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Food Environment Inequalities and Moderating Effects of Obesity on Their Relationships with COVID-19 in Chicago

Hao Huang

Department of Social Sciences, Illinois Institute of Technology, Chicago, IL 60616, USA; hhuang48@iit.edu

Abstract: The COVID-19 outbreak has raised challenges for people with health problems. Obesity is a global issue related to COVID-19. The Centers for Disease Control (CDC) finds that obesity worsens COVID-19 outcomes. As body mass index increases, the COVID-19 death risk increases. Additionally, due to different restriction policies, the pandemic has transformed our food environment. Thus, it is important to develop an antivirus-enabled paradigm to decrease the COVID-19 spreading rate in neighborhoods with obesity concerns and design a sustainable and healthy food environment. It is found that both COVID-19 and obesity inequalities are associated with food environment inequalities, but few studies have examined the moderating effects of obesity and food environment on COVID-19. According to the Chicago Department of Public Health, more than 30% of the Chicago adult population is obese. Additionally, Chicago has 340,676 COVID-19 cases during the period between 1 March 2020 and 26 November 2021. This study uses regression models to examine the moderating effects of obesity and food environment on COVID-19 in Chicago. Besides food environment factors, green spaces and transportation access are considered. The results show COVID-19 is concentrated in areas with a high obesity rate and low food access. A 1 percent increase in obesity rate is associated with a 2.83 percent increase in COVID-19 death rate in a community. Additionally, the moderating effects of obesity on the association between food environment and COVID-19 are shown in the results.

Keywords: COVID-19; food environment; obesity; urban health inequality

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1. Introduction

Since the first case on 24 January 2020, the number of COVID-19 cases and deaths have cumulatively increased to 340,676 confirmed cases and 6188 deaths in Chicago for the period between 1 March 2020 and 26 November 2021 [1]. The pandemic's effects are unequal among different racial groups. As of 26 November 2021, of the 340,676 confirmed cases, 34.7% were from the Latinx population, 24.5% were from the White population, and 22.2% were from the African American population; of the 6188 deaths, 40.8% were from the African American population, 32.2% were from the Latinx population, and 21.7% were from the White population [1]. The racial distribution of COVID-19 cases and deaths has a stark contrast with the racial makeup of Chicago's population, which is 33.3% White, 29.6% African American, and 28.8% Hispanic, according to U.S. Census Bureau population estimates, 1 July 2019 [2].

The COVID-19 outbreak has raised challenges for people with health problems. Obesity is a global issue related to COVID-19. Obesity has recently been found to be a risk factor for COVID-19 in different age groups [3,4]. As body mass index (BMI) increases, the COVID-19 death risk increases, especially for the population younger than 60 years [4,5]. The Centers for Disease Control and Prevention (CDC) lists overweight and obesity (BMI > 25) as one of the medical conditions with which adults of any age can be more likely to contract COVID-19 [6], showing that obesity worsens outcomes from COVID-19. According to the Healthy Chicago Survey from the Chicago Department of Public Health, Chicago has an adult overweight and obese population of about 30 percent [7].

The pandemic has transformed our food environment in terms of food security through challenges and opportunities. On the one hand, the food system was disrupted by different restriction policies, such as lockdown, social distance rules, and travel restrictions. On the other hand, e-shopping created opportunities to access and compare numerous categories of products among different food stores, even beyond local ones, to offer convenience and saved time [8–10]. Changing patterns in food availability, affordability, and accessibility [11,12] are expected to have severe impacts on the most vulnerable populations [13]. Racial segregation has recently been found to be a moderating effect on associations between obesity and access to food retailers [14]. Vulnerabilities to food insecurity and obesity imposed by the COVID-19 pandemic are likely to exacerbate health inequalities among racial and socioeconomic groups, perpetuating a syndemic [12,15,16]. There is no doubt that reversing the pandemic's impacts on the food syndemic is an immensely complex challenge, which highlights the fragility of the food structure [12].

It is necessary to develop an antivirus-enabled paradigm to decrease the COVID-19 spreading rate in neighborhoods with obesity concerns and thus design a sustainable and healthy built environment [17]. Structural and individual factors affecting COVID-19, including food environment and obesity, have been examined since the pandemic started [3–5,11,12,15]. It is found that both obesity and food environment are associated with COVID-19, but none of these studies examine the moderating effects of obesity and food environment on COVID-19. This research employs spatial statistics to explore the demographic spatial distribution of COVID-19 and uses regression models to examine the moderating effects of obesity and food environment on COVID-19 at the community level in Chicago. Besides the food environment, green spaces and transportation access are other built environmental factors to be considered. The results show COVID-19 is concentrated in areas with low food access. The food environment could be a risk factor for COVID-19. Additionally, the moderating effects of obesity and food environment on COVID-19 are shown in the results. After the introduction, the paper is structured as follows. In Section 2, I review the literature on inequalities in the food environment, obesity, and COVID-19, and identify the relevant research gap. Section 3 introduces the study sample data, statistical analysis, and regression modeling. I selected Chicago as the study area as an example of a racially segregated urban environment with unequal food access and obesity inequality to analyze the effects of the association between obesity and food environment on COVID-19. Section 4 presents the results of differences in the effects of food environments on COVID-19 between obese and non-obese communities. Section 5 identifies the moderating effects of obesity in the association between food environment and COVID-19 in Chicago from the results and discusses the formation of the findings for urban planning and policymaking. Section 6 concludes this study and makes recommendations for policies and further research.

2. Inequalities in Food Environment, Obesity, and COVID-19

2.1. Inequalities in Food Environment and Obesity

Food environment plays an important role in obesity [18–22]. Food environment policies focused on food injustice, such as food deserts and food apartheid, are common to increase access to healthy food for underserved urban and rural communities at both federal and state levels in U.S. cities [23–26]. For example, the 2008 Farm Bill passed by the U.S. Senate and the Healthy Food Financing Initiative proposed by the Obama Administration assess the prevalence of food deserts and develop measures to address their causes and effects to promote healthy food access for underserved urban and rural communities [24,25]. These food policies have mixed effects on obesity rates [27–30], so researchers should provide more evidence of the advantages and disadvantages of food environments in obesity prevalence to inform urban policymakers and planners of food environment planning and policy in different contexts, especially during the COVID-19 pandemic.

2.2. Urban Inequalities in COVID-19

Inequitable responses to and consequences of COVID-19 have been observed in terms of income, age, race, and other socioeconomic factors [31–33], which might reinforce existing structural inequalities in human social and economic systems [34,35]. Additionally, COVID-19 restriction policies, such as lockdowns and social distancing [36], have raised new inequalities and injustices, due to inequitable living, working, and environmental conditions and resulting unequal access to urban services and well-being resources, such as public transport, public spaces, and digital infrastructure among different groups of the population [37–42].

2.3. The Linkage between Food Environment, Obesity, and COVID-19

The COVID-19 pandemic has increased effects on the inequitable food environment systems and obesity [3,5,11,12]. At the same time, unequal food access might cause COVID-19-related inequalities due to unequal access to good sources of nutrients strengthening their immune system [43]. Grant et al., Messina et al., and Zhang and Liu reported that vitamins A, D, and E, minerals zinc and selenium, fiber, and essential fatty acids are potentially relevant to prevention and COVID-19 treatment due to their role in the promotion of the immune system [44–46]. A deep understanding of COVID-19 inequalities resulting from the food environment and obesity is required so that urban planners and policymakers can develop a safe and equitable strategy for reducing inequalities. COVID-19 restriction policies varyingly impact the food environment and obesity among different areas of a city. These restriction policies were a new factor influencing the food environment and obesity among communities during the pandemic, differing from greater food resources access within the community.

However, food environment inequality and obesity causing the inequality of COVID-19 were overlooked in previous studies. To narrow this research gap, this study tried to conceptualize the spatial inequality of the food environment and obesity and quantitatively explore where and what their effects are as the proof of concept. Access to food measures the relative ease with which healthy food can be reached. It reflects the benefits provided by healthy foods and costs and challenges experienced by those wishing to access healthy food [18,19,21,22]. This empirical study is designed to validate the conceptualization of COVID-19 inequality caused by food environment and obesity and their interaction effects, as shown in Figure 1.

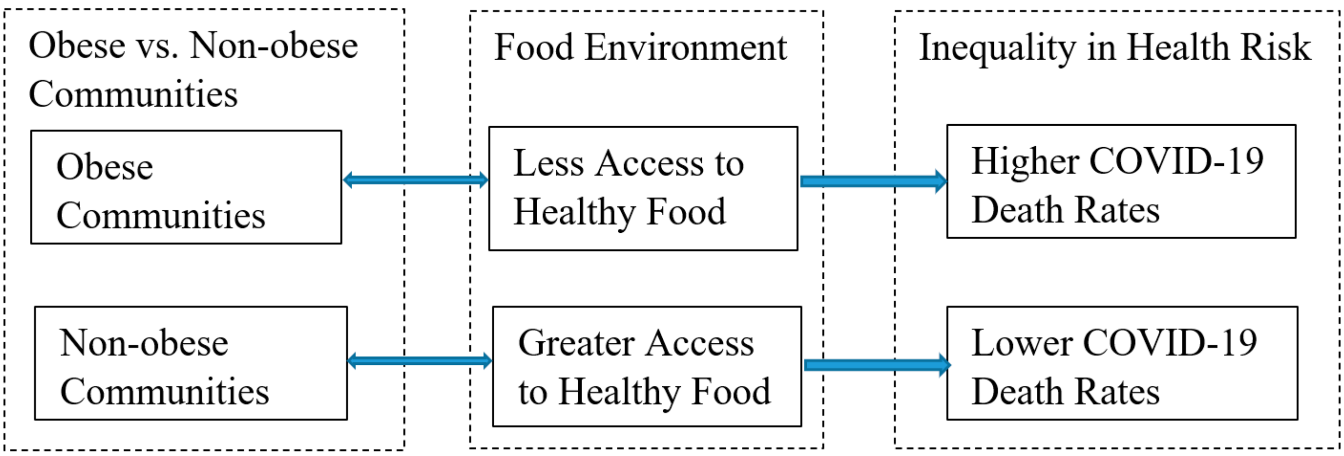

Figure 1. Conceptualization framework of COVID-19 by food environment and obesity.

3. Materials and Methods

3.1. Study Sample

3.1.1. COVID-19 Data

COVID-19 daily cases, hospitalization, and death data are collected for the period 1 March 2020 to 31 July 2021, from the Chicago Department of Public Health (CDPH) accessed via the COVID Dashboard from the City of Chicago government website [1]. COVID-19 cases and death data at the zip code level are from the CDPH accessed via the Chicago Data Portal website [47]. COVID-19-related death data at the community level for the same period are from the Cook County Medical Examiner's Office accessed via the Cook County Government Open Data website [48]. ArcGIS 10.6 was used to map the COVID-19 cases and death distribution by zip code. There are 60 zip codes and 77 communities in Chicago.

3.1.2. Obesity Data

The obesity data are from the Healthy Chicago Survey [7]. The Healthy Chicago Survey has been described in detail in a previous paper [14]. Briefly, it was a large cross-sectional survey conducted among adults aged 18 years or older in Chicago. The data were collected with the random-digit-dial method between 2016 and 2018. The obese population is made up of people with a BMI of 30 or greater. The obesity rate is calculated as the obese adult population divided by the adult population in a community [7].

3.1.3. Food Environment Data

Food stores data collected from the Dun & Bradstreet database include information of each store's location, annual sales, and the industry code. As shown in Table 1, North American Industry Classification System (NAICS) codes are used to classify food stores. Five types of food stores are identified according to NAICS codes and sales: (1) supermarkets are food stores with annual sales equal to or greater than USD 1 million and the industry code of 445110; (2) grocery stores are food stores with annual sales less than USD 1 million and the industry code of 445110; (3) convenience stores are food stores with the industry code of 445120; and (4) fast food restaurants are food stores with the industry code of 722513; (5) restaurants are food stores with the industry code of 722511. Variables measuring food environment at the community level include the number of each type of food store in a community and the number of each type of food store per capita in a community.

3.2. Explanatory Variables

Data from the U.S. Census American Community Survey (ACS) 5-year estimates between 2014 and 2018 [49] were used to retrieve variables measuring socioeconomic factors. The indicators from the U.S. Census ACS are race, household size, educational attainment, age, gender, and income. Latino Americans and African Americans have a higher prevalence of COVID-19 cases, hospitalizations, and deaths than other racial groups [50,51], so two race variables are the Latino population percentage and the African American population percentage. The five age categories are under 19, 20–34, 35–49, 50–64, and 65 and over. The reference group is age under 19. Females have a higher COVID-19 percent prevalence than males [52–54], so the gender variable is the female percentage in a community. Besides household median income, the six categories of annual household income are: less than USD 25,000, USD 25,000–49,999, USD 50,000–74,999, USD 75,000–99,999, USD 100,000–149,999, and USD 150,000 and over. Less than USD 25,000 is a reference group. The five education variables reflecting education levels are: graduate or professional degree, bachelor's degree, associate degree, some college, and high school. The reference group is an education of less than high school. The four types of household size include 1-person, 2-person, 3-person, 4-or-more person. The reference group is a 4-or-more person household.

Table 1. North American Industry Code System category code and definition.

Category	NAICS Code and Definition	
Supermarket (1)	445110—Supermarkets and Other Grocery (except Convenience) Stores: This industry comprises establishments generally known as supermarkets and grocery stores primarily engaged in retailing a general line of food, such as canned and frozen foods; fresh fruits and vegetables; and fresh and prepared meats, fish, and poultry. Included in this industry are delicatessen-type establishments primarily engaged in retailing a general line of food.	Sales: $\geq$1M
Grocery store (2)		Sales: <1M
Convenience store (3)	445120—Convenience Stores: This industry comprises establishments known as convenience stores or food marts (except those with fuel pumps) primarily engaged in retailing a limited line of goods that generally includes milk, bread, soda, and snacks.	
Fast food (4)	722513—Limited-Service Restaurants: This U.S. industry comprises establishments primarily engaged in providing food services (except snack and nonalcoholic beverage bars) where patrons generally order or select items and pay before eating. Food and drink may be consumed on premises, taken out, or delivered to the customer's location. Some establishments in this industry may provide these food services in combination with selling alcoholic beverages.	
Restaurant (5)	722511—Full-Service Restaurants: This U.S. industry comprises establishments primarily engaged in providing food services to patrons who order and are served while seated (i.e., waiter/waitress service) and pay after eating. These establishments may provide this type of food service to patrons in combination with selling alcoholic beverages, providing carry-out services, or presenting live nontheatrical entertainment.	

Data from the Chicago Metropolitan Agency for Planning (CMAP) were used to retrieve variables reflecting the built environment and travel behaviors [55]. The total park acres data from the CMAP 2013 land use inventory were used to measure the built environment. The two travel indicator variables are annual vehicle miles traveled per household and the mode of travel to work. The five modes of travel to work are walking or biking, transit, carpool, driving alone, working at home, and others. The reference group is the walking or biking mode. The options for the number of vehicles available for transportation to work for an occupied housing unit are zero, one, two, and three or more. No vehicle available is a reference group.

3.3. Spatial Statistics and Regression Modeling with Interaction Term

ArcGIS was employed to conduct spatial statistics, global and local statistics. Global Moran's I and Getis–Ord G are global statistics that use a single value for the entire dataset to describe the overall spatial pattern of the activity. Local statistics, local Moran's I and Getis–Ord G were used to identify exactly which local areas were similar or different to other local areas in their neighborhood. Local Moran's I and Getis–Ord G for COVID-19 both at the community level and the zip code level, and obesity and food environment at the community level, were employed to compute the spatial autocorrelation and identify cluster areas of COVID-19 and obesity. To examine the moderating effects of obesity and food environments on COVID-19, this research ran a multivariate regression model to investigate the relationships between COVID-19, obesity, and the food environment. Diagnostics for spatial dependence and heteroskedasticity were conducted to indicate that the Lagrange Multiplier Lag statistic and Lagrange Multiplier Error statistic were not significant; thus, the ordinary least square regression model was used to examine their individual and interaction effects on COVID-19.

4. Results

4.1. Descriptive Statistics of Demographic Characteristics

COVID-19 cases, hospitalizations, and deaths are disproportionately concentrated in the West Side and the South Side of Chicago where Latinx Americans and African Americans reside. As shown in Table 2, Latinx Americans have the highest case rate of 15.23% among all races. The COVID-19 case rates of Latinx Americans are more than twice those of Asian Americans with the lowest case rate of 6.46% and are approximately 1.6 times that of White Americans with a case rate of 9.31%. African Americans have the highest hospitalization rate of 1.78% among all races. The hospitalization rates for COVID-19 among African Americans are approximately three and a half times that of Asian Americans with the lowest hospitalization rate of 0.5% and are approximately 2.8 times that of White Americans with a case rate of 0.64%. Latinx Americans have been hospitalized at a rate approximately twice that of White Americans. African Americans account for 40.8% of COVID-19 mortality, which is higher than the proportion of 29.6% African Americans in Chicago. Figure 2 depicts COVID-19 cases and deaths in Chicago. As shown in Figure 2, the zip code areas with high COVID-19 case rates were concentrated on the west side of the city, and the zip code areas with high COVID-19 death rates were concentrated on both the west and the south side of the city. In terms of gender, the female case rate of 12.68% is higher than the male case rate of 12.51%, while the male hospitalization rate of 1.22% and male death rate of 0.28% are, respectively, higher than the female hospitalization rate of 1.11% and the female death rate of 0.19%. In addition, age plays a role in COVID-19 prevalence. The case rates decrease by age while the hospitalization rates and the death rates increase by age in Chicago. The youngest age group, aged 18–29, has the highest case rate of 15.7%, the lowest hospitalization rate of 0.44%, and the lowest death rate of 0.009%. The second youngest age group, aged 30–49, has the second-highest case rate of 14.88%, the second-lowest hospitalization rate of 0.84%, and the second-lowest death rate of 0.06%, and so on. The oldest age group, aged 70 years or older, has the lowest case rate of 9.22%, the highest hospitalization rate of 3.89%, and the highest death rate of 1.43%.

COVID-19 inequalities correlate closely with health inequalities in obesity in terms of race, age, and gender. As shown in Table 1, compared with other races, African Americans have the highest obesity rate of 39.3%, and Latinx Americans have the second-highest rate of 37.5%, while the average obesity rate in Chicago is 30.8%. Thus, this research considers African American communities and Latinx American communities as obese communities, while others are non-obese communities. Additionally, shown in Figure 3, these obesity inequalities make Chicago's African Americans on the south side of the city and Latinx Americans on the west side of the city more vulnerable to the effects of COVID-19. The obesity rate increases by age. The middle age and old adults have higher obesity rates than young adults, which is the same trend found in COVID-19 deaths by age. Additionally, female adults have a higher obesity rate than male adults, which is consistent with the COVID-19 case trend by gender. Thus, being older and female were associated with a higher case rate in Chicago. A similar trend between COVID-19 and obesity rate in terms of race, age, and gender implies a potential association between them, which is further examined in later sections.

4.2. Spatial Patterns of COVID-19: Global and Local Statistics

Global Moran's I for COVID-19 death rates at the community level is positive and the Z score for global Moran's I is 2.12, greater than 1.96, indicating the clustering pattern of positive spatial autocorrelation at the significance level of 5%. Similarly, global Getis–Ord G is positive and the Z score for global Getis–Ord G is 1.82, greater than 1.65, indicating the apparent clustering pattern of high COVID-19 death rates at the community level at the significance level of 10%.

Table 2. Descriptive characteristics of obesity and COVID-19 prevalence in Chicago.

Variable		Obesity Survey			COVID-19					
		N	%	Percent Obese	Cases		Hospitalizations		Deaths	
					N	%	N	%	N	%
Total		662,000	100.0	30.8	340,676	12.65	31,390	1.17	6188	0.23
Race/ethnicity										
Latino		211,000	31.9	37.5	118,159	15.23	8903	1.15	1993	0.26
African American		242,000	36.6	39.3	75,547	9.47	14,214	1.78	2522	0.32
Asian or Pacific Islander		15,000	2.3	9.8	11,491	6.46	889	0.50	279	0.16
White		185,000	27.9	23.7	83,478	9.31	5732	0.64	1342	0.15
Age										
Obesity	COVID-19									
18–29	18–29	119,000	18.0	21.2	82,691	15.70	2341	0.44	50	0.009
30–44	30–49	200,000	30.2	31.9	120,442	14.88	6809	0.84	522	0.06
45–64	50–69	234,000	35.3	37.0	71,607	12.88	11,996	2.16	2091	0.38
65+	70+	109,000	16.5	32.8	22,707	9.22	9578	3.89	3519	1.43
Gender										
Female		373,000	56.3	33.4	175,602	12.68	15,392	1.11	2578	0.19
Male		288,000	43.5	27.9	163,841	12.51	15,982	1.22	3610	0.28

Notes: COVID-19 data are accumulative totals between 1 March 2020 and 26 November 2021; Obesity data are from 2018. The total population for the city of Chicago used to calculate cases rates, hospitalization rates, and deaths rates, is 2,693,976, from the U.S. Census Bureau (2021b). Population data by age range for the city of Chicago are from the U.S. Census Bureau (2021c).

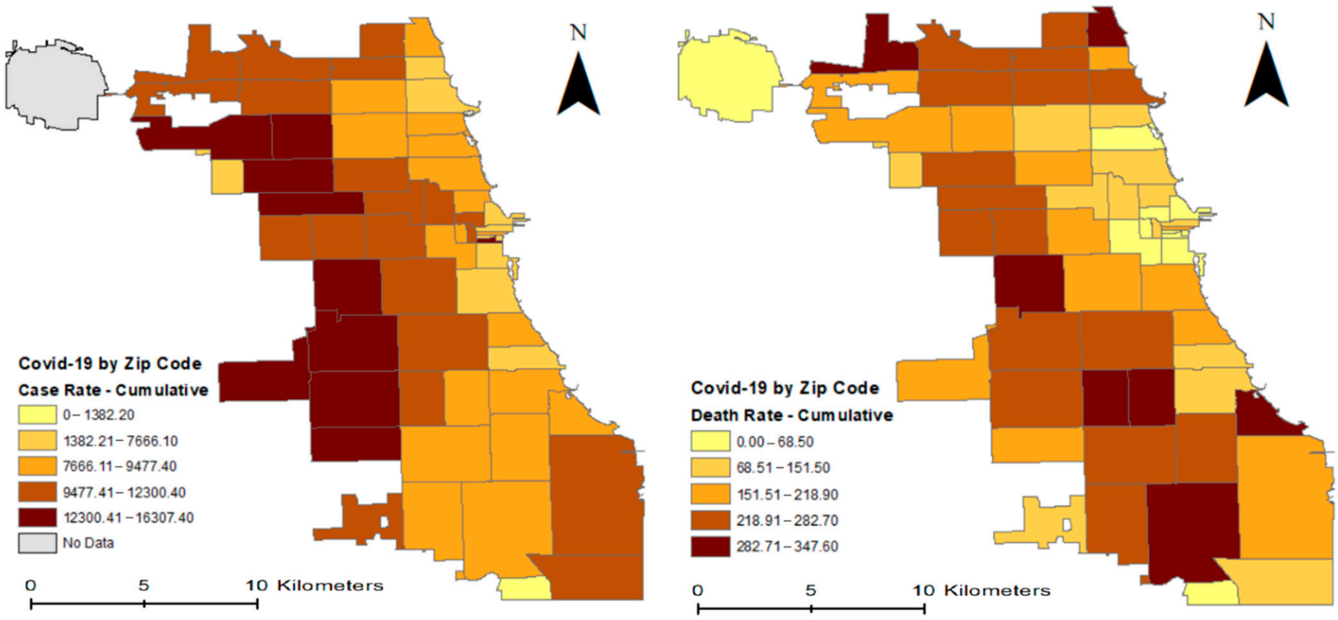

Figure 2. COVID-19 cumulative case rate by zip code (**left**) and COVID-19 cumulative death rate by zip code (**right**).

Global Moran's *I* statistics for COVID-19 case rates and death rates at the zip code level are positive and the Z scores for global Moran's *I* statistics are 1.74 and 6.38, respectively, greater than 1.65 and 2.58, indicating a COVID-19 case clustering pattern of positive spatial autocorrelation at a significance level of 10% and a COVID-19 death clustering pattern of positive spatial autocorrelation at the significance level of 1%.

Similarly, global Getis–Ord *G* statistics for COVID-19 case rates and death rates at the zip code level are 2.12 and 4.07, respectively, greater than 1.96 and 2.58, indicating a clustering pattern of high COVID-19 case rates at a significance level of 5% and a clustering pattern of high COVID-19 death rates at a significance level of 1%.

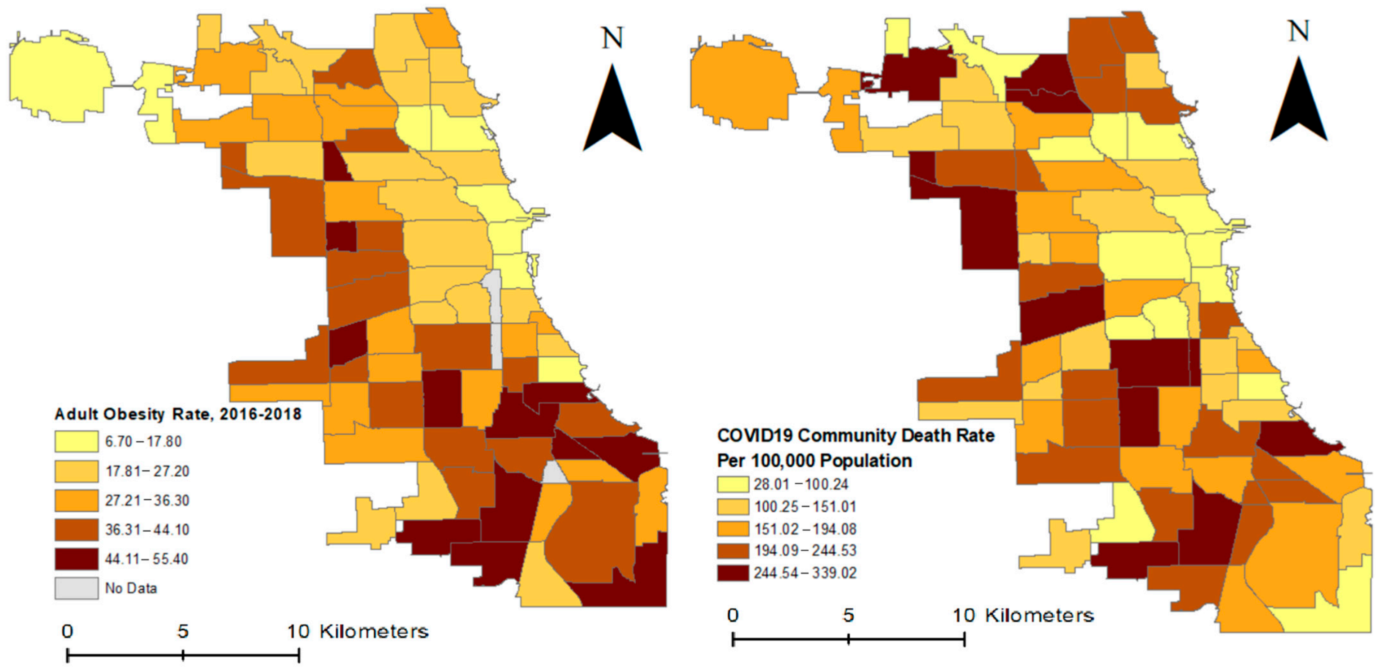

Figure 3. Adult obesity rate (**left**) and COVID-19 death rate (**right**) by community area in Chicago.

There are no local COVID-19 hotspots and coldspots at both the community level and at the zip code level, but there are COVID-19 clusters and outliers at both the community level and at the zip code level. As shown in Figure 4, at the zip code level, cluster areas with a high COVID-19 case rate are in Latinx American communities. Cluster areas with a high COVID-19 death rate at the zip code level are in African American communities. Four communities in the Loop and surrounding areas are cluster areas with a low COVID-19 death rate at both the community level and at the zip code level. As shown in Figure 5, these four communities are Near North Side, Near West Side, Near South Side, and The Loop. In addition, Beverly is an outlier area with a low COVID-19 death rate surrounded by areas with a high COVID-19 death rate.

4.3. Regression Analysis: Moderating Effects of Obesity and Food Environment on COVID-19

Table 3 describes the relationships between obesity, food environment, and COVID-19, presenting the individual and interaction effects of obesity and food environment on COVID-19. The model results indicate a positive association between obesity and COVID-19. A 1 percent increase in obesity rate was associated with a 2.83 percent increase in COVID-19 death rate in a community. The model results show significant positive associations between the number of convenience stores and restaurants and COVID-19 death rate. In Chicago, restaurant stores were fully open without pandemic restrictions, such as mask mandates, social distance rules, and capacity limits, for two months during the period of June to August 2021 [56], which might explain the positive associations of restaurants with COVID-19 death rate. Additionally, in terms of the model coefficients, the magnitude of the association between convenience stores and COVID-19 death rate was more than ten times higher than restaurants, indicating the significantly greater influence of convenience stores on the COVID-19 death rate in comparison to restaurants. This greater influence can be explained by the higher accessibility and availability of convenience stores. In terms of accessibility and availability of shopping opportunities, convenience stores have better spatial accessibility than traditional food stores such as grocery stores and supermarkets [57–59]. Therefore, the greater convenience store access might increase the shopping time, which could lead to more exposure to COVID-19 linked to a higher related death rate. However, the interaction terms between obesity rate and food store access indicate decreasing effects for the obese communities; more restaurants and convenience stores are significantly associated with greater COVID-19 death rates, although their effect decreases when obesity percent increases. In addition, the number of fast food restaurants has a significant negative association with the COVID-19 death rate. Drive-thru and mobile pickup operations provided by fast food restaurants might reduce the direct contact time between individuals compared to long dining times in full-service restaurants and in-store shopping time in convenience stores, supermarkets, and grocery stores. The interaction terms also show decreasing effects for the obese communities, where more fast food restaurants have a significant association with a lower COVID-19 death rate, although their effect decreases when obesity percent increases. This result shows the decreasing effects of fast food restaurants on obese communities, which caused their increased vulnerability to COVID-19.

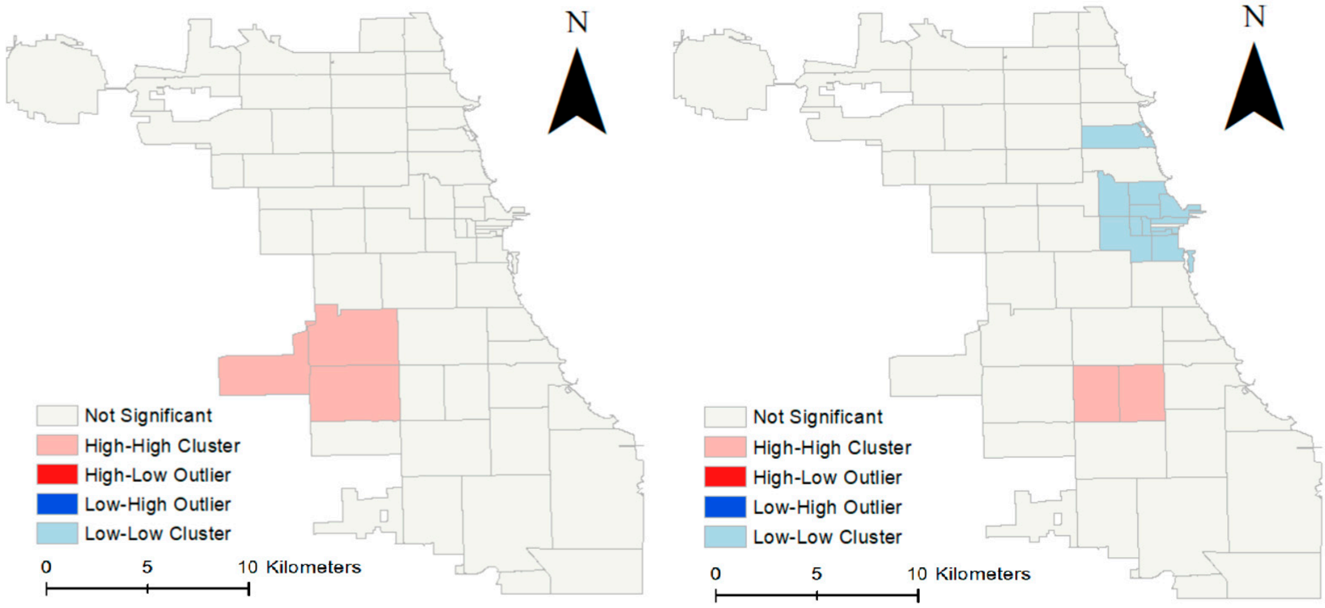

Figure 4. COVID-19 case cluster map (**left**) and COVID-19 death cluster map (**right**) at the zip code level.

Other sociodemographic factors in the model associated with the COVID-19 death rate are age and educational attainment. Individuals aged 20–34 and aged 65+ are two age groups associated with a higher COVID-19 death rate, which is consistent with the fact that the 20–34 age group has a high case rate and the 65+ age group has a high death rate. Populations with associate degrees and bachelor's degrees are linked to a higher COVID-19 death rate. Furthermore, households with an income of USD 75,000 to 99,999 are associated with a lower COVID-19 death rate, compared with households with an income of less than USD 25,000. An occupied housing unit with two available vehicles is associated with a lower COVID-19 death rate, compared with one without vehicles. In addition, households with one to three persons are associated with a lower COVID-19 death rate, compared with households with four or more persons. Living as a large family/household increases contact with others, especially those vulnerable to COVID-19 such as young children and the elderly.

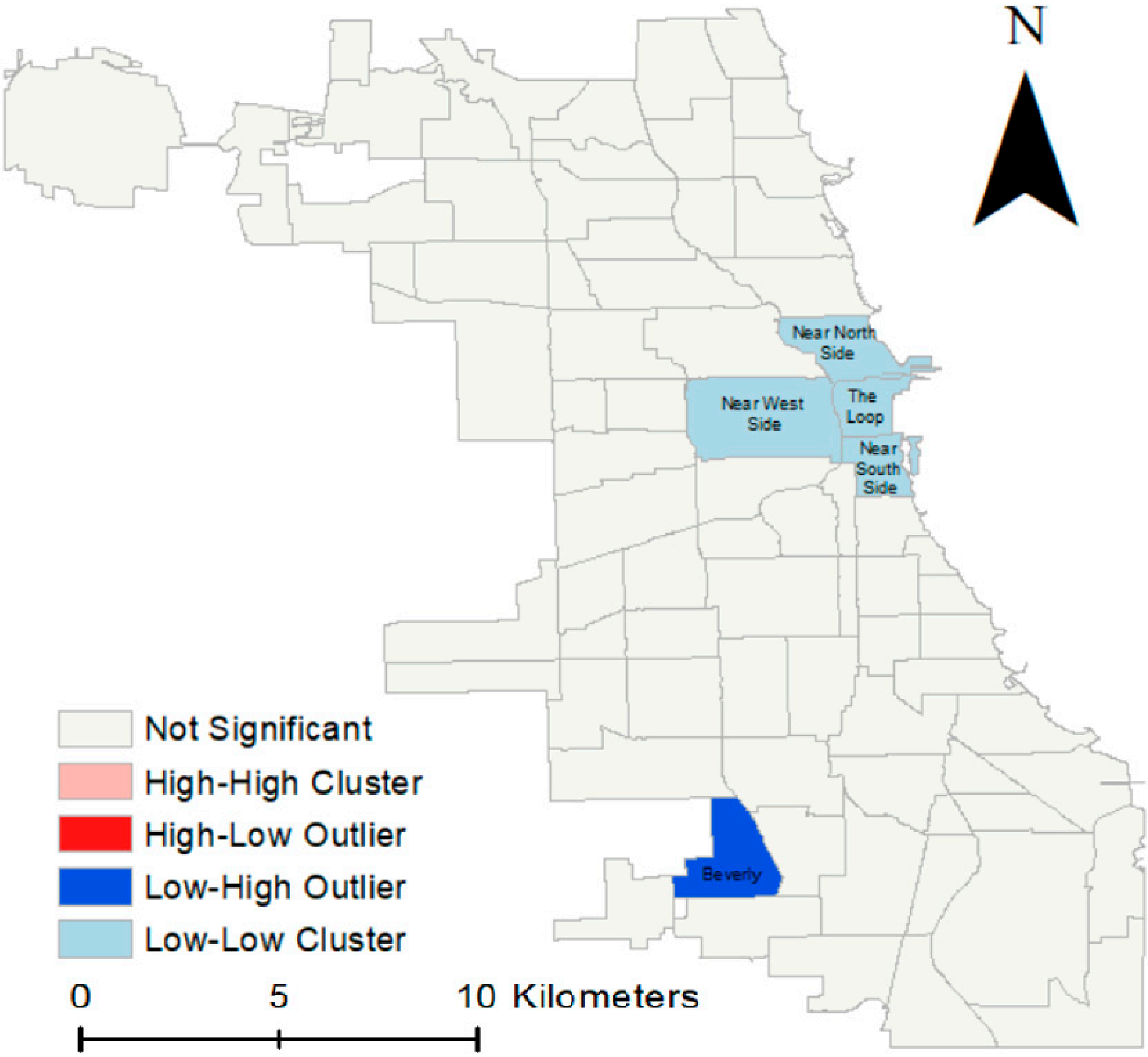

Figure 5. COVID-19 death cluster map at the community level.

Additionally, work travel mode reflecting lifestyle options influences COVID-19 prevalence. Compared to the walking or biking mode, transit is associated with a lower COVID-19 prevalence. This is opposite to the expectation that non-motorized travel modes are safer than public transportation since people on public transportation are confined to enclosed small spaces where it is hard to maintain the six feet social distancing rule and, thus, the virus can transmit more easily, which has been found in existing studies [60–67]. However, Chen et al. find the opposite results in Chicago that public transit is safer than walking due to policies on rigorous cleaning processes and restricting the number of passengers [62,68]. For example, the maximum rider capacity for a 40-foot bus is 25 passengers, and 36 passengers for a 60-foot bus and each railcar [69]. Additionally, enclosed spaces cause people to have strong self-protection awareness such as wearing masks. Marchiori found that wearing masks increases both average and maximum social distancing [70]. This finding might further explain why public transit is safer than walking since the federal transit mask mandate requires wearing masks on public transit compared to the unmasked pedestrian walking mode.

Table 3. Multivariate regression models for the relationship between obesity and environments.

Dependent Variable: COVID-19 Related Death Rate			Adjusted R Square: 0.53			
Independent Variables	**Unstandardized Coefficients**	**Coefficients Std. Error**	**Standardized Coefficients**	***p* Value**	**95% Confidence Interval**	
Constant	425.722	181.568		0.23	61.699	789.745
Access to food retailers						
The number of convenience stores	22.027	6.174	2.450	<0.001	9.650	34.404
The number of fast food stores	−9.204	2.605	−7.951	<0.001	−14.427	−3.980
The number of restaurant stores	2.029	0.939	3.789	0.035	0.146	3.912
The number of fast food stores per capita	0.706	0.352	1.031	0.050	0.001	1.411
Obesity %	2.825	1.433	0.427	0.054	−0.048	5.697
Age						
20–34%	6.580	2.260	0.688	0.005	2.049	11.111
65+ %	11.168	2.721	0.594	<0.001	5.713	16.623
Educational attainment						
Associate degree %	17.683	6.773	0.447	0.012	4.105	31.262
Bachelor's degree %	5.896	2.008	0.910	0.005	1.871	9.921
Income USD 75,000 to 99,999 %	−10.669	4.090	−0.431	0.012	−18.869	−2.469
Mode of travel to work						
Transit %	−3.383	1.607	−0.473	0.040	−6.604	−0.161
Vehicles available						
2 vehicles available %	−5.046	2.360	−0.712	0.037	−9.776	−0.315
Household size						
1-person household %	−7.199	2.395	−1.048	0.004	−12.000	−2.399
2-person household %	−5.513	2.534	−0.365	0.034	−10.594	−0.431
3-person household%	−8.704	4.189	−0.384	0.042	−17.103	−0.305
The number of convenience stores × Obesity %	−0.529	0.187	−1.406	0.007	−0.905	−0.154
The number of fast food × Obesity %	0.303	0.088	4.639	0.001	0.127	0.479
The number of restaurant stores × Obesity %	−0.075	0.036	−2.589	0.041	−0.148	−0.003
The number of fast food per capita × Obesity %	−0.028	0.012	−0.729	0.020	−0.052	−0.005

5. Discussion

COVID-19 in Chicago demonstrated a close association with obesity and food environment at the community level: COVID-19 cases and deaths are highly concentrated in areas with high obesity rates and low food access, which showed North–South and East–West gradients. The geographical process and potential effects of the food environment and obesity inequality are summarized in Figure 6. The Northeast Side has the least COVID-19 cases and deaths, the lowest Hispanic and African American population, the lowest obesity levels, and the greatest access to food; the West Side has the most COVID-19 cases, the highest Hispanic population, the highest obesity levels, and the least access to food; the South Side has the most COVID deaths, the highest African American population, the highest obesity levels, and the least access to food as well. This is consistent with the COVID-19 gradient associated with obesity that was found in the United States [52,71,72]. Disparities in COVID-19 prevalence were found for obese communities. Thus, given the influence of food environment, the associations between obesity and access to each type of food store are emphasized in COVID-19 in Chicago.

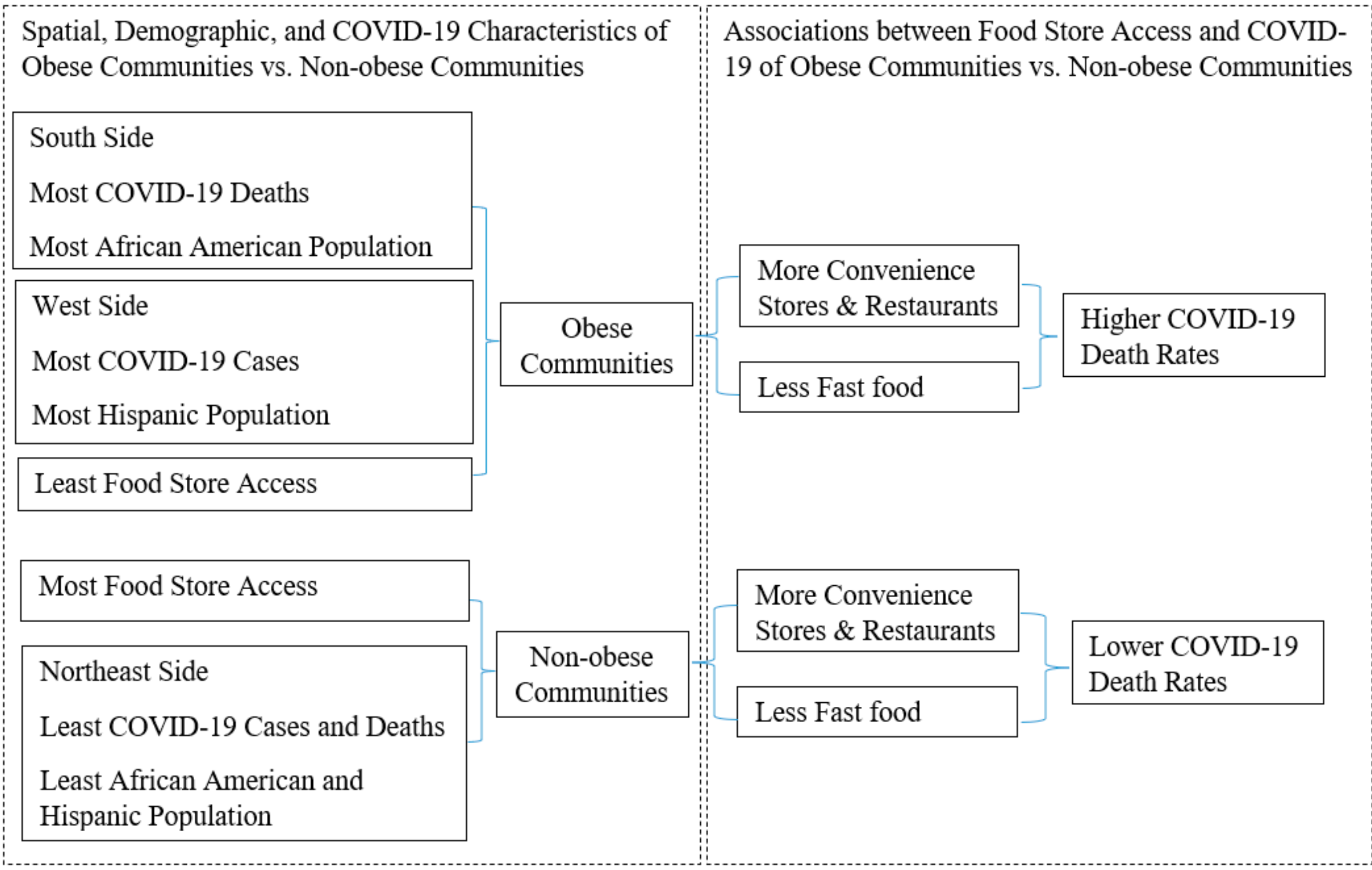

Figure 6. Obesity as a moderator of association between food environment and COVID-19.

This study found the opposite associations between different types of food stores and COVID-19—more convenience stores and restaurants are associated with a higher COVID-19 death rate, while more fast food restaurants are associated with a lower death rate. Similarly, there are the opposite associations between different types of food stores and COVID-19 in obese communities, and obese communities have decreasing effects of associations than non-obese communities. Among the obese communities, more restaurants and convenience stores are associated with a greater COVID-19 death rate, although its effect is lower than the non-obese community. Meanwhile, more fast food restaurants are associated with a lower death rate, although its protective effect is lower than in the non-obese community. The evidence demonstrates that access to convenience stores and restaurants contributes to the COVID-19 death rate in general, but their contributions to the COVID-19 death rate decrease among the obese community. This is consistent with the recent finding of an increase in the percentage of trips-shares to convenience stores during COVID-19 [73], which provides evidence of the potential effects of convenience stores on COVID-19. Comparatively, the contribution of access to fast food restaurants to lowering the COVID-19 death rate decreases in the obese community. These findings might reflect the results of governmental incentive policies—small business administration loans favor fast food chains rather than small independent food vendors in low-income neighborhoods [74]. The obese population are concentrated in African American communities in the South Side of Chicago, which are mainly low-income neighborhoods where small business administration loans favor fast food chains. This might explain how fast food chains crowded out nutrient-rich food alternatives, contributing to a higher COVID-19 death rate among the obese population.

Obesity is recognized as a moderating factor of the association between food environment and COVID-19. Obesity is found to moderate the relationship of access to food environment with COVID-19 death rates, which confirms the findings in the existing literature that different food environments in African American communities might lead to different exposures to different types of food stores and responses to exposures, since African American communities have the largest obese population in Chicago [14]. In the obese population, fast food restaurant access and two other types of access to food stores including convenience stores and restaurants access are oppositely associated with COVID-19, which suggests that it is important to differentiate types of food stores. Although there might be a sharp decline in fast food consumption [75], fast food consumption still contributes to COVID-19 in the obese population concentrated in African American communities, which is consistent with the negative health outcomes of African Americans resulting from fast food found in existing studies [76,77]. Comparatively, the negative associations between restaurants and COVID-19 in the obese communities might be explained by the racial inequalities of consumers' COVID-19 risk perceptions about restaurant food. Byrd et al. found that African Americans were more concerned about COVID-19 contraction from restaurant food than other racial/ethnic groups, which might explain their reduced access to restaurants, lowering COVID-19 risk [78]. The negative associations between convenience stores and COVID-19 in the obese population concentrated in African American communities echo Huang's findings that convenience stores are a source of positive health outcomes in African American communities due to the absence of access to healthy grocery stores and supermarkets in the South Side of Chicago [14], so convenience stores might have a larger influence on household food consumption by providing a limited choice of fresh produce.

6. Conclusions

This study attempts to answer the questions: What community food environment characteristics are associated with COVID-19 in Chicago? How is the obese communities' access to different types of food stores associated with COVID-19? What this study contributes is that obesity is recognized as a moderator of the association between food environment and COVID-19 inequality. Obesity prevalence has been found to moderate the relation between food store accessibility and COVID-19 death rate. The findings suggest that obese communities have food environments different from non-obese communities, which may lead to their different behavioral responses to different types of food stores. Obese communities have less access to healthy food while non-obese communities have greater access to healthy food. The findings contribute to the epidemiological inequality and urban development research regarding roles of obesity and food environment in inequalities related to COVID-19 outcomes [79]. COVID-19 has exposed existing obesity inequalities in a new context for Chicago, making healthy food access challenging and, thus, leading to further diffusion of the virus. More inclusive actions towards reducing healthy food access inequalities and addressing the needs of obese communities should be prioritized for urban planning and COVID-19 reduction.

In Chicago, restaurants, convenience stores, and fast food restaurants have the opposite effects on COVID-19 between the non-obese communities and obese communities—more restaurants and convenience stores are associated with higher COVID-19 mortality, and more fast food restaurants are associated with lower COVID mortality in the non-obese communities, while more restaurants and convenience stores are associated with lower COVID-19 mortality and more fast food restaurants are associated with higher COVID-19 mortality in the obese communities. Thus, both the abundance of less healthy foods and the absence of healthy foods account for obesity. Given that the most obese communities reside in the South Side and the least obese communities reside in the North Side, community developers and policymakers could consider developing policies attracting restaurant and convenience store investment in the South Side rather than the North Side to help reduce COVID-19 mortality in both sides of the city. Especially considering that the magnitude of association of convenience stores with COVID-19 is more than ten times higher than restaurants, building more convenience stores in the South Side might significantly help build an antivirus-enabled food environment in neighborhoods with obesity concerns.

Further, the differences between the North Side and the South Side also indicate that the associations between COVID-19 and obesity are socially patterned, involved in pathways that link biosocial interactions to racial inequalities in obesity [80,81]. In Chicago, the historical processes of segregation and the systemic racism as a set of policies and structures of neighborhood disadvantage, poverty, and racial segregation generate toxic environments that cause inequalities in the spatial distribution of food outlets and healthy food access, which mediate the social and spatial concentration of COVID-19 via physiological pathways including nutritional status and immune function [82]. Thus, reducing systemic racism and, thus, improving equalities in healthy food access might help build healthy environments that contain COVID-19.

There are some limitations in this study. First, cross-sectional data have limits in examining causal effects between the food environment and COVID-19. Second, the BMI figures are self-reported data, so systematic bias related to food environment predictors might exist. Third, there is a boundary issue since selecting the aggregation level is based on data availability. Fourth, unequal distribution of COVID-19 might be caused by unobserved demographic and neighborhood characteristics, such as health care facilities and insurance, since these demographic and neighborhood features might affect the respondents' health status [83,84]. Additionally, due to the unavailability of data, urban design and diversity are not included in the model. Last, food stores classification by the NACIS code assumes the availability of affordable food, but there are variations in the availability, affordability, acceptability, convenience, desirability, and large policy contexts in food stores [85]. Thus, further research is requested to consider the availability, price, and quality of foods.

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Data Availability Statement: Restrictions apply to the availability of food stores data from the Dun & Bradstreet database. Other data available in a publicly accessible repository that does not issue DOIs Publicly available datasets were analyzed in this study: These data webpage links can be found in corresponding references listed in the reference list.

Conflicts of Interest: The author declares no conflict of interest.

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