Food insecurity and healthy food consumption in Brazil: an spatial microsimulation approach

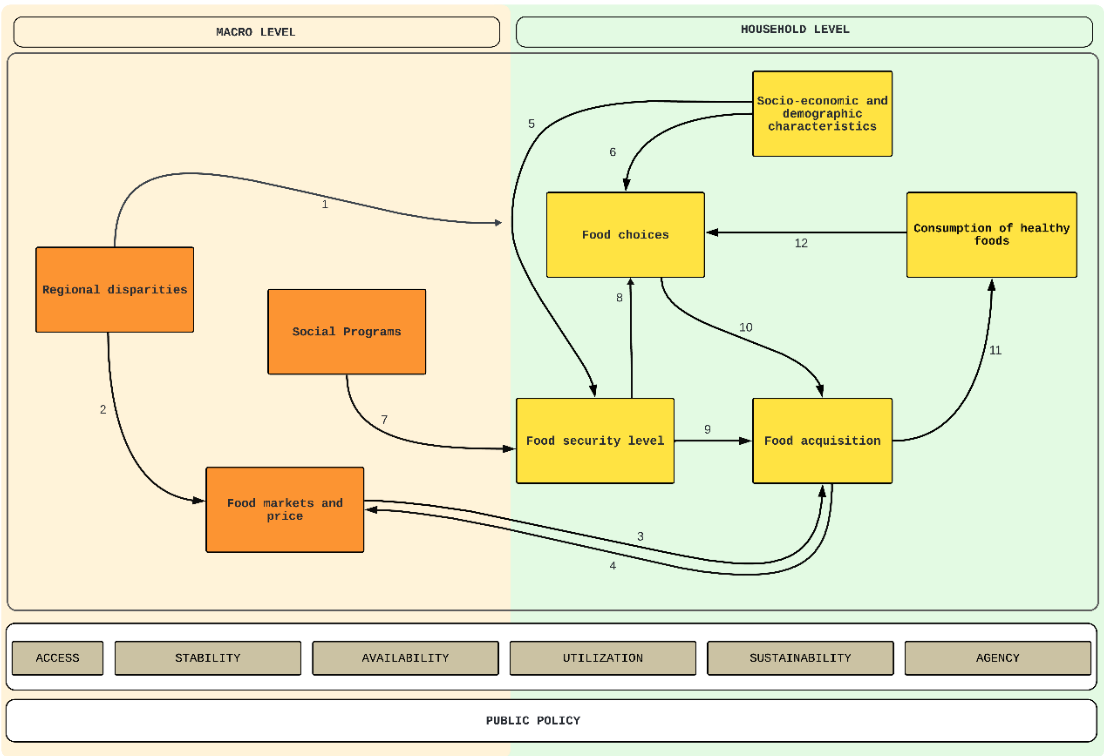
Background and aim

The use of spatial microsimulation to study food consumption and access has been implemented for a variety of purposes, including the exploration of regional inequalities in access to healthy diets[1], the study of public food and nutrition policies[2], and also to investigate the potential link between areas considered to have poor access to establishments for acquire food and spatial concentrations of diet-related health problems[3]. Spatial microsimulation permits the incorporation of individual variability and spatial patterns, which are essential for understanding regional inequalities in access to healthy food. Furthermore, spatial microsimulation involves creating and analysing individuals and their allocation in households and zones. But this does not necessarily imply interaction between these individuals[4].

The aim of this model is to simulate the spatial and temporal patterns of healthy food consumption in Brazilian households, taking into account characteristics of the food environment, sociodemographic factors and the level of food security. In particular, emphasis is placed on how these factors shape the spatial distribution of the choice of healthy foods consumption, according to the level of food security.

Our model is informed by a conceptual model (Figure 1) which takes into account elements and factors already described and consolidated in the literature, as well as data from Brazilian surveys on family budgets, food consumption and acquisition and food environments[5,6]. It underpins the multidimensionality of food insecurity and its contributing factors at the macro socioeconomic, regional, local and household levels[7], as well as aspects related to the process of food choice[8] and the food environment[9-11]. The conceptual model was evaluated by 24 Brazilian experts in the fields of food, food security and food systems.

Fig. 1. Conceptual model



Note: Click on the image for a better resolution.

Table 1 shows the constructs, operational definitions and references used to define this version of the conceptual model (Figure 2) and the meaning and assumptions of the relationships between the variables included in the conceptual model can be seen in Table 2.

Table 1. Operational definition of the constructs contained in the conceptual model

Construct		Operational definition	Reference
Food environment		Part of the food system where interactions take place regarding the adoption of healthy and sustainable diets.	Rideout, Mah & Minaker (2015)[9]; Downs et al. (2020)[10]; Bezerra et al. (2024)[11]
Level	Macro Household	Levels of the multiple and intersectoral determinants of the food security situation.	Kepple, Segall-Corrêa (2011)[7]
Regional disparities		Differences in the levels of food insecurity and the characteristics of the food environment, according to the region where the household is located.	IBGE (2020)[2]; Brasil (2018)[3]
Social programs		Inclusion of households in social programs (income transfer).	Baptistella (2012)[10]; Cotta & Machado (2013)[11]
Food markets provision and price		Availability of food in terms of places to buy healthy food and the price of healthy food (fruit and vegetables).	Brasil (2018)[5]; IBGE (2020)[6]
Food security level		Level of household food security or insecurity.	IBGE (2020)[6]
Socio-economic and demographic characteristics		Characteristics related to the household and the household reference person (gender, schooling, access to water, sewage, etc.).	IBGE (2020)[6]
Healthy food consumption		The practice of consuming healthy food over time.	-
Food choices		Food choice based on the factors that will influence this decision in the model.	Jomori, Proença e Calvo (2008)[8]
Food acquisition		Food purchased by households.	IBGE (2020)[6]
Pillars of food security	Access	People's ability to obtain food.	Clapp et al. (2022)[12]
	Stability	The ability of food systems to provide food consistently over time.	
	Availability	It refers to the quantity and quality of food available to the population.	
	Utilisation	Ability to absorb and utilise nutrients from the food consumed.	

	Sustainability	Long-term viability of the ecological and social bases of food systems.	
	Agency	Capacity of individuals and groups to exercise voice and make decisions about their food systems.	
Public policy		Public policies - of different dimensions - that affect the pillars of food and nutritional security and interfere with the food environment in Brazil.	Santarelli, Vieira & Constantine (2018)[13]; Jaime (2019)[14]; Watanabe et al. (2022)[16]; Domingos et al. (2023)[16]; Recine et al. (2024)[17]

Table 2. Meaning and assumptions of the relationships contained in the conceptual model

Regional disparities influence the relationship between household socio-economic and demographic characteristics and the level of food security (1). Households located in the North and Northeast regions have a higher level of food insecurity.
Regional disparities influence the availability of healthy food markets and the price of food (2), which influence food acquisition (3) and this relationship forms a loop (4). There are regions with more and fewer establishments for buying healthy food, which influences the price and the permanence of individuals in these regions.
Socioeconomic and demographic characteristics influence the level of household food security (5) and food choices (6). Better-off households tend to have lower levels of food insecurity and make more informed food choices.
The level of food security is also affected by participation in social programs (7) and, in turn, influences food choices (8) and food acquisition (9), which is also influenced by choices (10).
Healthy food consumption is a function of food acquisition (11). The more food you buy, the more you eat. This consumption, in turn, influences future food choices (12) and this creates a reinforcing loop.
Public policies have an impact on the pillars of food security and these pillars are manifested, to a greater or lesser degree, in the factors that constitute the model.

General model structure

The simulated units are households, modelled at state level. Each household has socio-demographic characteristics, a level of food security and information on food consumption, purchase and price. In addition, information on the presence of establishments for buying healthy food in the areas where these households are located is used. The model estimates the consumption of healthy foods per household based on regressions weighted by these characteristics. The attributes that characterise each unit are described in Table 3. The characteristics of the units will be derived from empirical data obtained from the Family Budget Survey 2017/2018 of the Brazilian Institute of Geography and Statistics (IBGE), based on a sample of 57,920 interviewed households across the country[6]. The food environment is represented by the density of healthy food establishments per state, obtained from the mapping of food deserts carried out by the Ministry of Citizenship of the Brazilian Federal Government (CAISAN)[5]. The databases will be integrated into a georeferenced shapefile.

Table 3. Household's attributes

Attribute	**Definition**	**Scale and domain**	**Initialisation process**	**Update process**
Space				
Region	Refers to the Brazilian region where the household is situated.	Discrete. 1 - 5, representing each region in Brazil.	Deterministic. Determined by the data set.	No update.
State	Refers to the Brazilian state where the household is situated.	Discrete. 1 - 27, representing each state in Brazil.	Deterministic. Determined by the data set.	No update.
Household situation	Refers to the urban or rural situation of the household, where it is situated.	Binary. 0 (urban) and 1 (rural).	Deterministic. Determined by the data set.	No update.
Location	Refers to patch in the state where the household is situated.	Cartesian coordinates.	Random. Discrete probability distribution conditional to state, region and food security level.	No update.
Food markets	Reflects the availability of healthy foods in space where the household is situated.	Continuous. From 0 to 100.	Deterministic. Determined by the data set.	Updated according to state, region and food acquisition. Each one year.
Food price	Refers to the healthy food prices.	Continuous. In Reais (R$).	Deterministic. Determined by the data set.	Updated according to state, region and food acquisition. Each one year.
Households				
Food security situation	Refers to the level of food security of the household.	Discrete. 0 (food security), 1 (mild food insecurity), 2 (moderate food insecurity) and 3 (severe food insecurity).	Deterministic. Determined by the data set.	Updated according to gender, race, number of residents, presence of children, level of education, per capita income, access to piped water and

				electricity and participation in social programs. Each one year.
Participation in a social program	Refers to whether or not the household is included in social programs.	Binary. 0 (included) and 1 (not included).	Random.	No update.
Gender	Refers to the gender of the head of the household.	Binary. 0 (male) and 1 (female).	Deterministic. Determined by the data set.	No update.
Race	Refers to the race of head of the household.	Discrete. 0 (brown), 1 (white), 2 (black), 3 (yellow) and 4 (indigenous).	Deterministic. Determined by the data set.	No update.
Age	Refers to the age of head of the household.	Discrete. 0 (adolescent; <20y.o.), 1 (adult; 20-30 y.o.), 2 (adult; 31-45 y.o.), 3 (adult; 45-59y.o.) and 4 (elderly; >60 y.o.)	Deterministic. Determined by the data set.	Updated conditional on the previous value. Each one year.
Level of education	Refers to the level of education of the head of the household.	Discrete. <= 8 years of schooling; 9 to 11 years of schooling; >= 12 years of schooling.	Deterministic. Determined by the data set.	No update.
Number of residents	Number of residents in the household.	Continuous. From 1 to 20.	Deterministic. Determined by the data set.	No update. Each one year.
Number of residents <18 years	Number of residents <18 years in the household.	Continuous. From 1 to 10.	Deterministic. Determined by the data set.	Updated conditional on the previous value. Each one year.
Income per capita	Household income per capita.	Continuous. In Reais (R$). From R$0 to R$23,414,94.	Deterministic. Determined by the data set.	Updated conditional on the level of food security, participation in social programmes, gender, race, age, level of education, total number of residents and < 18. Each one

				year.
Access to piped water	Refers to adequate or inadequate access to water by the household	Discrete.0 (inadequate access); 1 (adequate access).	Deterministic. Determined by the data set.	No update.
Access to electricity	Refers to adequate or inadequate access to electricity by the household	Discrete. 0 (inadequate access); 1 (adequate access).	Deterministic. Determined by the data set.	No update.
Acquisition and consumption of Nuts, Legumes, Fruits, Green vegetables, Red vegetables, Other vegetables, Whole grains, Potatoes and tubers.	Healthy food purchased and consumed in households	Continuous. From 0% to 100%.	Deterministic. Determined by the data set.	Updated according to the previous value. Each week.

Microsimulation methodology

The population will be synthesised using the proportional iterative fitting (IPF) method, ensuring correspondence between the distribution of known attributes in the real population - derived from the aggregated data (POF sample (2017/2018)) - and the distribution of these same attributes in the population synthesised by the model. The IPF is a method used to adjust a multidimensional matrix of simulated data so that its marginals correspond to the observed marginals, respecting the characteristics of different variables[4]. Data on the availability of establishments for the purchase of healthy food will be integrated with socio-demographic data and data on food consumption, purchase and price.

Transitions in the consumption of healthy foods are modelled according to the formulas below:

$$logit(P(FSL = 1)) = \beta_0 + \beta 1pc\_income + \beta 2gender + \beta 3race + \beta 4age + \beta 5education + \beta 6n\_members + \beta 7n\_members18 + \beta 8access\_water + \beta 9access\_eletricity + \beta 10social\_programs + \beta 11region + \beta 12UrbanRural\ \epsilon \quad (1)$$

Where:

- FSL: Food security level;
- logit(P(Y = 1)): Logarithm of the odds ratio (log-odds) of Y=1, the occurrence of the outcome;
- P(Y=1): Probability of the outcome occurring;
- β_0: Intercept;
- $\beta 1, \beta 2 ... \beta 11$: Coefficients of the independent variables;
- ϵ: *Error.*

$$HFC_i \rightarrow ln\ (\mu / 1-\mu) = \beta_0 + \beta 1consumption_{t-1} + \beta 2food\_purchased + \beta 3pc\_income + \beta 4gender + \beta 5race + \beta 6age + \beta 7education + \beta 8n\_members + \beta 9n\_members18 + \beta 10access\_water + \beta 11access\_eletricity + \epsilon \quad (2)$$

Where:

- HFC: Health food consumption;
- μ: Expected proportion of healthy food consumption;
- β_0: *Intercept;*
- *β1, β2...β11:* Coefficients of the independent variables;
- ϵ: *Error.*

$$FPu \rightarrow ln\ (\mu/1\text{-}\mu) = \beta_0 + \beta 1 food\_security\_level + \beta 2 food\_prices + \beta 3 food\_markets + \epsilon \quad (3)$$

Where:

- *FPu:* Food purchased;
- μ: Expected proportion of food purchased;
- *α: Intercept;*
- *β1, β2, β3:* Coefficients of the independent variables;
- ϵ: *Error.*

$$FM \rightarrow ln\ (\mu/1\text{-}\mu) = \alpha + \beta 1 region + \beta 2 food\_purchased + \epsilon \quad (4)$$

Where:

- *FM:* Food markets;
- μ: Expected density of healthy food markets;
- *α: Intercept;*
- *β1, β2:* Coefficients of the independent variables;
- ϵ: Error.

$$FPr = \alpha + \beta 1 region + \beta 2 food\_purchased + \epsilon \quad (5)$$

Where:

- *FPr:* Food prices
- *α: Intercept;*
- *β1, β2:* Coefficients of the independent variables;
- ϵ: Error.

The above equations estimate the probability of food security, consumption of healthy food, food purchased, the availability of establishments to buy healthy food and additionally, prices based on the variables related to each of these outcomes, as illustrated in the conceptual model (Figure 1), and is weighted by the POF sample (2017/2018), using the expansion factor. These equations will be implemented in the spatial microsimulation model.

The baseline scenario maintains the historical trends while the intervention scenarios include the creation of a loop to update the variables over the years. The model simulates healthy food consumption over a 12-year period (2018 to 2030). Each year is treated as a discrete period, with transitions calculated from probabilities based on predetermined rules (outlined in the conceptual model). Three scenarios will be tested: (I) reducing food insecurity; (II) increasing the density of establishments for purchasing healthy food; (III) reducing food insecurity and increasing the density of establishments for purchasing healthy food. The variables are updated iteratively each year. Consumption values are simulated each year and recalculated based on the updated values of the variables.

Income will be updated based on average annual growth; the density of establishments will be updated based on the calculation of an annual increase based on public policies; food prices will be adjusted annually based on the variation in the consumer price index and the level of food insecurity will be updated based on the average values of the historical series.

Validation

The simulated patterns will be compared with real data from the POF in different regions of the country and discussed in relation to previous studies on dietary inequalities in Brazil. In addition, the scenarios tested contribute to assessing impacts on healthy food consumption.

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