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ABSTRACT

One of the major challenges for Brazilian economic development is to eliminate hunger and malnutrition, especially among children. In this context, agriculture plays a fundamental role as a food provider. The objective of this study is to assess whether a greater female presence in the management of agricultural establishments is associated with lower rates of malnutrition among children up to five years of age. To this end, the quasi-experimental Propensity Score Matching (PSM) method is used. The treatment group consists of municipalities belonging to spatial clusters with a high female presence in charge of agricultural activities, and the control group consists of similar municipalities that do not belong to these clusters. The data on female leadership are from the latest Agricultural Census (IBGE, 2017), and the indicators of child malnutrition are from the Food and Nutrition Surveillance System (Ministry of Health, 2026). The results indicate that female leadership reduces the rate of malnourished children in municipalities where family farming predominates. Therefore, family farming acts as a mediator of the effect of female leadership on child malnutrition.

Keywords: Food Security. Brazil. Agriculture. Gender. Propensity Score Matching.

RESUMO

Um dos grandes desafios para o desenvolvimento econômico brasileiro é eliminar a fome e a subnutrição, principalmente de crianças. Nesse contexto, a atividade agropecuária tem um papel fundamental como provedora de alimentos. O objetivo deste estudo é avaliar se uma maior presença feminina na gestão de estabelecimentos agropecuários está associada a menores taxas de subnutrição de crianças de até cinco anos. Para tanto, é utilizado o método quase experimental *Propensity Score Matching* (PSM). O grupo de tratamento é formado por municípios pertencentes a clusters espaciais de alta presença feminina no comando de atividades agropecuárias, e o grupo de controle, por municípios similares, mas não pertencentes a esses clusters. Os dados de liderança feminina são do último Censo Agropecuário (IBGE, 2017), e os indicadores de subnutrição infantil são do Sistema de Vigilância Alimentar e Nutricional (Ministério da Saúde, 2026). Os resultados indicam que a liderança feminina diminui a taxa de crianças subnutridas nos municípios em que há predomínio de agricultura familiar. Portanto, a agricultura familiar funciona como mediadora do efeito da liderança feminina sobre a subnutrição infantil.

Palavras-chave: Segurança Alimentar. Brasil. Agropecuária. Gênero. *Propensity Score Matching.*

INTRODUCTION

Hunger remains a major challenge to development in many countries. Although some progress has been made in recent years, a long way remains before hunger and food insecurity can be eradicated (FAO, 2025). Brazil, despite having been removed from the UN Hunger Map in 2024/2025, continues to face a concerning situation. The proportion of households experiencing severe food insecurity declined from 4.1% to 3.2% between 2023 and 2024, indicating that approximately 2 million people were no longer affected by hunger during this period. Nevertheless, official statistics show that 24.2% of Brazilian households still experience some degree of food insecurity (mild, moderate, or severe), affecting an estimated 54.7 million people (IBGE, 2024).

Undernutrition poses health risks at all stages of life but is particularly critical during childhood. Unlike adults, children are in a period of rapid growth and development of vital physiological systems, making the effects of nutrient deficiency more severe and often irreversible. Broadly speaking, undernutrition during this stage of life can lead to both physical and cognitive impairments, with lasting consequences extending into adulthood (Ministério da Saúde, 2005; Dipasquale, 2020; Kirolos et al., 2024; Roger et al., 2022; Ansuya et al., 2023).

With respect to physical health, undernutrition increases susceptibility to disease by weakening the immune system, thereby creating a vicious cycle in which more frequent illnesses (such as diarrhea and infections) lead to further nutrient loss. It also results in growth retardation (low height-for-age), as the body prioritizes essential survival functions over skeletal and muscular growth under conditions of nutritional deprivation. Furthermore, studies indicate that undernourished children are more likely to develop chronic diseases in adulthood, including diabetes, hypertension, and cardiovascular disorders (Ministério da Saúde, 2005; Dipasquale, 2020). Regarding cognitive development, childhood represents a critical period for neural development. Nutrient deficiencies during this stage may cause permanent impairments in memory, reasoning, and learning, thereby reducing educational achievement and future labor market potential (Kirolos et al., 2024; Roger et al., 2022; Ansuya et al., 2023).

In Brazil, according to data from the Ministry of Health's Food and Nutrition Surveillance System (SISVAN), between 260,000 and 350,000 children were undernourished in 2025 (representing 3.3% to 4.5% of the total child population), based on weight-for-age and thinness indicators. When the indicator of

very low or low height-for-age is considered specifically, this number rises to nearly 850,000 children (11% of the total) (Ministério da Saúde, 2026).

Previous studies have consistently shown a direct association between greater women's decision-making power and improved child nutritional outcomes. This relationship is largely explained by the fact that women are more likely to allocate household resources toward healthcare, education, and nutritious food for their children. In contrast, men tend to devote a larger share of household income to personal consumption, whereas women generally allocate a greater proportion of their resources to family expenditures (Hoddinott; Haddad, 1995; Quisumbing, 2003). The World Bank report (World Bank, 2012) emphasizes that increasing women's control over resources leads to immediate improvements in child survival and nutritional status. Likewise, the United Nations (2019) highlights investment in women's economic empowerment as one of the most effective strategies for eliminating child hunger.

The care economy emphasizes activities that are essential for sustaining life, such as household cleaning, food preparation, and breastfeeding. When women occupy leadership positions or have financial autonomy, they are better able to promote policies that recognize and value caregiving time, ensuring that children receive the nutritional care required during the first years of life. In the sphere of political decision-making, greater female representation has been associated with a stronger commitment to implementing food security programs and policies that support early childhood development. In Brazil, the *Bolsa Família* program prioritizes women as the primary recipients of cash transfers precisely because they have been shown to manage these resources more effectively in reducing child undernutrition (Chattopadhyay; Duflo, 2004; Folbre, 2006; Hoppania, 2015).

The objective of this study is to assess whether a greater presence of women leading agricultural establishments is associated with lower rates of undernutrition among children under five years of age across Brazilian municipalities. To this end, the study employs the quasi-experimental Propensity Score Matching (PSM) method, in which the treatment group consists of municipalities belonging to spatial clusters characterized by high levels of female leadership in agriculture, while the control group comprises otherwise similar municipalities that do not belong to these clusters. Data on female leadership are obtained from the latest Brazilian Agricultural Census (IBGE, 2017), whereas indicators of child undernutrition are drawn from SISVAN (Ministério da Saúde, 2026).

In addition to this introduction, Section 2 presents the theoretical and empirical literature review. Section 3 describes in detail the methodological procedures adopted in the study. Section 4 presents and discusses the empirical findings. Finally, the concluding section summarizes the study's main findings.

LITERATURE REVIEW

Child food and nutrition security is a multidimensional challenge shaped by factors ranging from food availability to caregiving practices and local governance. In rural and low-income settings, two factors have received increasing attention in the literature: female leadership and the presence of family farming. This literature review provides the theoretical and empirical foundation for understanding how these variables may interact and influence indicators of child undernutrition through mechanisms such as the care economy, production diversification, food accessibility, and the market orientation of agricultural systems.

FEMALE LEADERSHIP AND THE CARE ECONOMY

The notion that women in leadership positions tend to prioritize social and environmental policies is grounded in the care economy framework (Folbre, 2006; Hoppania, 2015). According to this perspective, women are socialized to assume reproductive and caregiving responsibilities, which may translate into greater attention to issues such as health, nutrition, education, and social protection. Studies on political representation have shown that women holding public office tend to allocate a larger share of public resources to social sectors (Chattopadhyay; Duflo, 2004).

Using longitudinal data and fixed-effects regression models, Ogutu et al. (2024) examined the effects of female leadership on household dietary diversity and indicators of child undernutrition in India. Their findings indicate that women's empowerment enhances dietary diversity and reduces the prevalence of underweight and wasting among children, although it does not significantly affect the prevalence of stunting. The authors conclude that female leadership contributes to improved household dietary diversity and child nutrition, representing a promising strategy for enhancing family diets and children's nutritional outcomes.

A growing body of evidence indicates that when women control household resources and actively participate in decision-making, the prevalence of child undernutrition within the household declines (Emongor et al., 2021; Ahmed et al., 2012; Allendorf, 2007). Moreover, when women participate in the production or marketing of agricultural products, their influence over decisions regarding household income allocation increases. This, in turn, leads to improvements in household consumption patterns (Ogutu et al., 2024; Aziz et al., 2021; Mutsami; Maina; Khonje, 2025; Ruel; Alderman, 2013).

In a study conducted in Bangladesh, Ahmed et al. (2012) investigated the effects of female leadership on child nutrition. Their results show that children whose mothers were responsible for household decision-making were less likely to experience stunting, underweight, and wasting than children whose mothers did not participate in household decisions. Similarly, Allendorf (2007) examined whether women's land ownership empowers them and whether this empowerment affects child health in Nepal. The findings support both hypotheses: women who own land have greater decision-making power within the household, and children of land-owning mothers are less likely to be undernourished (underweight).

Brollo and Troiano (2016), in a study of Brazilian municipalities, found that female leadership in municipal executive offices is associated with higher levels of investment in primary healthcare and early childhood education, although these effects are moderated by underlying structural conditions of poverty.

FAMILY FARMING, PRODUCTION DIVERSIFICATION, AND LOCAL FOOD MARKETS

Empirical evidence indicates that production diversification can improve nutritional outcomes by increasing access to and consumption of high-quality diets (Herforth; Ballard, 2016). Foods produced through agricultural activities contribute to greater dietary diversity, particularly among resource-constrained households in remote areas with limited access to markets (Ruel; Quisumbing; Balagamwala, 2018).

Family farming is commonly associated with more diversified production systems oriented toward both household consumption and local markets, thereby increasing the physical availability of food within municipalities. This relationship underpins the concept of Short Food Supply Chains (SFSCs). By bringing producers closer to final consumers, SFSCs promote local development by ensuring that income circulates within the region, while also enhancing the value of family-farmed

products and increasing producers' incomes. A substantial body of research has examined the relationship between SFSCs and food security (FAO, 2014; Freitas; Rambo, 2019; Tittonell et al., 2021; Renting; Marsden; Banks, 2003).

Whereas modern agribusiness is integrated into long supply chains that primarily serve export markets or food-processing industries, family farming predominantly supplies nearby markets, including municipal farmers' markets, direct-to-consumer sales, and institutional procurement programs such as the Food Acquisition Program (Programa de Aquisição de Alimentos–PAA) and the National School Feeding Program (Programa Nacional de Alimentação Escolar–PNAE). These SFSCs reduce the number of intermediaries and lower food prices, thereby improving access to fresh foods for low-income urban populations while keeping income circulating within the local economy (Schneider, 2009; FAO, 2014; Darolt; Rover, 2021).

Several case studies employing the SFSC framework support these hypotheses. By strengthening the link between farmers and consumers, these marketing channels foster local development by ensuring that financial resources remain within the region, while simultaneously increasing the value of family-farmed products and improving producers' incomes. Direct marketing also allows prices to be determined on the basis of product quality as well as cultural and environmental values. Research in this field has examined experiences such as open-air markets, specialized local food stores, and on-farm direct sales. Beyond their economic benefits, SFSCs reduce the distance food travels, thereby decreasing food losses, lowering environmental impacts, and reducing greenhouse gas emissions (Darolt et al., 2016; Gazolla; Schneider, 2017; Darolt; Rover, 2021; Verano; Figueiredo; Medina, 2021; Freitas; Nascimento; Costa, 2025).

A case study conducted in Brazil's semi-arid region (Lopes et al., 2022) found that municipalities with a higher share of family farming offer a greater variety of foods at farmers' markets and lower food prices than municipalities that rely on food imported from other regions. From an economic perspective, greater local food supply reduces post-harvest losses and may exert downward pressure on food prices. In local markets, domestic production is therefore a key determinant of the cost of maintaining an adequate food diet (FAO, 2014).

Roldan et al. (2021) examined Short Food Supply Chains (SFSCs) in the marketing of artisanal cheeses produced in the Brazilian state of Rio Grande do Sul, highlighting their role in strengthening trust and long-term relationships between producers and consumers. Similarly, Miranda, Wegner, and Dias (2024) analyzed family farming markets, emphasizing that they contribute to greater price stability compared with wholesale distribution centers. Camilo (2023) concluded that, despite the constraints of local markets, SFSCs enhance the connection between producers and consumers, thereby increasing agricultural income. Santos, Coca, and Salvaterra (2023), in turn, emphasized the importance of agroecological food baskets in promoting food security by strengthening partnerships between rural and urban communities.

Finally, Pedrada et al. (2022) investigated the role of SFSCs among family farmers in the state of Amapá during the food crisis triggered by the COVID-19 pandemic. Using primary data collected through structured interviews, the authors found that family farmers successfully adapted to the crisis by establishing alternative marketing channels, including direct home deliveries, farmers' markets within rural communities, food basket deliveries to residential condominiums, and drive-through distribution systems.

FEMALE LEADERSHIP, FAMILY FARMING, AND FOOD ACCESSIBILITY

The impact of agriculture on child nutrition is not automatic. Rather, it depends on who controls productive resources and how agricultural production is linked to food consumption. Women farmers tend to allocate a larger share of both household income and agricultural output to children's nutrition, but this effect is maximized when production is diversified and connected to accessible local markets—features that are characteristic of family farming systems. According to Quisumbing, Meinzen-Dick, and Malapit (2022), the nutritional benefits of women's control over agricultural resources are mediated by the structure of the food system: where women produce for household consumption or local markets, the effects are stronger; where production is integrated into long value chains, the effects are more limited.

In a review of agricultural policies, Verhart et al. (2016) found that policies simultaneously promoting family farming and strengthening female leadership generate nutritional impacts that are

2.5 times greater than policies targeting only one of these dimensions. This synergy arises because family farming provides the productive foundation through which women's decision-making can be translated into greater food availability and accessibility.

According to the FAO report (2014), family farming constitutes the backbone of local food systems in developing countries. Where family farming is well established, food prices tend to be more stable and the nutritional quality of available foods is generally higher, thereby creating an environment in which other determinants of child nutrition can operate more effectively. The report further argues that gender-sensitive agricultural policies exhibit diminishing marginal returns when local food systems are weak, but increasing marginal returns when supported by a well-developed family farming sector.

Food security depends not only on the availability of food but also on households' economic access to it. Low-income families devote a large share of their income to food expenditures, making them particularly vulnerable to price fluctuations (IBGE, 2019). Consequently, an environment characterized by greater local food supply and lower prices—potentially generated by family farming—can substantially improve food accessibility, especially for poorer households. This mechanism represents one of the most direct theoretical links between the presence of family farming and reductions in child undernutrition at the municipal level.

In an analysis of the factors associated with food insecurity in Brazil, Jesus and Hoffmann (2024) argue that the country's food access problem is not one of insufficient supply but rather of inadequate household purchasing power. Estimating the effects of per capita household income and other socioeconomic factors, the authors conclude that income is a fundamental determinant of food insecurity in Brazil. In this context, the diversified production and local marketing of food by family farmers may improve food access by reducing or stabilizing food prices (Miranda; Wegner; Dias, 2024).

From a spatial perspective, both rural female leadership and family farming are unevenly distributed across Brazil rather than randomly dispersed. They are more heavily concentrated in regions characterized by lower levels of economic dynamism and greater social vulnerability (Figure 2). Consequently, studies assessing the effects of female leadership on child undernutrition must account for these spatial patterns, as the potential benefits of female leadership may be obscured by the broader context of deprivation and poverty in which it occurs. Econometric models that fail to consider this spatial context are unable to

isolate treatment effects adequately and are therefore more likely to produce biased estimates.

Based on the theoretical and empirical literature reviewed above, it is possible to develop a conceptual framework explaining the relationship between female leadership, family farming, and child undernutrition. Figure 1 summarizes the main relationships identified in the literature. The framework is organized around three key dimensions: (a) female leadership is more strongly oriented toward promoting food security and caregiving; (b) family farming contributes to production diversification and the local supply of food; and (c) increased local food availability and lower food prices improve food accessibility. Together, these mechanisms are expected to contribute to lower rates of child undernutrition across municipalities.

Figure 1 |. Relationships between Female Leadership, Family Farming, and Child Undernutrition

Rural female leadership Family farming	Local food market	Municipality
Greater local food production Greater diversity of food products Lower food prices Greater attention to food security	Urban farmers' markets Direct door-to-door sales Restaurants Retail trade	Greater family access to food products Lower rates of child undernutrition

Source: authors' own elaboration.

METHODOLOGY

The econometric models were specified to capture municipal characteristics and the contexts in which the variables of interest are embedded, as highlighted in the literature review. To represent the response variables, four indicators of the nutritional status of children under five years of age were selected. The treatment variable was defined based on municipalities belonging to spatial clusters of female leadership in rural establishments. In addition to these, other control variables were used to represent the socioeconomic characteristics of the municipalities (lpib, lpop, pvabind, turural, metro, pPBF) and of the agricultural establishments (area, ocup, temp, leite, atec, fam, educ), along with five dummy variables to capture regional effects. All variables are defined in Table 1.

Table 1 | Variables used in the study

Code	Description	Source
subnpi	Percentage (%) of children up to 5 years of age in the municipality classified as having very low or low weight-for-age (2019)	Response variable (SISVAN)
subnpa	Percentage (%) of children up to 5 years of age in the municipality classified as having severe thinness or thinness (weight-for-height) (2019)	Response variable (SISVAN)
subnai	Percentage (%) of children up to 5 years of age in the municipality classified as having very low or low height-for-age (2019)	Response variable (SISVAN)
subnii	Percentage (%) of children up to 5 years of age in the municipality classified as having severe thinness or thinness (BMI-for-age) (2019)	Response variable (SISVAN)
trat	Municipality belonging to a cluster (LISA HH) of female leadership in agricultural activity (yes=1, no=0) (2017)	Treatment
area	Average area (ha) of agricultural establishments located in the municipality (2017)	IBGE
ocup	Average number of employed persons per agricultural establishment in the municipality (persons) (2017)	IBGE
temp	Percentage (%) of agricultural establishments in the municipality with economic activity in temporary crop production (2017)	IBGE
leite	Percentage (%) of agricultural establishments in the municipality whose main purpose of cattle raising is milk production (2017)	IBGE
atec	Percentage (%) of agricultural establishments in the municipality receiving technical assistance (2017)	IBGE
fam	Percentage (%) of agricultural establishments in the municipality classified as family farming (Decree No. 9,064) (2017)	IBGE
educ	Percentage (%) of producers in the municipality with at most elementary education (2017)	IBGE
turural	Presence of rural tourism in the municipality (Yes=1, No=0) (2017)	IBGE
lpop	Natural logarithm of the municipality's total population (2018)	IBGE
lpib	Natural logarithm of the municipality's Gross Domestic Product (GDP) (2018)	IBGE
pvabind	Percentage (%) of Industrial Gross Value Added in the total (2018)	IBGE
metro	Binary variable indicating whether the municipality belongs to a Metropolitan Region (Yes=1; No=0) (2018)	IBGE
pPBF	Percentage of people receiving benefits from the Bolsa Família Program in the municipality (%) (2018)	MDS
Central-West	Central-West Region	IBGE
Northeast	Northeast Region	IBGE
Norte	North Region	IBGE
Southeast	Southeast Region	IBGE
South	South Region	IBGE

Source: authors' own elaboration.

Notes: MDS = Ministry of Social Development and Fight Against Hunger; the undernutrition information used is from SISVAN/Ministry of Health, available only from 2019 onward.

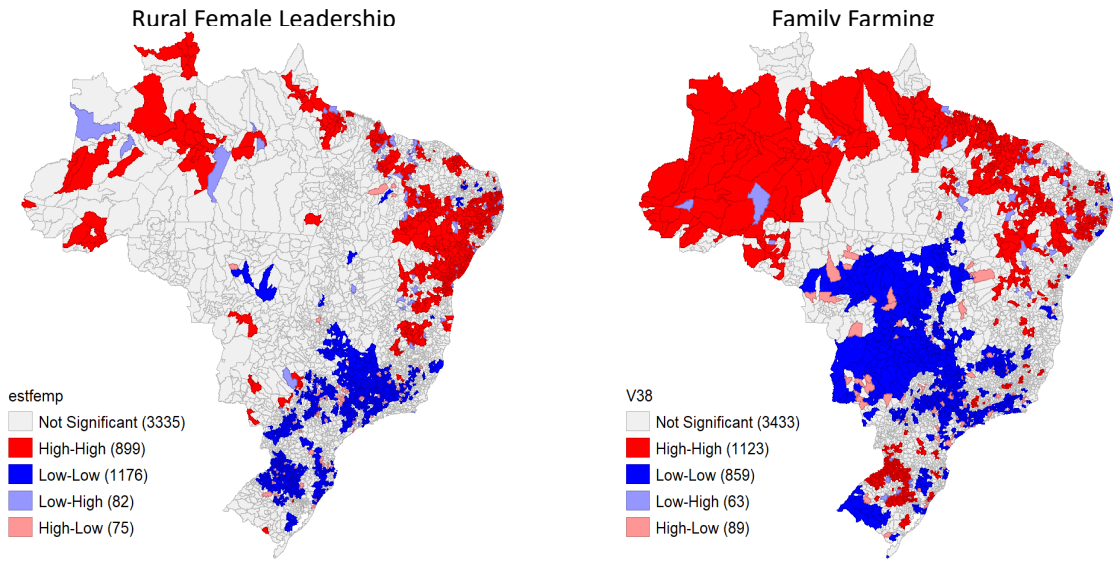
To measure the effect of treatment (treat) on child undernutrition indicators, the Propensity Score Matching (PSM) method was employed. This approach allows municipalities belonging to these clusters (treatment group) to be compared with similar municipalities that do not belong to them (control group) (Rosenbaum; Rubin, 1983; Imbens, 2004; Austin, 2011; Austin, 2017).

The choice of PSM is justified by the nature of the available data. The most recent information on women leading agricultural establishments at the municipal level comes from the 2017 Agricultural Census conducted by IBGE (IBGE, 2017). Although comparable data are available from previous censuses, the long interval between them (11 years) prevents the use of longitudinal analysis methods. Such an extended period may introduce numerous intervening variables and structural changes in local economies that cannot be adequately captured, compromising the identification of the specific causal effect.

PSM allows for the construction of a robust counterfactual by matching municipalities based on observable characteristics. Its implementation involved the following steps: formation of the treatment group; estimation of the propensity score; matching procedure; balance test; and estimation of the average treatment effect on the treated (ATT).

The first step was to define the treatment group. For this purpose, using the LISA (Local Indicators of Spatial Association) method, spatial clusters (high-high) of female leadership in agricultural management were identified. To apply this method, a first-order contiguity spatial weights matrix (Queen) was used (Anselin, 1988; Almeida, 2012; Arbia, 2014). Figure 2 shows the distribution of these clusters across Brazilian municipalities. The 899 municipalities marked in red (high-high) on the female leadership map constitute the treatment group.

Figure 2 | Spatial clusters of rural female leadership and family farming in Brazil, 2017



Source: authors' own elaboration.

The results of the spatial clusters of female leadership and family farming show a strong concentration in municipalities located in the Northeast and North Regions of Brazil. These regions generally present worse indicators of child undernutrition. This reality justifies the inclusion of the controls GDP per capita (lpib), industrial sector participation (pvabind), Bolsa Família Program coverage (pPBF), and the interaction term between family farming and female leadership (fam*trat) (Equations 1 and 2).

The propensity score modeling involves the selection of covariates for matching and, through a logit model, the estimation of the probability of each municipality receiving treatment, that is, belonging to a spatial cluster of female leadership in rural areas (Caliendo; Kopeinig, 2008). The propensity score is defined as the conditional probability of receiving treatment, given the observed characteristics (Wooldridge, 2002):

$$\text{logit}[Pr(trat_i = 1)] = \beta_o + \beta_1 X_1 + \beta_2 X_2 + ... + \beta_n X_n + \varepsilon \quad (1)$$

where: $trat_i$ is a dummy variable indicating treatment (trat); X_1, X_2, ..., X_n = covariates of observable characteristics (Table 1); and β_1, β_2, ..., β_n = parameters to be estimated.

The matching strategy aims to identify a control group that is similar to the treated group. In this process, all 5,570 Brazilian municipalities were considered, and the nearest neighbor algorithm (*nearest neighbor*) was applied using a 1:1 ratio, without replacement, to identify a control municipality with the closest possible propensity score to that of the treated municipality. After matching, the sample consisted of 1,798 observations (899 treated municipalities + 899 control municipalities).

To assess the quality of the balance between the groups, several tests can be applied. In this study, the standardized difference of covariates was used (Becker; Ichino, 2002). The matching results are presented in Table 2. By observing the columns of standardized differences, it can be concluded that the matching procedure was successful. Before matching, 15 of the 18 covariates were unbalanced, indicating the need to correct for selection bias. After matching, only five covariates remained unbalanced, considering the criterion of a standardized difference lower than or equal to 0.1. Therefore, it can be stated that the groups became statistically equivalent regarding the observed characteristics.

Table 2 | Variable values and statistical differences with and without matching

Variables	Without matching			With matching		
	Mean of the treated group	Mean of the control group	Standardized Difference	Mean of the treated group	Mean of the control group	Standardized Difference
area	30.949	107.966	-1.601	30.949	37.859	-0.144
ocup	3.337	4.104	-0.335	3.337	3.515	-0.078
tmp	36.778	27.969	0.451	36.778	38.075	-0.066
leite	9.630	23.495	-1.406	9.630	10.750	-0.114
atec	9.625	31.463	-2.282	9.625	10.345	-0.075
fam	79.187	71.183	0.776	79.187	78.906	0.027
educ	56.964	53.019	0.393	56.964	57.262	-0.030
turural	0.234	0.295	-0.144	0.234	0.182	0.121
lpop	9.832	9.400	0.429	9.832	9.693	0.138
lpib	12.165	12.393	-0.181	12.165	12.015	0.119
pvabind	9.866	13.957	-0.331	9.866	9.417	0.036
metro	0.025	0.031	-0.040	0.025	0.021	0.022
pPBF	50.044	26.506	1.818	50.044	50.329	-0.022
Central-West	0.010	0.098	-0.884	0.010	0.007	0.034
Northeast	0.850	0.221	1.762	0.850	0.833	0.047
Norte	0.082	0.081	0.007	0.082	0.095	-0.045
Southeast	0.055	0.347	-1.287	0.055	0.059	-0.020
South	0.003	0.254	-4.352	0.003	0.007	-0.058

Source: authors' own elaboration.

Note: Variables are considered balanced when the standardized difference between the groups is less than or equal to one.

The estimation of the average treatment effect on the treated (ATT) was performed using a weighted ordinary least squares (WLS) model. The weights result from the matching process and indicate the contribution of each observation to the estimations. Equation (2) presents the general specification of the estimated models.

$$Y = \alpha + \delta trat + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n + \varepsilon \quad (2)$$

where: *Y* = response variables (subnpi, subnpa, subnai, subnii); $X_1, X_2, \ldots, X_n$ = covariates (area, ocup, temp, leite, atec, fam, educ, turural, lpop, lpib, pvabind, metro, pPBF, regional dummies); $\alpha, \delta, \beta_1, \ldots, \beta_n$ = estimated parameters; ε = residuals. The variables used in the matching procedure were maintained in the impact estimation equations to capture any residual heterogeneity among observations after matching (Bang; Robins, 2005; Austin, 2017; Nguyen et al., 2017). However, only the coefficients associated with the treatment should be used in the impact analysis. All variables are defined in Table 1.

To capture the possible moderating effect of family farming on the effect of female leadership on child undernutrition indicators, an interaction term was included in the model (famtrat). The statistical interaction indicates whether the effect of an independent variable (trat) on the dependent variable (subnpi, subnpa, subnai, subnii) depends on the level of another independent variable (fam). By specifying a model with an interaction term to test whether one variable alters the effect of another, a moderation model is being estimated.

RESULTS AND DISCUSSION

The results are presented in Table 3. The models present adjusted R^2 values ranging from 0.069 to 0.254, which are acceptable for cross-sectional studies with endogenous variables that tend to be influenced by multiple factors. The greater explanatory power for subnai (height-for-age deficit) is expected, as this indicator reflects chronic undernutrition, which is associated with poverty conditions. The maximum VIF value of 4.485 indicates the absence of multicollinearity, and the use of robust standard errors provides greater reliability to the results.

When observing the coefficients associated with treatment (trat), it can be seen that, in three of the four estimated models, the coefficient of the variable is positive and statistically significant (subnpi, subnpa, subnii). This result indicates that, in the absence of family farming (fam = 0), municipalities with a high concentration of female leadership present, on average, higher percentages of undernourished children

than municipalities in the control group. The coefficient of the family farming variable (fam) is positive and statistically significant in all models. This result suggests that, in the absence of female leadership (trat = 0), greater participation of family farming is associated with higher rates of child undernutrition. These findings contradict the hypothesis that female leadership and family farming improve child food security.

Table 3 | Results of the estimation models (robust standard errors)

Variables	subnpi		subnpa		subnai		subnii	
	coef	sig	coef	sig	coef	sig	coef	sig
(Intercept)	-0.656		3.320	**	1.599		5.924	***
	(1.228)		(1.474)		(2.781)		(1.704)	
trat	1.708	*	2.037	*	0.778		2.459	**
	(**1.005**)		(**1.060**)		(**2.033**)		(**1.172**)	
fam*trat	-0.025	**	-0.025	*	-0.025		-0.029	**
	(**0.013**)		(**0.013**)		(**0.026**)		(**0.015**)	
area	0.004	***	0.005	**	0.003		0.006	**
	(0.001)		(0.002)		(0.002)		(0.003)	
ocup	0.081		0.010		0.188		0.003	
	(0.067)		(0.036)		(0.161)		(0.036)	
temp	0.004		0.000		0.020	**	-0.002	
	(0.003)		(0.004)		(0.008)		(0.004)	
leite	-0.017	***	-0.024	***	-0.037	***	-0.027	***
	(0.006)		(0.007)		(0.013)		(0.008)	
atec	-0.017	***	-0.029	***	-0.024	*	-0.040	***
	(0.006)		(0.006)		(0.013)		(0.007)	
fam	0.026	***	0.025	***	0.029	*	0.027	**
	(0.009)		(0.009)		(0.017)		(0.011)	
educ	-0.012	**	-0.016	**	-0.051	***	-0.024	***
	(0.006)		(0.006)		(0.014)		(0.007)	
turural	-0.226		-0.211		-0.668	**	-0.343	*
	(0.138)		(0.161)		(0.325)		(0.181)	
lpop	1.548	***	1.506	***	2.470	***	1.717	***
	(0.249)		(0.274)		(0.503)		(0.315)	
lpib	-1.053	***	-1.129	***	-1.193	***	-1.314	***
	(0.228)		(0.247)		(0.451)		(0.282)	
pvabind	0.019	***	0.029	***	0.017		0.038	***
	(0.007)		(0.008)		(0.016)		(0.009)	
pPBF	0.025	***	0.014	**	0.102	***	0.015	**
	(0.006)		(0.007)		(0.014)		(0.007)	
metro	1.453		1.186		0.850		1.437	
	(1.127)		(0.982)		(1.001)		(1.032)	
Northeast	-0.552		-0.407		-2.736	**	-0.155	
	(0.516)		(0.721)		(1.104)		(0.859)	
North	0.818		-1.466	*	3.237	***	-1.354	
	(0.592)		(0.761)		(1.148)		(0.888)	
Southeast	0.030		-0.356		-3.242	***	-0.205	
	(0.443)		(0.674)		(1.021)		(0.804)	
South	0.375		-0.634		-0.949		-0.893	
	(0.527)		(0.707)		(1.490)		(0.863)	
Observations	1798		1798		1798		1798	
Adjusted R^2	0.131		0.069		0.254		0.081	
AIC	8557.96		9021.95		11252.05		9442.78	

Source: authors' own elaboration.

Notes: coef = estimated coefficients; standard errors in parentheses; sig = statistical significance (*10%, **5%, and ***1%); maximum VIF = 4.485 (lpib).

However, these results must be interpreted considering the territorial distribution of female leadership and family farming in Brazil. As documented in the literature (Schneider, 2009; IBGE, 2017) and illustrated in Figure 2, these variables are concentrated in the Northeast and North Regions, where structural determinants of undernutrition, such as poverty, are more prevalent. The positive coefficients of trat and fam likely reflect these circumstances of greater socioeconomic vulnerability (Jesus; Hoffmann; Miranda, 2024).

The interaction coefficient (fam*trat) is negative in all models and statistically significant for subpi, subpa, and subnii. The negative sign of the interaction indicates that the marginal effect of female leadership on child nutrition improves as the participation of family farming in the municipality increases. To quantify this improvement, the conditional marginal effect of female leadership is calculated as:

$$\partial undernutrition / \partial trat = \beta trat + \beta interaction \times fam \quad (3)$$

where: ∂undernutrition / ∂trat = marginal treatment effect on undernutrition indicators (subpi, subnai, subpa, subnii); βtrat = coefficient associated with treatment without interaction; βinteraction = estimated coefficient of the interaction fam*trat; and fam = proportion of family farmers in the municipalities. By substituting the coefficients from the models with significant interactions, the inflection points are obtained, as shown in Table 4.

Table 4 | Inflection points of the interaction between treatment and family farming

Undernutrition indicator	βtrat	βinteraction	Inflection point (fam)
subpi	1.708	-0.025	68.32%
subpa	2.037	-0.025	81.48%
subnii	2.459	-0.029	84.79%

Source: authors' own elaboration.

The inflection point represents the value of fam from which the effect of female leadership becomes negative (that is, begins to reduce undernutrition). Considering the sample distribution of fam (mean = 72.48%; median = 74.84%; 1st quartile = 64.03%), it can be observed that: a) for subpi, the inflection point (68.32%) is below the median and the third quartile, indicating that, in more than half of the municipalities in the sample, female leadership already produces a reducing effect on this indicator; and b) for subpa and subnii, the inflection points are higher (81.48% and 84.79%, respectively), being above the median but still within the observed range (maximum = 100%). This means that, for these indicators, the beneficial effect of female leadership is manifested only in municipalities with a very high participation of family farming (above the 3rd quartile).

Female leadership in agricultural establishments, by itself, is not a sufficient condition to improve child food security. For this to occur, it must be accompanied by a productive structure oriented toward local markets and diversified food production. Family farming, by promoting short food supply chains and greater product diversity, creates the conditions for differentiated management practices by women to translate into an effective improvement in food access. Without this productive foundation, the potential effects of female leadership do not materialize, becoming overshadowed by the context of structural poverty in which these leaders are generally situated.

This result is consistent with the care economy theory (Folbre, 2006) and the territorialized food systems approach (FAO, 2014). Women in leadership positions tend to prioritize food security and child well-being, but this priority only translates into concrete outcomes when the territory has a productive and commercial infrastructure capable of enabling access to healthy and affordable food. The evidence that rural female leadership, in isolation, is associated with worse nutritional indicators, but that this relationship changes in contexts with a strong presence of family farming, supports the thesis of a synergistic effect between the two variables (Verhart et al., 2016; Loli; Lima; Silochi, 2020; Quisumbing; Meinzen-Dick; Malapit, 2022).

CONCLUSIONS

This study aimed to assess whether a greater presence of women in the management of agricultural establishments is associated with lower rates of child undernutrition in Brazilian municipalities. To achieve this objective, the PSM method was employed, in which the treated group was composed of municipalities belonging to LISA high-high spatial clusters with a high presence of female leadership in agricultural activities.

The first finding of the study is that there is no evidence that female leadership, by itself, reduces child undernutrition. On the contrary, the coefficients of the treatment variable (trat) are positive and statistically significant for three of the four undernutrition indicators (subpi, subpa, and subnii). This result may be associated with the context of deprivation in which the treated municipalities are located, where poverty acts as a strong determinant of undernutrition (Jesus; Hoffmann, 2024).

The second finding is that family farming (fam) significantly moderates the effect of female leadership. The interaction coefficient fam*trat is negative and statistically significant for subpi, subpa, and subnii. This result indicates that, in municipalities with a high presence of family farming, female leadership reduces child undernutrition. The calculation of the inflection points reveals that the weight-for-age indicator becomes negative when family farming exceeds 68% of agricultural establishments, a level below the sample median. For the other indicators, the reduction in undernutrition occurs when the participation of family farming reaches levels above 81%.

In summary, female leadership in agricultural management is associated with a reduction in child undernutrition only when combined with contexts of high participation of family farming. This pattern supports the thesis of a synergistic effect: family farming provides a diversified productive platform oriented toward local markets, enabling the materialization of women's care practices regarding food security.

It is important to highlight two limitations of the study. First, the nature of the research does not allow definitive causal relationships to be established. Although propensity score matching reduces selection bias, it does not completely eliminate it, and the possibility of bias due to unobserved omitted variables remains. Second, the treatment variable (trat) was constructed based on municipal spatial clusters, which implies a possible aggregation of intraregional heterogeneities.

The results provide insights for the design of policies aimed at improving food security in Brazilian municipalities. First, it is suggested that policies promoting gender equity in agriculture should be integrated with other programs, such as the National Program for Strengthening Family Farming (PRONAF), the National School Feeding Program (PNAE), and the Food Acquisition Program (PAA). These programs can be designed to expand the participation of women farmers, either as suppliers or as protagonists in defining the products to be purchased. Second, in the territorial targeting of policies, it is suggested that not only socioeconomic vulnerability should be considered, but also the synergistic potential between female leadership and family farming. Municipalities that already present both characteristics could be prioritized in food security programs, given that they tend to generate greater social returns on investments.

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