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# Early-life undernutrition and adult obesity among Indigenous women in Brazil: a population-based study grounded in the DOHaD framework

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## Abstract

# Background

Early-life undernutrition may have lasting effects on growth and metabolism and may contribute to the development of obesity later in life. According to the Developmental Origins of Health and Disease (DOHaD) theory, nutritional and other environmental exposures during critical periods of development can shape long-term health and disease susceptibility. However, evidence on the relationship between early-life undernutrition and adult obesity among Indigenous populations remains limited. This study therefore investigated the association between early-life undernutrition and obesity among Indigenous women in Alagoas, Brazil, within the DOHaD framework.

# Methods

Analytical, population-based cross-sectional study with a probabilistic sample (n = 813). The association between early-life undernutrition (exposure) and adult obesity (outcome) was examined using logistic regression, in an analytical approach analogous to a case–control design, with participants stratified according to current nutritional status (BMI < 30 or ≥ 30 kg/m²). Exposure was defined by an elevated Head Circumference-to-Height Index (HHI > 1.028), used as a marker of undernutrition during critical periods of growth, ensuring biological plausibility and temporal precedence of the investigated relationship.

# Results

After adjustment, early-life undernutrition was associated with higher odds of adult obesity (OR = 2.46; 95% CI: 1.75–3.45). Additionally, participation in the labor market (OR = 1.42; 95% CI: 1.03–1.96) and living with a partner (OR = 2.12; 95% CI: 1.47–3.45) were independently associated with obesity.

# Conclusion

The findings support the DOHaD theory, indicating that early-life undernutrition constitutes a risk factor for obesity—and consequently for its comorbidities—among Indigenous women. These results reinforce the importance of public policies and early interventions aimed at promoting food and nutritional security from childhood, focusing on preventing undernutrition and mitigating its long-term effects across the life course.

# Clinical trial number:

not applicable.

# BACKGROUND

Noncommunicable diseases (NCDs) constitute one of the major contemporary challenges for public health, both due to their substantial burden of morbidity and mortality and the complexity of their determinants. In Brazil, these conditions accounted for 54.7% of all deaths recorded in 2019, totaling more than 730,000 deaths, of which 41.8% occurred prematurely, between 30 and 69 years of age. Beyond their epidemiological magnitude, NCDs exhibit marked social inequalities in their distribution. Data from Vigitel Brazil 2023 show that the prevalence of arterial hypertension reaches 45.3% among adults with up to eight years of schooling, whereas among those with 12 or more years of schooling this percentage is 19.0%. This educational gradient demonstrates that the risk of developing NCDs is conditioned by the social and economic circumstances in which people live, grow, and age [1].

Recent scientific evidence corroborates the existence of social inequalities in the occurrence of NCDs in Brazil. Hypertension, diabetes, cardiovascular diseases, and multimorbidity are more frequent among individuals with lower educational attainment and income, and among socially vulnerable groups, reflecting the persistent influence of social determinants of health [2]. Analyses of NCD mortality also indicate a higher burden of these conditions in municipalities with lower Human Development Index values, while studies on multimorbidity show a greater accumulation of chronic conditions among individuals with lower schooling [3, 4]. Taken together, these findings indicate that inequalities in the occurrence of NCDs mirror inequalities in living conditions and access to material, environmental, and healthcare resources.

This perspective is particularly relevant for Indigenous peoples, who have historical trajectories and living conditions distinct from the non-Indigenous population and remain exposed to significant social, territorial, and healthcare access inequalities. Among these groups, the nutritional transition occurs heterogeneously and overlaps with the persistence of nutritional problems related to poverty and food insecurity. Brazilian literature simultaneously documents the persistence of undernutrition and food insecurity and the growing prevalence of overweight, obesity, and other cardiometabolic risk factors, characterizing a scenario of double burden of malnutrition [5, 6]. Among Indigenous women in Brazil, the prevalence of overweight and obesity had already reached 46.2% and 15.8%, respectively, in the first national survey, with important differences according to region and socioeconomic conditions [6]. This scenario indicates that the Indigenous nutritional transition should not be understood solely as the result of individual choices, but rather within the context of territorial, economic, dietary, and sociocultural transformations.

These aspects are especially relevant in Alagoas, a state historically marked by socioeconomic inequalities and high food insecurity. The Brazilian Northeast has a long history of food insecurity and poverty [7], and in Alagoas, approximately 36.7% of the population was experiencing food insecurity according to the Food Insecurity Survey in the Context of the Covid-19 Pandemic [8]. Among Indigenous peoples in Alagoas, food insecurity reaches even higher levels, particularly in households headed by women [9]. During pregnancy, food insecurity acquires additional importance, given the increased

nutritional demands of this period and the role of maternal nutrition in fetal growth and development [10]. Prolonged exposure to adverse food and nutritional conditions may therefore affect not only immediate health but also subsequent health trajectories.

This possibility is supported by the paradigm of the Developmental Origins of Health and Disease (DOHaD), which posits that nutritional and environmental exposures during critical periods of development can produce lasting alterations in the structure and function of organisms, influencing disease risk across the life course. Accumulated evidence associates adverse conditions from gestation and early childhood with increased later risk of obesity, diabetes, cardiovascular diseases, and other NCDs [11]. Thus, the DOHaD framework allows early social and nutritional conditions to be integrated with biological processes that may contribute to the production of health inequalities in adulthood.

Among the conditions observed in adulthood that are associated with early-life undernutrition, obesity stands out as one of the main NCD-related conditions and an important risk factor for cardiovascular diseases, diabetes, and other morbidities [12]. Obesity affects more than 25% of the adult Brazilian population, with higher prevalence among women [13]. Its occurrence results from the complex interaction between biological, environmental, social, and behavioral factors, whose expression is shaped by living conditions throughout the life course [14, 15]. In Indigenous populations, this interaction assumes particular characteristics in the context of rapid changes in dietary patterns, shifts in subsistence practices, and increasing integration into market economies [6].

Understanding the repercussions of undernutrition during the first years of life is, however, limited by the scarcity of historical records on childhood nutritional status, especially in Indigenous populations. In this context, retrospective anthropometric indicators may constitute useful tools for inferring early nutritional exposures. Although short stature has traditionally been used as a marker of past undernutrition, its interpretation in adults is limited because final height also results from genetic factors and other environmental conditions throughout growth [16]. The search for indicators capable of capturing body disproportionality resulting from adaptations to early nutritional deficits led to the proposal of the Head Circumference-to-Height Index (HHI).

The HHI is based on the hypothesis that, during critical periods of growth, the organism exhibits adaptive mechanisms that may relatively preserve brain growth at the expense of somatic growth, such that nutritional restrictions occurring during these periods may compromise linear growth more intensely than head growth. The literature on the brain growth spurt demonstrates that brain growth has particular characteristics during development, with high growth velocity during fetal life and the first postnatal years [17, 18]. Under conditions of nutritional restriction or fetal growth impairment, adaptive mechanisms may favor the relative supply of nutrients and oxygen to the brain, a phenomenon described as brain sparing, resulting in relative preservation of brain growth compared to peripheral tissues. This preservation, however, is not absolute and does not prevent severe or prolonged restrictions from compromising brain development [19, 20]. As a consequence, undernutrition occurring during critical periods of life may produce a disproportionate reduction in linear growth, while head growth is relatively

preserved, establishing a higher ratio between head circumference and height. This disproportionality may persist into adulthood and constitutes the biological basis for using the HHI as a retrospective anthropometric marker of early-life undernutrition.

Based on this biological principle, Ferreira et al. proposed the HHI as an anthropometric marker of early-life undernutrition. In a study conducted with 3,109 women from Alagoas, the elevated index was associated with obesity, abdominal obesity, arterial hypertension, hypercholesterolemia, and hypertriglyceridemia, and showed stronger associations with these outcomes than short stature alone [16]. These findings provide empirical plausibility for the use of the HHI as a retrospective marker of exposure to undernutrition in early childhood, although its interpretation remains based on anthropometric inference rather than direct measurement of childhood nutritional exposure.

Applying this indicator in Indigenous populations may therefore expand the possibility of investigating the relationship between early nutritional conditions and metabolic outcomes in adulthood, even in the absence of childhood anthropometric records. In the case of Indigenous peoples in Alagoas, the coexistence of socioeconomic vulnerability, food insecurity, changes in dietary patterns, and high exposure to conditions potentially adverse to growth makes it particularly relevant to investigate the contribution of early nutritional exposures to women's health in adulthood [9, 21]. The articulation between the HHI and the DOHaD paradigm offers an approach capable of integrating social, nutritional, and biological dimensions of health inequalities, allowing the investigation of whether anthropometric markers compatible with early-life undernutrition are associated with a key outcome of the nutritional transition: obesity.

The aim of this study was to evaluate the association between early-life undernutrition and the occurrence of obesity among Indigenous women in the state of Alagoas, in light of the Developmental Origins of Health and Disease theory.

# METHODS

This was an analytical, population-based cross-sectional study conducted with a probabilistic sample of 813 Indigenous women, developed within the umbrella project entitled *Study of Nutrition, Health, and Food Security among Indigenous Peoples of the State of Alagoas – ENSSAIA*.

The association between early-life undernutrition, indicated by the Head Circumference-to-Height Index (HHI) as a retrospective exposure, and adult obesity as the outcome, was examined using an analytical strategy analogous to a case–control design. Participants were stratified according to their current nutritional status, classified as obese or non-obese, and early-life exposure was defined by the presence of an elevated HHI (> 1.028), considered a retrospective anthropometric marker of undernutrition in early life.

## Study population

In the state of Alagoas, there are 11 Indigenous ethnic groups distributed across 29 communities, located predominantly in the Agreste and Sertão regions.

ENSSAIA consisted of a population-based, cross-sectional household survey that investigated a probabilistic sample of Indigenous peoples in Alagoas. The target population comprised households in the selected communities that had individuals registered in the Indigenous Health Care Subsystem (SasiSUS).

The sample size was planned considering food insecurity as the main outcome of the project, adopting a conservative prevalence of 50%, a sampling error of 2.5%, and a 95% confidence interval. Considering an estimated universe of 4,036 families — calculated from the number of Indigenous individuals registered in SasiSUS in 2022 and the average of three people per household based on the 2022 Census — a minimum sample of 1,113 families was obtained. The adoption of a 50% prevalence aimed to maximize sample size and ensure adequate precision for the various outcomes investigated by ENSSAIA [22].

To ensure representation of the ethnic diversity in the state, one community per ethnic group was included. The four ethnic groups represented by only one community - Aconã, Kariri-Xocó, Katokinn, and Wassú - were included with probability equal to 1; for the remaining groups, when more than one community existed, a simple random selection was performed.

In communities with more than 1,500 inhabitants, sectors corresponding to approximately one-third of the population were randomly selected. When the selected community represented less than one-third of the population of its respective ethnic group, the sample was complemented with areas from other communities of the same group. Thus, although 11 communities were initially selected, 14 localities were ultimately investigated, with Roçado, Baixa do Galo, and Campinhos serving as complementary areas.

Household selection was conducted among those registered in SasiSUS and residing in the areas covered by the study, with support from the Indigenous Health Agent (AIS) responsible for each territory. Household identification was supervised by the AIS, particularly in areas where Indigenous and non-Indigenous households coexisted (the latter were not included).

All families residing in these areas were eligible for the study, provided they were registered in SasiSUS and thus covered by Indigenous Health Agents. This procedure resulted in 1,400 households evaluated. Data collection occurred between September 5, 2022, and December 22, 2023.

Further methodological details, particularly regarding the sampling plan, can be found in another publication [22, 23].

For the present study, eligible participants were Indigenous women aged 19 to 59 years, non-pregnant, without anatomical conditions that could compromise anthropometric assessment, and residing in the selected communities. In each visited household, only one eligible woman was included. When more than one eligible woman was present, a simple random selection was performed. Household

identification was based on records provided by the Indigenous Primary Health Unit (UBSI), and household listing and data collection were conducted with the support of the AIS responsible for each area.

## Data collection

The field team consisted of 14 members, distributed across the following roles: coordinator, field supervisor, anthropometrist, anthropometry assistant, laboratory assistants, and interviewers. Considering the cultural specificities of Indigenous peoples and aiming to facilitate communication and increase adherence, the team included, in each village, the support of an AIS (designated by the local UBSI coordination) and a collaborator from the Indigenous community (indicated by the chief or shaman).

Data collection was preceded by a pilot study, which simulated the research process to test the questionnaires, verify the accuracy of anthropometric measurements, standardize interviewer procedures, and evaluate the quality of the collected material. The pilot was conducted in part of the area belonging to the Wassú ethnic group, selected for convenience. During this stage, all training and standardization activities were finalized and evaluated.

Data collection took place between September 2022 and December 2023 through household interviews using mobile devices (tablets) with electronic forms structured on the Epicollect5® platform (https://five.epicollect.net). Information was periodically transferred to a computer.

In addition to socioeconomic, demographic, and health-related data, anthropometric measurements were collected to assess nutritional status. These data enabled the diagnosis of obesity and the investigation of the relationship between NCDs and early-life undernutrition.

## Variables

# Dependent variable

Obesity was defined as a Body Mass Index (BMI) ≥ 30 kg/m². Body weight was measured using portable digital scales (Seca®, model 813), with a capacity of 200 kg and 100 g subdivisions, calibrated against standard weights. Height was measured using portable stadiometers (Seca®, model 213), with a measurement range of 20 to 205 cm and 1 mm sensitivity. Head circumference was measured using non-extensible fiberglass measuring tapes.

## Independent variable

Early-life undernutrition was defined by an HHI value greater than 1.028. This marker reflects body disproportionality and, consequently, the inference of a history of undernutrition during early life.

HHI was calculated as the ratio between head circumference and height. Head circumference was measured using a non-extensible tape positioned over the most prominent part of the forehead (glabella) and the posterior region of the skull (occipital). The tape was kept level, above the ears and eyebrows, with slight compression to reduce hair volume [16].

# Covariates

# Sociodemographic and economic variables

Individual monthly income (≤ ½ minimum wage, >½ to 1 minimum wage, > 1 to 2 minimum wages, and > 2 minimum wages), adopting the minimum wage value in effect at the beginning of data collection (R$ 1,212.00 in 2022) [24]. Educational level (illiterate to incomplete elementary I; complete elementary I to complete elementary II; complete elementary II to incomplete secondary; complete secondary to incomplete higher education; complete higher education). Marital status (with or without partner). Occupational status (employed or unemployed/no paid work). Food (in)security (food security or mild, moderate, or severe food insecurity), assessed using the Brazilian Food Insecurity Scale adapted for Indigenous peoples [25]. Household beneficiary of government assistance programs (yes/no). Type of housing (brick, wattle-and-daub, wood). Sewage disposal (sewage system, septic tank or rudimentary pit, ditch, river, lake, other). Waste disposal (public collection, burning, vacant lot, buried, other). Source of drinking water (public supply, cistern, well, spring, river/stream, bottled water, water truck, other).

## Reproductive and lifestyle variables

Age at menarche (< 12 years; ≥12 years), number of living children (none, 1–2, ≥ 3). Women who used tobacco and/or alcohol in the past three months were classified as smokers or drinkers, assessed using the Alcohol, Smoking and Substance Involvement Screening Test (ASSIST) [26].

# Data processing and analysis

Data were processed using forms generated in Epicollect5 version 4.0.0, exported to Stata® 18.0 for statistical analysis. The translated data collection form has been provided as supplementary material (Supplementary File 1).

The database was progressively checked for consistency, and discrepancies were verified to eliminate information errors. Implausible or inconsistent data were excluded.

Cases were defined as women with BMI ≥ 30 kg/m², and controls were women without obesity.

Odds ratios (OR) and 95% confidence intervals (95% CI) were estimated using univariate logistic regression to describe crude associations, and multivariable logistic regression to test associations and control for potential confounding factors.

Variables with $p < 0.20$ in bivariate analyses were included in the adjusted model. A significance level of 5% ($p < 0.05$) was adopted for multivariable analyses. Variable selection followed the backward stepwise method, beginning with the simultaneous inclusion of all eligible variables and sequentially removing those that did not remain statistically significant. The final model included only variables with $p < 0.05$.

# Ethical considerations

The study was approved by the Brazilian National Research Ethics Commission (CONEP) (CAAE: 29121120.0.0000.5013). All legal and ethical guidelines for conducting research involving Indigenous peoples were followed [27–29]. All participants received detailed information about the study objectives, potential risks and benefits, and all provisions of the informed consent form, ensuring conscious and voluntary participation. All participants signed the informed consent form.

# RESULTS

Of the 856 women identified, 43 were excluded due to missing anthropometric data, resulting in 813 participants. Among them, 281 (34.6%) were obese and comprised the case group, while the remaining 532 (65.4%) formed the control group.

Regarding socioeconomic characteristics, 645 women (79.5%) reported monthly income up to one minimum wage. Most (62.4%) did not engage in paid work. A majority (71.9%) of households were beneficiaries of government assistance programs, and 72.3% experienced some degree of food insecurity (mild, moderate, or severe).

Concerning sanitation conditions, 64.0% lived in households with rudimentary pits, ditches, or other forms of inadequate sewage disposal. Conversely, 83.3% lived in areas with good coverage of public waste collection.

Regarding reproductive variables, 53.9% had three or more children, and age at menarche was ≥12 years for 80.4% of participants. In terms of lifestyle, 34.2% reported alcohol consumption and 34.8% were smokers or former smokers.

Table 1 presents the frequencies of the investigated variables and the results of the crude logistic regression.

***Table 1***

A statistically significant association was observed between early-life undernutrition and obesity (OR=1.88; 95% CI: 1.10–3.23; p=0.022), indicating that women with this history had approximately 88% higher odds of obesity compared to those without early undernutrition.

Another condition significantly associated with obesity was having a partner (OR=3.81; 95% CI: 1.33–10.86; p=0.012).

Food insecurity, as well as other variables such as type of housing, waste disposal, sewage disposal, drinking water source, smoking, alcohol consumption, number of children, and participation in government assistance programs, did not show significant associations with obesity.

In bivariate analysis, the variables “occupational status,” “individual income,” and “education” presented p-values <0.20 and were therefore included in the multivariable model. The results were: being employed (OR=1.78; 95% CI: 0.90–3.51; p=0.095), complete secondary or incomplete higher education (OR=0.37; 95% CI: 0.11–1.22; p=0.103), income >½ to 1 minimum wage (OR=3.78; 95% CI: 0.77–18.54; p=0.101), and ≤½ minimum wage (OR=3.02; 95% CI: 0.63–14.59; p=0.169).

Table 2 presents the results of the multivariable analysis, with obesity as the dependent variable. Two models were constructed. Model 1 included socioeconomic and demographic variables with p<0.20 in bivariate analysis, aiming to identify factors associated with the outcome and potential confounders. In Model 2, the exposure variable—early-life undernutrition—was added along with the covariates that remained associated with obesity in Model 1, specifically marital status and occupational status. After adjustment, all variables remained statistically significant (p<0.05), forming the final model.

***Table 2***

Thus, early-life undernutrition remained significantly associated with obesity (OR=2.46; 95% CI: 1.75–3.45; p<0.001), indicating that women with this history had approximately 2.5 times higher odds of obesity compared to those not exposed to early undernutrition, even after adjustment. These findings reinforce the relevance of early-life undernutrition as an important risk factor for the investigated outcome.

Among the covariates, “being employed” and “having a partner” also remained independently associated with increased odds of obesity in the final model.

# DISCUSSION

In this study, grounded in the Developmental Origins of Health and Disease (DOHaD) paradigm, a robust and independent association was observed between early-life undernutrition - inferred through an elevated Head Circumference-to-Height Index (HHI) - and the occurrence of obesity in adulthood. Women with elevated HHI had 2.46 times higher odds of being obese, even after adjustment for socioeconomic and demographic variables in the final model. These findings corroborate and extend previous evidence reported by Xavier Júnior among non-Indigenous women in Alagoas, in whom elevated HHI was also associated with obesity and metabolic syndrome [30]. The convergence of results across different populations within the same state provides epidemiological consistency to the indicator and reinforces its plausibility as a retrospective anthropometric marker of undernutrition during critical periods of growth.

From a pathophysiological perspective, the observed relationship is supported by the thrifty phenotype hypothesis [11]. Under conditions of fetal or early postnatal nutritional restriction, the organism activates homeostatic adaptive mechanisms aimed at preserving the supply of oxygen and nutrients to the brain at the expense of somatic growth (a phenomenon known as brain sparing). Classical literature on the brain growth spurt demonstrates that brain growth exhibits particularly high velocity during fetal life and the early postnatal years, making the central nervous system highly sensitive to nutritional insults during this developmental window [17, 18]. As a consequence, a disproportionate reduction in linear growth (final height) occurs while head circumference is relatively preserved, generating the body disproportionality expressed by elevated HHI in adulthood. Although this biological redistribution is adaptive in the short term to ensure survival under scarcity, it induces permanent metabolic, structural, and epigenetic alterations oriented toward maximal energy efficiency. When individuals thus programmed are later exposed to Westernized or transitional nutritional environments - characterized by greater energy availability and lower caloric expenditure - these alterations become disadvantageous, favoring accelerated fat accumulation and the development of NCDs.

Moreover, recent scientific literature warns that preservation of cranial somatic growth does not equate to preservation of functional or structural neural integrity. Early-life undernutrition compromises critical neurodevelopmental processes - including brain maturation, myelination, and synaptic plasticity - with lasting repercussions for cognition, executive functions, motor skills, and socioemotional development [31]. From this perspective, elevated HHI may reflect not only a chronic anthropometric marker of somatic deprivation but also potential underlying neurobiological alterations in hypothalamic circuits regulating appetite, energy expenditure, and eating behavior, amplifying metabolic risk across the life course.

The findings of this study also align with the phenomenon of the double burden of malnutrition, characterized by the coexistence of undernutrition and overweight within the same population or even within the same individual across the life cycle [32, 33]. The prevalence of obesity observed in the sample (34.6%) is alarming. It substantially exceeds national estimates for Brazilian women reported by the National Health Survey (29.5%) [34], historical data for the state of Alagoas (20.9%) [35], and findings from other Indigenous populations in the Northeast, such as the survey conducted by Fávaro et al. in Pernambuco (21.0%) [36]. The fact that nearly half (49.7%) of the obese women investigated presented elevated HHI indicates that current excess weight is frequently rooted in nutritional insults experienced during early life [37]. This same pattern of epidemiological overlap has been reported in traditional communities in the Brazilian Amazon [38] and in Indigenous populations internationally, such as in Malaysia [39]. This complex epidemiological reality must be interpreted in light of the structural socioeconomic vulnerability that characterizes Indigenous territories in Alagoas. The vast majority of participants reported individual income up to one minimum wage (79.5%) and absence of paid work (62.4%), in addition to living under precarious sanitation conditions (64.0% with inadequate sewage disposal) and persistent food insecurity (72.3%), consistent with previous findings in the state [9].

Although contemporary food insecurity did not remain statistically associated with obesity in the adjusted model, its high prevalence consolidates it as a critical structural determinant. This vulnerability imposes severe budgetary constraints and drives a rapid and unfavorable dietary transition. The loss of traditional agricultural practices and subsistence modes, combined with the increasing economic accessibility and penetration of ultra-processed products—dense in calories and rich in saturated fats and free sugars—progressively replaces traditional *in natura* foods [40–42]. This process of dietary Westernization operates synergistically with early metabolic programming, exacerbating the observed rates of obesity and NCDs [43–45].

Additionally, the multivariable model identified that labor market participation and marital status were independently associated with the outcome. Women engaged in paid work had significantly higher odds of obesity (OR = 1.42), which may reflect the impacts of urbanization and occupational transition on physical activity levels. The shift toward modern formal or informal jobs often imposes more sedentary routines and prolonged periods of inactivity, reducing daily energy expenditure [46]. Living with a partner was associated with 2.12 times higher odds of obesity in the adjusted model.

A similar pattern has been documented in cross-sectional studies in Ceará [47] and by Onita et al. [48]. As highlighted in the systematic review by Werneck et al. [49], changes in time-use dynamics and the assumption of family responsibilities associated with marriage often correlate with reduced physical activity among women. In Indigenous contexts, however, such sociodemographic variables should be understood as broad markers of profound transformations in collective ways of life, rather than merely isolated behavioral risk factors.

In assessing the limitations and strengths of this investigation, several methodological considerations must be acknowledged. The cross-sectional design precludes the formal establishment of direct causality. Nevertheless, the use of a retrospective biological marker ensures temporal precedence and plausibility of the investigated association, mitigating typical limitations related to reverse causality. Additionally, HHI is an indirect anthropometric inference rather than a direct measure of childhood undernutrition, and although previously validated in the state context [30], it was not originally calibrated for Indigenous populations. The absence of historical records on childhood nutritional status among these women prevented direct validation of the indicator in this specific population. Furthermore, early-life undernutrition occurs within a context of multiple chronic socioenvironmental adversities (such as low parental education and extreme poverty), which may act as confounders or effect modifiers. Since variables related to current physical activity levels and dietary intake were not included in the final model, interpretation of the results requires caution and should be guided by a multicausal framework that considers the interdependence between early biological programming and modern contextual determinants [31].

On the other hand, the study presents significant methodological strengths. It is a robust population-based survey structured through probabilistic sampling with high representativeness of the diverse Indigenous ethnic groups and territories in Alagoas. The use of HHI represents an innovative and low-

cost analytical strategy to overcome the chronic scarcity of historical health data in ethnic minorities. Finally, by integrating social, nutritional, and biological dimensions through the DOHaD framework, the study fills a critical gap in the national literature on Indigenous health, offering crucial empirical evidence for understanding the link between early social inequities and the contemporary burden of metabolic diseases in adulthood.

# CONCLUSION

The results of this study demonstrate that early-life undernutrition, inferred through elevated HHI, is independently associated with higher odds of adult obesity among Indigenous women in Alagoas. This association, consistent even after adjustment for socioeconomic and demographic covariates, reinforces the biological plausibility proposed by the Developmental Origins of Health and Disease (DOHaD) paradigm. The model shows that adverse nutritional exposures during critical periods of early development can produce lasting effects on organism structure and function, negatively influencing cardiometabolic risk across the life course.

The high prevalence of food insecurity, low income, dependence on assistance programs, and precarious sanitation conditions observed in the sample reveal a context of structural vulnerability. This vulnerability intensifies both early nutritional exposures and current metabolic risks. In this sense, the findings suggest that adult obesity reflects health trajectories marked by persistent social and sanitary inequalities, in which childhood undernutrition and contemporary nutritional transition overlap, shaping the double burden of malnutrition in these territories.

These findings have important implications for public policy, particularly within Indigenous primary healthcare. They highlight the urgent need for integrated structural and intersectoral interventions capable of addressing the social, territorial, and cultural determinants that shape health–disease processes. Therefore, promoting food and nutritional security from early childhood should be prioritized as a central strategy to interrupt the intergenerational cycle of undernutrition and obesity, effectively contributing to health promotion and the reduction of inequities among Indigenous women across the life course.

# Abbreviations

CAPES: Coordination for the Improvement of Higher Education Personnel (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior)

DOHaD: Developmental Origins of Health and Disease

NCDs: Noncommunicable Diseases

FI: Food Insecurity

HHI: Head Circumference-to-Height Index

ENSSAIA: Nutrition, Health and Food Security Study of Indigenous Peoples of the State of Alagoas (Estudo de Nutrição, Saúde e Segurança Alimentar dos Povos Indígenas do Estado de Alagoas)

IHA: Indigenous Health Agents

IPHCU: Indigenous Primary Health Care Unit

LNBA: Laboratory of Basic and Applied Nutrition (Laboratório de Nutrição Básica e Aplicada)

BMI: Body Mass Index

ASSIST: Alcohol, Smoking and Substance Involvement Screening Test

OR: Odds Ratio

95% CI: 95% Confidence Interval

CONEP: National Research Ethics Commission (Comissão Nacional de Ética em Pesquisa)

UFAL: Federal University of Alagoas (Universidade Federal de Alagoas)

# Declarations

**Ethics approval and consent to participate**: The study was approved by the Brazilian National Research Ethics Commission (Comissão Nacional de Ética em Pesquisa, CONEP), part of the National Health Council (Conselho Nacional de Saúde, CNS), under the Brazilian Ministry of Health (Ministério da Saúde) (CAAE No. 29121120.0.0000.5013). All study procedures were conducted in accordance with relevant ethical guidelines and regulations, including the principles of the Declaration of Helsinki, as applicable, and applicable Brazilian ethical and legal requirements for research involving Indigenous peoples. Before participation, all participants received detailed information about the study objectives, procedures, potential risks and benefits, and the conditions of participation. Written informed consent was obtained from all participants prior to their inclusion in the study. All study procedures were conducted in accordance with the approved research protocol.

**Consent for publication:** Not applicable. This manuscript does not contain any individual person's data, images, or videos requiring consent for publication.

**Availability of data and materials:** The datasets generated and/or analyzed during the current study are not publicly available due to ethical and confidentiality considerations regarding the Indigenous communities involved in the study. However, the data may be made available by the corresponding author upon reasonable request and subject to appropriate justification and compliance with applicable ethical and data protection requirements.

**Competing interests:** The authors declare that they have no competing interests.

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**Authors' contributions:** ABFS participated in data collection, analysis and interpretation, methodology development, and drafting of the initial version of the manuscript. JFA co-supervised the first author during the Master's program, contributing to academic supervision and critical review of the intellectual content of the manuscript. HSF was responsible for the conception and coordination of the research, funding acquisition, methodological development, supervision of the first author, overall supervision of fieldwork during data collection, and critical revision of the manuscript. All authors approved the final version and assume responsibility for the content of the manuscript.

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# Tables

**Table 1.** Socioeconomic, demographic, behavioral, and reproductive characteristics of Indigenous women according to case status (obese women) or control status (women without obesity). Alagoas, Brazil, 2022–2023.

| Variables | Total n | Cases (n=281) n (%) | Controls (n=532) n (%) | Crude OR[1] | 95% CI[2] | p-value[3] |
|---|---|---|---|---|---|---|
| **Early-life undernutrition[4]** | **813** | | | | | |
| No | 622 | 186 (66.2) | 436 (82.0) | 1 | | |
| Yes | 191 | 95 (33.8) | 96 (18.0) | 1.88 | 1.10–3.23 | 0.022 |
| **Marital status** | **813** | | | | | |
| No partner | 220 | 52 (18.5) | 168 (31.6) | 1 | | |
| Partner | 593 | 229 (81.5) | 364 (68.4) | 3.81 | 1.33–10.86 | 0.012 |
| **Educational attainment** | **464** | | | | | |
| Completed higher education | 34 | 15 (8.9) | 19 (6.4) | 1 | | |
| Completed secondary education to incomplete higher education | 191 | 50 (29.6) | 141 (47.8) | 0.37 | 0.11–1.22 | 0.103 |
| Completed lower secondary to incomplete upper secondary | 68 | 25 (14.8) | 43 (14.6) | 0.78 | 0.22–2.77 | 0.703 |
| Completed primary education to incomplete lower secondary | 83 | 40 (23.7) | 43 (14.6) | 0.85 | 0.24–3.04 | 0.799 |
| Illiterate to incomplete primary education | 88 | 39 (23.1) | 49 (16.6) | 0.62 | 0.17–2.21 | 0.463 |
| **Monthly individual income[5]** | **811** | | | | | |
| >2 minimum wages | 48 | 20 (7.1) | 28 (5.3) | 1 | | |
| >1 to 2 minimum wages | 118 | 43 (15.4) | 75 (14.1) | 2.45 | 0.56–10.80 | 0.235 |
| >1/2 to 1 minimum wage | 222 | 81 (29.0) | 141 (26.6) | 3.78 | 0.77–18.54 | 0.101 |
| ≤1/2 minimum wage | 423 | 136 (48.6) | 287 (54.1) | 3.02 | 0.63–14.59 | 0.169 |
| **Food security/insecurity status[6]** | **809** | | | | | |
| Food security | 224 | 71 (25.3) | 153 (29.0) | 1 | | |
| Mild food insecurity | 366 | 135 (48.0) | 231 (43.8) | 1.25 | 0.72–2.17 | 0.421 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Moderate food insecurity | 148 | 52 (18.5) | 96 (18.2) | 1.06 | 0.49–2.26 | 0.888 |
| Severe food insecurity | 71 | 23 (8.2) | 48 (9.1) | 0.94 | 0.28–3.10 | 0.917 |
| **Family beneficiary of a government program** | **807** | | | | | |
| No | 227 | 72 (25.7) | 155 (29.4) | 1 | | |
| Yes | 580 | 208 (74.3) | 372 (70.6) | 0.92 | 0.54–1.58 | 0.772 |
| **Occupational status** | **813** | | | | | |
| No paid work | 573 | 185 (65.8) | 388 (73.0) | 1 | | |
| Employed | 240 | 96 (34.2) | 144 (27.1) | 1.78 | 0.90–3.51 | 0.095 |
| **Type of dwelling** | **809** | | | | | |
| Masonry | 792 | 278 (99.0) | 514 (97.4) | 1 | | |
| Adobe | 14 | 3 (1.1) | 11 (2.1) | 1.16 | 0.14–9.57 | 0.891 |
| Wood | 3 | 0 (0) | 3 (0.6) | 1 | | |
| **Source of drinking water** | **809** | | | | | |
| Public distribution network | 405 | 144 (51.3) | 261 (49.4) | 1 | | |
| Cistern | 53 | 20 (7.1) | 33 (6.3) | 1.32 | 0.52–3.35 | 0.563 |
| Well, shallow well, river, stream, or spring | 269 | 93 (33.1) | 176 (33.3) | 0.88 | 0.52–1.48 | 0.621 |
| Bottled water | 50 | 16 (5.7) | 34 (6.4) | 1.02 | 0.39–2.65 | 0.972 |
| Water truck | 30 | 6 (2.1) | 24 (4.6) | 0.86 | 0.22–3.42 | 0.831 |
| Other | 2 | 2 (0.7) | 0 (0) | 1 | | |
| **Sewage/wastewater disposal** | **809** | | | | | |
| Sewerage network or septic tank | 291 | 99 (35.2) | 192 (36.4) | 1 | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Rudimentary pit latrine, ditch, river, lake, or other | 518 | 182 (64.8) | 336 (63.6) | 0.90 | 0.56–1.44 | 0.660 |
| **Waste disposal** | **809** | | | | | |
| Public collection | 674 | 240 (85.4) | 434 (82.2) | 1 | | |
| Burning | 133 | 41 (14.6) | 92 (17.4) | 0.96 | 0.51–1.81 | 0.903 |
| Vacant lot | 2 | 0 (0) | 2 (0.4) | 1 | | |
| **Age at menarche (years)** | **809** | | | | | |
| ≥12 | 650 | 212 (75.4) | 438 (83.0) | 1 | | |
| <12 | 159 | 69 (24.6) | 90 (17.1) | 0.95 | 0.53–1.61 | 0.784 |
| **Number of children** | **722** | | | | | |
| 0 | 11 | 5 (1.9) | 6 (1.3) | 1 | | |
| 1–2 | 322 | 95 (36.4) | 227 (49.2) | 0.58 | 0.11–3.07 | 0.519 |
| ≥3 | 389 | 161 (61.7) | 228 (49.5) | 0.85 | 0.16–4.50 | 0.850 |
| **Smoking** | **812** | | | | | |
| No | 529 | 184 (65.7) | 345 (64.9) | 1 | | |
| Yes | 283 | 96 (34.3) | 187 (35.2) | 0.75 | 0.46–1.24 | 0.263 |
| **Alcohol consumption** | **812** | | | | | |
| No | 534 | 191 (68.2) | 343 (64.5) | 1 | | |
| Yes | 278 | 89 (31.8) | 189 (35.5) | 0.79 | 0.49–1.29 | 0.344 |

[1]OR: Odds Ratio; [2]95% CI: 95% confidence interval; [3]p-value: statistical significance ($p<0.05$); variables included in the multivariable analysis model ($p<0.20$); [4]Early-life undernutrition was defined by a high Head Circumference-to-Height Index (>1.028); [5]The minimum wage corresponds to BRL 1,212.00; [6]Defined according to the adapted Brazilian Food Insecurity Scale (reference 25).

**Table 2.** Association between early-life undernutrition and obesity in Indigenous women. Multivariable logistic regression model. Alagoas, Brazil, 2022–2023.

| Variables | Adjusted OR | 95% CI | p-value |
|---|---|---|---|
| **Early-life undernutrition[1]** | | | |
| No | 1.00 | – | – |
| Yes | 2.46 | 1.75–3.45 | <0.001 |
| **Marital status** | | | |
| No partner | 1.00 | – | – |
| Partner | 2.12 | 1.47–3.45 | <0.001 |
| **Occupational status** | | | |
| No paid work | 1.00 | – | – |
| Employed | 1.42 | 1.03–1.96 | 0.031 |

OR: Odds Ratio; 95% CI: 95% confidence interval.

p-value: statistical significance was considered when $p<0.05$.

[1]Early-life undernutrition was defined by a Head Circumference-to-Height Index >1.028.

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