random, since no differences were found when analyzing them according to macro-regions.

The food establishments were classified according to the Locais–Nova methodology [18]. Locais–Nova is based on the NOVA classification, which is a widely recognized system that categorizes foods according to the extent and purpose of their processing. It includes four groups: (G1) unprocessed or minimally processed foods, such as fruits, vegetables, grains, milk, and eggs, which preserve their natural characteristics; (G2) processed culinary ingredients like oils, sugar, and salt, used in cooking; (G3) processed foods, such as canned vegetables and cheeses, made by adding culinary ingredients to whole foods; and (G4) ultra-processed foods, which are industrial products made mostly from food-derived substances and additives, such as soft drinks, packaged snacks, and instant meals(30).

The Locais-Nova methodology used data from the 2017–2018 Brazilian Household Budget Survey to categorize types of establishments according to household food acquisition profiles. For this categorization, cut-off points were established based on the average percentage contribution of each food group to the total grams purchased in each macro-region of the country (North, Northeast, Southeast, South, and Center-West). The average percentage of the contribution of each food group at each place of acquisition was compared. When the average percentage contribution of a food group in a given place of acquisition was equal to or greater than the average contribution of the macro-region under analysis, that place was classified as a source of acquisition for that food group [18]. Unprocessed or minimally processed foods and processed culinary ingredients were evaluated as a single group (G1+G2) in the Locais-Nova methodology. The final classification of food retail establishments into groups G1+G2, G3, and G4 is presented in the Supplementary Table 1.

Based on the classification of establishments, food deserts were defined as census tracts in which the number of G1+G2 businesses per 10,000 inhabitants falls below the 25th percentile of the distribution of this ratio (no/yes) [6].

Racial Spatial Segregation

Data on self-identified race/skin color (Black, Brown, and White) and population counts were obtained from the 2022 Census conducted by the Brazilian Institute of Geography and Statistics (IBGE). For the segregation analyses, the proportion of Black, Brown, and White residents in each census tract was calculated by dividing the population of each race/skin-color group by the total population of the tract.

Racial segregation was assessed using a Local Indicator of Spatial Association (LISA) to identify local patterns of spatial autocorrelation by comparing the distribution of Black residents (self-identified as Brown or Black) and White residents. The analysis was implemented with the Python library PySAL [19]. In Brazil, anti-black racism targets the Black population, understood as all individuals who self-identify as Black or Brown and who, collectively, are classified as Black ("negros") by official statistics and Black social movements. This group constitutes the Afro-Brazilian population, which experienced historical and contemporary experiences shaped by colonialism, slavery, racialized exclusion, and enduring socioeconomic inequalities.

Spatial autocorrelation is a family of spatial indices designed to measure the degree to which the values of a particular variable in one location tend to be similar or dissimilar to the values of that same variable in its surrounding locations, effectively quantifying the correlation of a variable with itself while accounting for its spatial distribution [20]. Positive spatial autocorrelation occurs when similar values cluster together, negative autocorrelation occurs when units are surrounded by contrasting values, and values near zero indicate a random distribution [20]. This method allows for the detection of clusters of racial composition, indicating areas where the proportion of a given racial group is significantly higher or lower than expected in relation to neighboring tracts [21,22].

The analysis uses the Univariate Local Moran's I [21] to indicate the spatial autocorrelation. It applies the "Queen" contiguity criterion to define spatial neighbors between census tracts, because it considers both common edges and vertices, capturing more nuanced spatial relationships in irregular urban grids, such as the Brazilian census tracts mesh [23].

LISA results can be interpreted as follows: High–High (HH) clusters represent census tracts with a high proportion of Black residents surrounded by similar tracts, while Low–Low (LL) clusters denote tracts with a predominance of White residents in predominantly White surroundings. High–Low (HL) outliers indicate tracts with a high proportion of Black residents adjacent to predominantly white tracts, whereas Low–High (HL) outliers reflect the opposite pattern. Together, these four categories provide a spatially explicit measure of racial segregation, highlighting not only areas of concentration but also racial boundaries and transitions across urban space. Census tracts that did not show significant correlation patterns offer no interpretative contribution for understanding segregation patterns and, thus, were not included in the tables.

Analyses were conducted separately for each of Brazil's major macro-regions (North, Northeast, Central-West, Southeast, and South), considering its distinct colonial and settlement histories and the presence of Afro-Brazilian populations nowadays, using the average proportion of black/brown individuals within each major region as a reference.

Income

The mean income of the household head in 2022 for each census tract was obtained from the 2022 Census and used as a covariate in the analyses.

Data Analysis

Analyses were conducted using R (version 4.5) and Stata 1.8 software. Descriptive data are presented by means, standard deviation, minimum and maximum values, or by absolute and proportional values. Bivariate analyses compared the racial composition of food desert and non-food desert tracts using t-tests for continuous variables and chi-square tests for categorical variables. We also compared the mean percentage of Black populations and the mean income of the household head across LISA clusters.

Poisson regression with robust variance was employed to estimate the association between racial spatial segregation and the prevalence of food deserts, presenting prevalence ratios (PR) and 95% confidence intervals (CI). Models were first run unadjusted (crude) and then adjusted for income at the census tract level, allowing us to assess the independent contribution of racial spatial segregation to food retail deprivation. All analyses were stratified by the five Brazilian macro-regions to capture regional heterogeneity. Statistical significance was set at $p < 0.05$.

Spatial overlay maps of intra-urban racial segregation patterns and food deserts were created by overlaying the LISA clusters with food deserts in the two state capitals with the highest prevalence of food deserts by macro-region (n = 10), aiming to visually understand the relationship between intra-urban spatial racial segregation patterns and the outcome.

Results

The analyses included 319 Brazilian municipalities with more than 100,000 inhabitants. 7.84% (n = 25) of those municipalities are in the Center-West region, 8.15% (n = 26) are in the North region, 17.24% (n = 55) are in the South region, 20.06% (n = 64) are in the Northeast region, and 46.71% (n = 149) are in the Southeast region. Of the 239,276 initial census tracts, 4,466 had no residents and 2,909 lacked information on race/skin color; these were excluded, resulting in 231,901 tracts included in the analyses.

Table 1 presents descriptive statistics of food retail density (number of food retailers for 10,000 inhabitants) by census tract. A higher density of ultra-processed food outlets (G4) was observed across all macro-regions, especially in the Central-West and Southeast. Overall, 77.06% of census tracts in Brazil were classified as food deserts, with the highest prevalence found in the North (81.17%) and Northeast (79.01%) regions. The Central-West region had the lowest prevalence (66.2%). **Supplementary Table 1** details the mean number of food retailer establishments by type and by macro-region.

Table 2 shows the prevalence of food deserts by racial composition and spatial segregation patterns. Overall, food desert tracts had higher proportions of Brown and Black residents and lower proportions of White residents ($p < 0.001$). LISA clusters patterned these differences. HH clusters (high presence of Black residents tracts surrounded by similar tracts) showed the highest prevalence of food deserts nationwide (over 85%), followed by HL clusters (high presence of Black residents tracts adjacent to low presence of Black residents areas). LL clusters, predominantly White tracts in White surroundings, consistently had the lowest prevalence. Regional differences revealed that Brown populations were the main drivers of these patterns in the North and Northeast, whereas both Brown and Black groups were overrepresented in food desert tracts in the Southeast. In the South, despite the predominance of White residents, food desert tracts were disproportionately concentrated in HH and HL clusters, indicating a consistent pattern of poor-quality food environments in areas shaped by localized racial spatial segregation.

Supplementary Table 2 presents the mean percentage of the Black population across different LISA clusters. Higher percentages of the Black population were consistently found in HH and HL clusters than in LH, indicating strong racial concentration in specific territories. Additionally, the HH clusters have the lowest average income, followed by HL, LH and LL, both nationally and regionally (**Supplementary Table 3)**

Table 3 presents the prevalence ratios and confidence intervals of associations between racial segregation and food deserts. Adjusting for income slightly attenuated associations, suggesting that racial spatial segregation has an independent effect on the spatial distribution of food retail. Nationally, census tracts in HH, HL, and LH clusters were significantly more likely to be food deserts compared to LL clusters, with adjusted PRs of 1.30 (95% CI: 1.29–1.32) in HH clusters. Regional analyses revealed the highest effect sizes in the North, where adjusted PR for HH clusters was 1.58 (95% CI: 1.45-1.68).

Maps overlaying the HH clusters and food deserts for the two cities with the highest incidence (% of census tracts) of food deserts in each region were created to visualize the overlap between intra-urban spatial patterns of racial segregation and food availability in different macro-regions (**Figure 1**). Census tracts characterized simultaneously as spatially correlated concentrations of Black population (HH) and food deserts are colored purple, while the main city center is marked in black. The dark gray color on the base map represents coasts, rivers, lakes, and other bodies of water next to the cities. The results show that, except for Salvador, which has the largest Black population in Brazil (80.7%), the HH areas identified as food deserts tend to be located mainly in peripheral areas.

Discussion

This study examined the relationship between spatial racial segregation and inequities in the quality of the community food environment in major Brazilian cities, assessed through the notion of food deserts, a recognized indicator of restricted access to healthy food options [4]. We found that food deserts are widespread across urban Brazil, affecting more than three-quarters of census tracts, with the highest prevalence in the North and Northeast regions. Food retail density was consistently dominated by outlets selling ultra-processed foods, while exposure to healthy food outlets was limited.

This is the first study to map the prevalence of food deserts in Brazil comprehensively. Previous studies conducted in Brazilian state capitals, following the same methodology to classify food deserts, identified a prevalence of 28.5% in Recife [8], 31.20% in Belo Horizonte [6], and 48.3% in Porto Alegre [24]. In addition, the Brazilian government conducted a mapping of food deserts in 91 Brazilian cities with more than 300,000 inhabitants; it was observed that 1 in 3 Brazilians live in food deserts in these cities [25]. This study included smaller cities, which may explain the higher prevalence found. Living in food deserts is associated with poorer health outcomes, such as a higher risk of chronic diseases, and also with greater food insecurity, characterized by reduced physical and economic access to healthy foods [26].

Our results also indicated that food deserts were not evenly distributed across racial groups or urban space: tracts with higher proportions of Black residents were significantly more likely to be food deserts, and these patterns were strongly structured by spatial segregation, as captured by LISA clusters. HH clusters, areas with concentrated Black populations surrounded by similar tracts, showed the highest prevalence of food deserts nationwide, followed by HL clusters, which reflect Black-majority tracts bordering White-majority areas. Interestingly, LH clusters, White-majority tracts surrounded by Black-majority areas, had lower percentages of Black residents than even LL clusters, revealing asymmetrical segregation patterns.

The systematic application of local spatial analysis has revealed that racial segregation in Brazilian cities is characterized by complex, localized arrangements of concentration and differentiation, both of which are linked to adverse food environments [11,27,28]. Traditionally, Brazilian researchers have primarily described residential segregation as a phenomenon shaped by economic factors, given the widespread claim that racial segregation in Brazil is relatively moderate. This empirical assumption was established by comparing the Brazilian case to the United States, where residential segregation has historically constituted a central mechanism of anti-Black racism after the abolition of slavery, formalized through explicit segregationist legislations and policies, and reinforced by judicial decisions, economic and social institutions, and interpersonal discriminatory practices. In Brazil, despite the absence of a formally institutionalized segregation regime, the legacy of slavery, land dispossessions, the lack of reparative policies, and persistent informal and extralegal forms of racism have contributed to the systematic exclusion of the Black population from central urban areas with greater access to infrastructure, services, and opportunities [29,30]. In this regard, recent studies, such as those by Telles [31,32] and França [33,34], emphasize the importance of integrating economic and racial dimensions. By examining residential segregation based on occupational status and race in three Brazilian metropolitan areas (São Paulo, Salvador, and Fortaleza), França identified a pattern in which blacks and whites from lower social classes tend to live in closer proximity, whereas racial separation increases gradually as socioeconomic stratification rises.

Although this paper did not intend to analyze income segregation (or the influence of the income variable), the results confirm the ubiquitous presence of both homogeneous clustering (HH and LL clusters) and, to a much lesser extent, spatial contrasting (HL and LH clusters) across all analyzed cities and regions, providing empirical evidence that racial spatial segregation is a consistent and widespread phenomenon in Brazil. The prevalence of HH clusters empirically demonstrates the isolation and concentration of racially marginalized populations, in line with recent studies [11,27]. This concentration is a key outcome of historical marginalization imposed upon Black and Brown populations in Brazil, reflecting systematic exclusion and the lack of reparative policies following the abolition of slavery [31,35]. This pattern often associates Black communities with marginalized spaces, mainly in the peripheral zones of cities. In contrast, the LL clusters reflect the spatial isolation of predominantly White groups, who often occupy the privileged central and affluent zones of the city [36]. HL and LH clusters amount to less than 1,5% of the Brazilian territory, and delineate frontiers where geographical proximity exists between groups with starkly opposing racial compositions [27,35]. In general, HL clusters often represent areas with higher concentrations of Black residents directly adjacent to neighborhoods with significantly lower concentrations, characterizing "enclaves" [36,37].

This racialized spatial structure of the Brazilian cities, materialized by different types of racial clusters and spatial distances, reveals another feature of segregation: the unequal chances of accessing material and symbolic resources [10,33]. In this study, this inequality is reflected in the lack of availability to healthy food, confirming that the spatialization of racial subordination or privilege directly translates into tangible inequalities that limit access to essential services and resources necessary for health and well-being. This finding is consistent with the literature from the US linking racial residential segregation to an inverse density of health-related facilities and adverse exposure to unhealthy food environments [9,28,38,39]. Studies in the US have demonstrated that segregated black neighborhoods often have 2–3 times fewer supermarkets and 2–3 times more fast-food outlets when compared to white neighborhoods [38], confirming the association between racial-spatial segregation and adverse food environments [9,28]. Although this is the first analysis with measures of racial segregation in Brazil, previous studies conducted in capitals of the Northeast, Southeast, and South macro-regions have shown less access to establishments that sell healthy foods and greater access to ultra-processed foods in areas with a higher proportion of ethnic-racial minorities (Black, Brown, and Indigenous populations) [6,7,40–42].

These results indicated that structural and institutional racism, expressed through discriminatory policies and unequal urban planning, contributes to the formation of food deserts and restricts the availability of fresh, minimally processed foods in predominantly Black neighborhoods. The lack of access to healthy and culturally adequate foods has several consequences for food security and the health of racial minorities in Brazil [7]. In the country, the Black population, especially women and individuals with lower income and education, is disproportionately affected by both the highest rates of food insecurity [43] and malnutrition [44], as well as the highest prevalence of obesity [45]. This coexistence of undernutrition and overweight, known as the double burden of malnutrition, represents one of the most pressing public health challenges in Brazil.

Recent efforts by the Brazilian government, particularly by the Ministry of Social Development, have attempted to improve food environments through the development of public food facilities that primarily offer fresh and minimally processed foods, many of which have received international recognition. These initiatives have largely targeted communities identified as economically vulnerable [46]. While low-income areas in Brazil often overlap with ethnic-racial minority populations, targeted interventions in racially segregated neighborhoods are crucial for improving nutritional and health conditions of the Afro-Brazilian population, as well as confronting the structural injustices embedded in the food system that reproduce racial health inequities. Food deserts may be a paradigmatic example, as they may contribute to the formation or perpetuation of racial clusters, creating a feedback loop in which unequal food environments and racial spatial segregation mutually reinforce one another.

Strengths and Limitations

This study has some methodological limitations. The choice of Brazilian census tracts as the unit of data aggregation, although justified by the wide availability of sociodemographic information, represents a methodological limitation given the incidence of the Modifiable Areal Unit Problem (MAUP), which states that there is a statistical dependence of results as a function of the scale and boundaries of units [47]. This is exacerbated in census tracts, which exhibit great heterogeneity in their shapes and sizes [48]. To minimize the zoning and scale biases of MAUP in future work, the methodological trend points toward the adoption of more homogeneous and disaggregated spatial units, such as cells, rasters, and grids [17]. The secondary data from RAIS used to characterize the food retail environment include only formal establishments, excluding informal markets that may play an important role in food access. Additionally, RAIS provides only ZIP codes for food retailers, and the use of ZIP code centroids for geocoding may have resulted in location inaccuracies. Inconsistencies in the reporting of skin color also led to the exclusion of some census tracts. The use of mean household income may introduce inaccuracies, as it can underestimate total household income in multi-earner households; however, it was the only income indicator publicly available in the 2022 Census and was used solely as a covariate. Finally, our study measured the availability of food retailers, which does not necessarily reflect accessibility, since physical proximity does not guarantee that residents have the means or capability to reach or use these establishments.

On the other hand, the study also has several strengths. First, it used national data, including the 319 large Brazilian cities, covering approximately 50% of the Brazilian population. The extensive geographic coverage provides a robust and granular understanding of how racialized spatial patterns shape the community food environment. Second, the analysis employs advanced spatial methods to identify meaningful clusters of racial concentration and contrast. Traditional, non-spatial, and global measures of segregation, such as the Dissimilarity Index (D) and Entropy (H), yield a single aggregate value representing the overall uneven distribution of groups and were criticized for treating areas as independent entities and ignoring their spatial arrangement. In contrast, spatial autocorrelation explicitly captures the effect of neighborhood, or spatial lag, which is the behavior of the variable across adjacent units [20,21,27]. To capture the local variability and complexity of this issue, second-generation indices such as LISA explicitly identify geographical patterns of concentration and contrast between locations, also helping mitigate some effects of census tracts' MAUP by incorporating the spatial relationships between neighboring units that transcend administrative boundaries. Third, the use of a recent and contextually validated classification of food retail supports consistency with the Food Guide for the Brazilian Population and Brazilian research, and enhances the applicability of the findings to public policy.

Conclusion

This study provides evidence that racial spatial segregation is a key structural determinant of inequities in the community food environment in Brazilian cities. We demonstrated that food deserts are disproportionately concentrated in racially segregated areas where the Black population is spatially clustered, amplifying structural disadvantages faced by Black and Brown communities. These patterns persisted even after accounting for household income, indicating that segregation operates through mechanisms that extend beyond socioeconomic disadvantage alone. The findings also underscore the role of structural and institutional racism in shaping unequal access to fresh and minimally processed foods, thereby reinforcing long-standing nutritional and health disparities experienced by Afro-Brazilian communities. Addressing food deserts in Brazil, therefore, requires confronting the broader urban and racial inequalities that underpin them. Policies aimed at improving food environments must consider the spatial distribution of racialized populations, ensuring that interventions reach not only economically vulnerable areas but also neighborhoods historically marginalized by racial segregation.

Future studies should incorporate measures of food accessibility, including transportation, affordability, and mobility constraints, to allow for a more complete understanding of barriers faced by residents of segregated neighborhoods. And, exploring interactions between racial segregation, gender, and other axes of inequality may reveal intersectional dynamics that further shape food security and health outcomes in Brazilian cities.

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Table 1. Description of the food environment and percentage of food deserts in Brazil and by regions.

Variables	Mean	SD	Min	Max
Brasil (n=222.59)				
G1+G2	34.15	1040.05	0	25500
G3	6.74	212.64	0	75000
G4	58.94	1462.85	0	330000
Deserts n (%)	171.52 (77.06%)			
Central-West Region (n=16.21)				
G1+G2	49.18	1532.99	0	16000
G3	13.56	598.73	0	75000
G4	77.94	2674.23	0	330000
Deserts n (%)	10.72 (66.16%)			
Northeast Region (n=3.06)				
G1+G2	26.68	828.88	0	105000
G3	6.82	197.91	0	30000
G4	38.30	861.21	0	90000
Deserts n (%)	30.86 (79.01%)			
North Region (n=12.71)				
G1+G2	17.68	274.69	0	16250
G3	4.23	72.10	0	5000
G4	33.40	401.16	0	26250
Deserts n (%)	10.31 (81.17%)			
Southeast Region (n=12.00)				
G1+G2	36.58	1132.77	0	255000
G3	6.30	142.87	0	30000
G4	65.73	1556.00	0	320000
Deserts n (%)	101.68 (78.82%)			
South Region (n=25.62)				
G1+G2	32.00	604.19	0	80000
G3	5.77	30.40	0	2222222
G4	56.83	815.49	0	90000
Deserts n (%)	17.95 (70.06%)			

Descriptive analysis of food retail density indicators in Brazilian census tracts and by macroregion.
(G1) unprocessed or minimally processed foods, such as fruits, vegetables, grains, milk, and eggs, which preserve their natural characteristics;
(G2) processed culinary ingredients like oils, sugar, and salt, used in cooking;
(G3) processed foods, such as canned vegetables and cheeses, made by adding culinary ingredients to whole foods;
(G4) ultra-processed foods, which are industrial products made mostly from food-derived substances and additives, such as soft drinks, packaged snacks, and instant meals)
Values are presented as mean, standard deviation (SD), minimum, and maximum.

Table 2. Prevalence of food deserts according to racial characteristics of census tracts and cluster of racial segregation in Brazilian Major cities (n=319).

	Total	Non-Food Deserts	Food Deserts	*p-value*
Brazil				
% Brown (mean SD)	10.85 (±8.05)	35.44 (± 18.26)	41.47 (±18.54)	<0.001
% Black (mean SD)	40.08(±18.65)	8.74 (±6.58)	11.49 (±8.33)	<0.001
% Brown + Black (mean SD)	50.94 (±23.03)	44.17 (±22.23)	52.96 (±22.88)	<0.001
% White (mean SD)	47.20 (±22.35)	54.46 (21.45)	45.60 (21.73)	<0.001
LISA (n%)				
Low-low	21.05%	17042 (36.34%)	29852 (63.66%)	<0.001
High-Low	0.84%	289 (15.30%)	1600 (84.70%)	
Low-High	0.54%	199 (16.49%)	1008 (83.51%)	
High-high	23.26%	7578 (14.64%)	44199 (85.36%)	
Central-West Region				
% Brown (mean SD)	49.31(±13.54)	47.20 (±13.20)	50.39 (±13.58)	<0.001
% Black (mean SD)	9.57(±4.92)	8.90 (±4.48)	9.91 (±5.10)	<0.001
% Brown + Black (mean SD)	58.88(±16.53)	56.11 (±16.05)	60.31 (±16.61)	<0.001
% White (mean SD)	39.31(±15.54)	42.63 (±15,38)	37.62 (±15.35)	<0.001
LISA (n%)				
Low-low	18%	1360 (45.58%)	1624 (54.42%)	<0.001
High-Low	1.11%	47 (26.11%)	133 (73.89%)	
Low-High	0.48%	16 (20.51%)	62 (79.49%)	
High-high	23.98%	1017 (26.17%)	2869 (73.83%)	
Northeast Region				
% Brown (mean SD)	54.63 (±11.91)	51.03 (±11.29)	55.59 (±11.89)	<0.001
% Black (mean SD)	15.06 (±11.03)	12.37 (±9.46)	15.79 (±11.31)	<0.001
% Brown + Black (mean SD)	69.70 (±15.78)	63.41 (±15.75)	71.37 (±15.36)	<0.001
% White (mean SD)	28.91(±14.53)	35.77 (±15.38)	27.09 (13.74)	<0.001
LISA (n%)				
Low-low	15.01%	2412 (41.13%)	3453 (58.87%)	<0.001
High-Low	1.24%	68 (13.96%)	419 (86.04%)	
Low-High	0.40%	23 (14.84%)	132 (85.16%)	
High-high	19.66%	939 (12.22%)	6742 (87.78%)	
North Region				
% Brown (mean SD)	8.89 (±4.64)	60.81 (±11.28)	65.95 (±11.89)	<0.001
% Black (mean SD)	64.98 (±11.94)	8.58 (±4.33)	9.04 (±4.71)	<0.001
% Brown + Black (mean SD)	73.93 (±12.40)	69.40 (±12.11)	74.99 (±12.23)	<0.001
% White (mean SD)	24.19 (±9.98)	29.08 (±10.95)	23.06 (±09.32)	<0.001
LISA (n%)				
Low-low	10.02%	571 (44.82%)	703 (55.18%)	<0.001
High-Low	1.74%	22 (9.91%)	200 (90.09%)	
Low-High	0.85%	8 (7.34%)	101 (92.66%)	
High-high	16.00%	184 (9.05%)	7460 (82.27%)	
Southeast Region				
% Brown (mean SD)	36.0 (±16.10)	31.35 (±15.45)	37.36 (±16.04)	<0.001
% Black (mean SD)	10.88 (±7.73)	8.70 (±5.93)	11.47 (±7.51)	<0.001
% Brown + Black (mean SD)	46.96 (±21.10)	40.06 (±19.78)	48.82 (±21.07)	<0.001
% White (mean SD)	50.99 (±20.28)	57.88 (±19.12)	49.14 (±20.18)	<0.001
LISA (n%)				
Low-low	24.09%	10118 (32.55%)	20967 (67.45%)	<0.001
High-Low	0.62%	115 (14.39%)	684 (85.61%)	
Low-High	0.51%	115 (17.42%)	545 (82.58%)	
High-high	25.96%	4472 (13.35%)	29014 (86.65%)	
South Region				
% Brown (mean SD)	19.86(±11.82)	16.96 (±10.51)	21.10 (±12.14)	<0.001
% Black (mean SD)	6.07(±5.59)	4.90 (±4.31)	6.57 (±6.00)	<0.001
% Brown + Black (mean SD)	25.93(±13.87)	21.86 (±12.29)	27.68 (±14.15)	<0.001
% White (mean SD)	72.44 (±14.99)	77.00 (±12.57)	70.51 (±15.52)	<0.001
LISA (n%)				

Low-low	22.20%	2581 (45,39%)	3105 (54.61%)	<0.001
High-Low	0.78%	37 (18,41%)	164 (81.59%)	
Low-High	0.01%	37 (18,05%)	168 (81.95%)	
High-high	18.30%	966 (20,60%)	3724 (79.40%)	

High–High: census tracts with a predominance of Black residents surrounded by similar tracts; Low–Low tracts with a predominance of White residents in predominantly White surroundings; High–Low: census tracts with a predominance of Black residents adjacent to predominantly White tracts; Low–High:census tracts with a predominance of White residents surrounded by similar tracts.

LISA: comparing the distribution of Black residents (self-identified as Brown or Black) and White residentes; Non-signficative cluster did not present.

Table 3. Prevalence ratios and respective confidence intervals of associations between racial segregation and food deserts in Brazil major cities (n=319)

Variable	Food Deserts Crude RP (IC95%)	*p*-value	Food Deserts Adjusted* RP (IC95%)	*p*-value
Brazil				
Low–Low	1	<0.001	1	<0.001
High–Low	1.33 (1.30-1.36)		1.30 (1.27-1.32)	
Low–High	1.31 (1.28-1.35)		1.25 (1.21-1.29)	
High–High	1.34 (1.33-1.35)		1.30 (1.29-1.32)	
Central-West Region				
Low–Low	1	<0.001	1	<0.001
High–Low	1.36 (1.24-1.49)		1.38 (1.25-1.52)	
Low–High	1.46 (1.30-1.64)		1.35 (1.15-1.60)	
High–High	1.36 (1.31-1.41)		1.38 (1.31-1.45)	
Northeast Region				
Low–Low	1	<0.001	1	<0.001
High–Low	1.46 (1.40-1.52)		1.32 (1.26-1.38)	
Low–High	1.45 (1.35-1.55)		1.35 (1.25-1.47)	
High–High	1.49 (1.46-1.53)		1.34 (1.30-1.38)	
North Region				
Low–Low	1	<0.001	1	<0.001
High–Low	1.63 (1.53-1.74)		1.57 (1.46-1.69)	
Low–High	1.68 (1.56-1.80)		1.60 (1.47-1.74)	
High–High	1.65 (1.57-1.74)		1.58 (1.48-1.68)	
Southeast Region				
Low–Low	1	<0.001	1	<0.001
High–Low	1.27 (1.23-1.31)		1.28 (1.24-1.32)	
Low–High	1.22 (1.18-1.27)		1.18 (1.12-1.24)	
High–High	1.28 (1.27-1.30)		1.30 (1.28-1.31)	
South Region				
Low–Low	1	<0.001	1	<0.001
High–Low	1.49 (1.39-1.60)		1.31 (1.22-1.41)	
Low–High	1.50 (1.40-1.61)		1.33 (1.23-1.44)	
High–High	1.45 (1.41-1.50)		1.25 (1.21-1.29)	

High–High: census tracts with a predominance of Black residents surrounded by similar tracts; Low–Low tracts with a predominance of White residents in predominantly White surroundings. High–Low: census tracts with a predominance of Black residents adjacent to predominantly White tracts; Low–High:census tracts with a predominance of White residents surrounded by similar tracts.
*ajusted by income.

SUPPLEMENTARY MATERIAL

Supplementary Table 1. Characteristics of food retail in Brazil **major** ***cities (n = 222,59 census tracts).***

Type of establishment	Mean	SD	Min/Max
Brazil			

G1+G2	0.69	2.48	0-192
G3	0.20	0.67	0-39
G4	1.36	4.24	0-437
Bakeries	0.18	0.61	0-38
Bars	0.02	0.19	0-8
Butcher shops	0.07	0.40	0-30
Candy and confectionery stores	0.05	0.37	0-47
Canteens	0.01	0.12	0-7
Convenience stores	0.02	0.18	0-9
Dairy and cold cuts stores	0.02	0.18	0-17
Fish markets	0.01	0.16	0-21
Fruit and vegetable markets	0.06	0.56	0-113
General or unspecified food product stores	0.16	1.03	0-349
Hypermarkets	0.01	0.11	0-6
Prepared food outlets	0.08	0.39	0-26
Restaurants	0.05	1.89	0-169
Retail of beverages not consumed on the premises	0.11	0.44	0-32
Small grocery stores	0.29	1.00	0-130
Snack bars	0.40	1.85	0-230
Street vendors	0.02	0.15	0-9
Supermarkets	0.08	0.38	0-28
Central-West Region			
G1+G2	0.98	2.76	0-93
G3	0.32	0.82	0-19
G4	1.94	4.19	0-130
Butcher shops	0.10	0.42	0-9
Bakeries	0.23	0.63	0-15
Bars	0.04	0.25	0-7
Candy and confectionery stores	0.05	0.34	0-11
Canteens	0.01	0.09	0-2
Convenience stores	0.05	0.28	0-8
Dairy and cold cuts stores	0.03	0.18	0-5
Fish markets	0.15	0.14	0-5
Fruit and vegetable markets	0.07	0.64	0-59
General or unspecified food product stores	0.24	0.82	0-27
Hypermarkets	0.01	0.12	0-3
Prepared food outlets	0.08	0.35	0-8
Restaurants	0.63	2.24	0-86
Retail of beverages not consumed on the premises	0.21	0.58	0-19
Small grocery stores	0.37	0.88	0-5
Snack bars	0.48	1.77	0-72
Street vendors	0.23	0.17	0-7
Supermarkets	0.15	0.50	0-12
Northeast Region			
G1+G2	0.64	2.71	0-131
G3	0.22	0.77	0-39
G4	1.06	3.84	0-241
Butcher shops	0.65	0.41	0-30
Bakeries	0.16	0.62	0-36
Bars	0.02	0.17	0-8
Candy and confectionery stores	0.04	0.32	0-18
Canteens	0.01	0.08	0-3
Convenience stores	0.24	0.20	0-9
Dairy and cold cuts stores	0.03	0.25	0-12
Fish markets	0.01	0.18	0-20
Fruit and vegetable markets	0.06	0,92	0-113
General or unspecified food product stores	0.14	0.72	0-41
Hypermarkets	0.01	0.12	0-4
Prepared food outlets	0.06	0.30	0-7
Restaurants	0.41	1.94	0-111
Retail of beverages not consumed on the premises	0.09	0.42	0-2
Small grocery stores	0.37	1.46	0-130
Snack bars	0.31	1.69	0-143
Street vendors	0.02	0.14	0-4
Supermarkets	0.06	0.35	0-19

North Region			
G1+G2	0.49	1.89	0-68
G3	0.15	0.58	0-20
G4	1.10	3.30	0-135
Butcher shops	0.06	0.37	0-14
Street vendors	0.01	0.12	0-5
Bars	0.02	0.16	0-8
Retail of beverages not consumed on the premises	0.08	0.36	0-14
Canteens	0.01	0.08	0-3
Convenience stores	0.03	0.22	0-4
Candy and confectionery stores	0.03	0.23	0-7
General or unspecified food product stores	0.12	0.55	0-20
Hypermarkets	0.01	0.10	0-3
Fruit and vegetable markets	0.04	0.65	0-67
Snack bars	0.21	1.01	0-26
Small grocery stores	0.36	0.15	0-5
Dairy and cold cuts stores	0.02	0.15	0-5
Bakeries	0.12	0.48	0-15
Fish markets	0.02	0.15	0-5
Prepared food outlets	0.04	0.22	0-5
Restaurants	0.29	1.33	0-37
Supermarkets	0.07	0.36	0-14
Southeast Region			
G1+G2	0.63	2.32	0-192
G3	0.17	0.59	0-38
G4	1.28	4.34	0-437
Butcher shops	0.06	0.37	0-14
Bakeries	0.12	0.48	0-15
Bars	0.02	0.16	0-8
Candy and confectionery stores	0.03	0.23	0-7
Canteens	0.01	0.08	0-3
Convenience stores	0.03	0.22	0-4
Dairy and cold cuts stores	0.02	0.15	0-5
Fish markets	0.02	0.15	0-5
Fruit and vegetable markets	0.04	0.65	0-67
General or unspecified food product stores	0.12	0.55	0-20
Hypermarkets	0.01	0.10	0-3
Prepared food outlets	0.04	0.22	0-5
Restaurants	0.29	1.33	0-37
Retail of beverages not consumed on the premises	0.08	0.36	0-14
Small grocery stores	0.36	0.15	0-5
Snack bars	0.21	1.01	0-26
Street vendors	0.01	0.12	0-5
Supermarkets	0.07	0.36	0-14
South Region			
G1+G2	1.01	2.87	0-85
G3	0.27	0.74	0-23
G4	1.98	4.66	0-144
Butcher shops	0.07	0.33	0-9
Bakeries	0.25	0.71	0-23
Bars	0.04	0.24	0-6
Candy and confectionery stores	0.06	0.39	0-14
Canteens	0.01	0.13	0-3
Convenience stores	0.03	0.21	0-5
Dairy and cold cuts stores	0.02	0.13	0-5
Fish markets	0.01	0.14	0-10
Fruit and vegetable markets	0.06	0.37	0-22
General or unspecified food product stores	0.24	0.83	0-30
Hypermarkets	0.02	0.15	0-4
Prepared food outlets	0.12	0.45	0-9
Restaurants	0.71	2.32	0-58
Retail of beverages not consumed on the premises	0.16	0.52	0-10
Small grocery stores	0.38	0.10	0-39
Snack bars	0.56	2.03	0-50
Street vendors	0.02	0.15	0-4

Supermarkets	0.11	0.42	0-15

Average number of food retail establishments per census tract in Brazil and by macroregion. Values are presented as mean, standard deviation (SD), and minimum and maximum observed values for each type of establishment.

Supplementary Table 2. Percentage of Black population in census tracts across different LISA clusters.

	Mean	**SD**
Brazil		
Low–Low	24.62%	14.97%
High–Low	64.44%	16.20%
Low–High	30.20%	24.34%
High–High	70.38%	13.06%
Central-West Region		
Low–Low	35.34%	11.48%
High–Low	68.06%	8.03%
Low–High	35.85%	24.42%
High–High	73.85%	5.84%
Northeast Region		
Low–Low	46.67%	12.61%
High–Low	77.31%	6.63%
Low–High	46.13%	28.72%
High–High	86.20%	5.95%
North Region		
Low–Low	54.67%	14.09%
High–Low	80.83%	5.89%
Low–High	59.16%	25.94%
High–High	82.93%	4.67%
Southeast Region		
Low–Low	20.61%	9.73%
High–Low	58.76%	10.29%
Low–High	25.12%	20.08%
High–High	69.29%	8.53%
South Region		
Low–Low	11.43%	5.29%
High–Low	34.49%	10.52%
Low–High	16.99%	9.13%
High–High	43.98%	8.70%

Values are presented as mean and standard deviation (SD) for each category.

High–High: census tracts with a predominance of Black residents surrounded by similar tracts; Low–Low: tracts with a predominance of White residents in predominantly White surroundings. High–Low: census tracts with a predominance of Black residents adjacent to predominantly White tracts; Low–High: census tracts with a predominance of White residents surrounded by similar tracts.

Supplementary Table 3. Income of head of family across different LISA clusters (Brazilian Reais - R$).

	Mean	**SD**
Brazil (R$)		
Low–Low	7486,34	5008,57
High–Low	2423,06	1564,51

Low–High	3945,88	3293,05
High–High	1949,67	1085,64
Central-West Region (R$)		
Low–Low	9396,44	5466,49
High–Low	3166,36	1674,45
Low–High	5098,82	4658,49
High–High	2153,52	648,14
Northeast Region (R$)		
Low–Low	6437,01	4522,24
High–Low	1672,08	949,92
Low–High	4267,98	4045,20
High–High	1596,66	900,24
North Region (R$)		
Low–Low	7094,83	4573,82
High–Low	1978,71	881,88
Low–High	2798,21	2212,92
High–High	2538,26	561,86
Southeast Region (R$)		
Low–Low	7625,99	5164,74
High–Low	2688,72	1756,53
Low–High	3928,23	3204,45
High–High	1972,94	1186,90
South Region (R$)		
Low–Low	6887,01	4007,50
High–Low	3008,01	1585,46
Low–High	4021,02	2713,28
High–High	2352,69	823,69