Diagnosis of the Brazil nut value chain in the Amazonas, Brazil: Econometric and market analysis of a traditional agroforestry system

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Abstract

The Brazil nut (*Bertholletia excelsa* H.B.K.) is one of the most valuable non-timber forest products in the Amazon, yet its production chain remains underexplored in terms of structure, efficiency, and territorial dynamics. This study aims to analyze the spatial distribution, productive performance, and socioeconomic drivers of the Brazil nut value chain in the state of Amazonas, Brazil, identifying critical bottlenecks and opportunities for sustainable development. To this end, official data from 2010 to 2023 were used to perform descriptive spatial analysis and log-log econometric modeling. Results show a high concentration of production in the microregions of Purus, Rio Negro/Solimões, and Jutaí/Solimões/Juruá, where traditional extractivism, community governance, and fluvial accessibility favor regular output. In contrast, regions such as Alto Rio Negro and Baixo Amazonas face infrastructural limitations and low organizational capacity. The econometric model indicates that a 10% increase in the number of extractivists raises total production by 15.62%, and a 10% increase in yield results in a 10.06% increase, highlighting the labor-dependence of the chain. Furthermore, average producer price positively affects output, while higher per capita income correlates negatively, suggesting that extractivism tends to be abandoned as other income sources emerge. These findings reveal a structurally vulnerable chain that lacks technological intensification and value aggregation. Public policies focused on infrastructure, cooperativism, technological inclusion, and socio-biodiversity valorization are essential to enhance the competitiveness and resilience of the Brazil nut sector in the Amazon.

1. Introduction

The growing global demand for high-value natural products and agroforestry *commodities* has intensified the debate around the sustainable use of tropical biodiversity and the socioeconomically viable exploitation of forest resources (Zaman, 2022). Brazil, often referred to as the "farm of the world," plays a leading role in this scenario as one of the largest producers and exporters of agricultural goods and non-timber forest products (Silva et al., 2020; Gasparinetti et al., 2022). This position is reinforced by vast cultivable land, favorable climatic conditions, investments in technology, and well-structured value chains that boost productivity and competitiveness (Gasparinetti et al., 2022). Among the various products that contribute to the country's agribusiness gross domestic product (GDP), extractive goods like Brazil nuts (*Bertholletia excelsa*) stand out for their economic, ecological, and cultural relevance in the Amazon rainforest (Thomas et al., 2015).

Brazilian Amazon, which houses approximately 60% of the Amazon rainforest (Zaman, 2022), constitutes a unique ecosystem where the Brazil nut tree occurs naturally, often forming dense groves across vast expanses of "terra firme" forest (Anjos et al., 2024). Although Brazil remains the largest global producer of Brazil nuts, their distribution is geographically limited, with major production concentrated in municipalities such as Tapauá, Tefé, and Boca do Acre, in the state of Amazonas (Pacheco et al., 2021; Marin et al., 2023). These nuts are not only vital for biodiversity conservation but are also deeply intertwined with the cultural and economic practices of traditional forest communities (Pacheco et al., 2021; Rubem et al., 2025).

Despite the recognized nutritional and functional value of Brazil nuts, particularly their richness in selenium, essential fatty acids, and proteins, the value chain faces major bottlenecks (da Silva et al., 2022; Gomes et al., 2024). These include irregular yields due to climatic variability, logistical constraints, low levels of technological adoption in processing, and health-related export restrictions such as aflatoxin contamination (Rêgo et al., 2021; Kluczkovski et al., 2023). Furthermore, while domestic consumption has grown over 700% in the last 15 years, internal prices remain volatile and high, limiting broader market access (Rêgo et al., 2021; dos Santos et al., 2023).

The international market reflects similar contradictions: although Brazil exported approximately 56% of the world's Brazil nut volume between 2014 and 2022, its share of value-added processed products remains low when compared to Bolivia, the main competitor, which invests more heavily in industrialization and export of shelled nuts (Soriano et al., 2021; Gasparinetti et al., 2022). In this context, the Brazilian Brazil nut sector still largely operates under a subsistence-oriented extractivist model, vulnerable to external shocks and marked by limited profitability, especially in remote regions like the state of Amazonas (Ubiali and Alexiades, 2022; Vieira, 2023).

Understanding the economic networks tied to Amazonian biodiversity is essential for designing strategies that improve production efficiency and enhance the market value of local goods (Gasparinetti et al., 2022). However, a persistent lack of accurate data on the Brazil nut value chain in Amazonas hampers sustainable development, undermining public policy formulation and limiting the evaluation of key metrics such as operational yield, competitiveness, market behavior, and critical bottlenecks (Thomas et al., 2015; Vieira, 2023; Rubem et al., 2025). Therefore, the systematic organization of economic data is crucial to optimize value chain performance and expand market access. In this context, this study aimed to assess the structure of the Brazil nut value chain in the state of Amazonas, mapping its geographic distribution across microregions and applying econometric tools to analyze its production dynamics.

2. Material and methods

The Brazil nut production chain in the Amazonas state, Brazil, was initially characterized based on the territorial division into microregions adopted by the Instituto de Desenvolvimento Agropecuário e Florestal Sustentável do Estado do Amazonas (IDAM). The study covers the period from 2010 to 2023, considering cumulative data from January to December for each year. The microregions analyzed were composed of the following municipalities:

- Alto Rio Negro: Barcelos, Santa Isabel do Rio Negro, and São Gabriel da Cachoeira;
- Alto Solimões: Amaturá, Atalaia do Norte, Benjamin Constant, São Paulo de Olivença, Santo Antônio do Içá, Tabatinga, and Tonantins;
- Baixo Amazonas: Barreirinha, Boa Vista do Ramos, Nhamundá, Parintins, São Sebastião do Uatumã, and Urucará;
- Juruá: Carauari, Eirunepé, Envira, Guajará, Ipixuna, and Itamarati;
- Jutaí/Solimões/Juruá: Alvarães, Fonte Boa, Japurá, Juruá, Jutaí, Maraã, Tefé, and Uarini;

- Madeira: Apuí, Borba, Humaitá, Manicoré, Santo Antônio do Matupi, and Novo Aripuanã;
- Médio Amazonas: Itacoatiara, Itapiranga, Maués, Nova Olinda do Norte, Novo Remanso, Presidente Figueiredo, Silves, and Urucurituba;
- Purus: Boca do Acre, Canutama, Lábrea, Vila Extrema, Pauini, and Tapauá;
- Rio Negro/Solimões: Anamã, Anori, Autazes, Beruri, Caapiranga, Careiro, Careiro da Várzea, Coari, Codajás, Iranduba, Manacapuru, Manaquiri, Manaus, Novo Airão, Rio Preto da Eva, and Vila Rica de Caviana.

The data used in this study are secondary and were sourced from IDAM's internal database, which collects information through questionnaires administered to active Brazil nut producers in all municipalities of Amazonas who are registered with its local units. It is worth noting that IDAM is the official body responsible for collecting primary sector data in Amazonas, with local offices and technical personnel deployed throughout the state, an institutional feature that lends considerable reliability to the database it maintains on primary production chains. The data were processed and analyzed by the researchers. Initially, the information was grouped by municipality based on questionnaire samples, considering production volume and the number of active producers. Subsequently, the data were consolidated by microregion according to IDAM's territorial classification described above.

Brazil nut production data refer exclusively to agricultural cultivation activities. In the descriptive stage, annual Brazil nut production in each microregion was expressed as a percentage of the state's total production for each year, alongside the number of active producers. Additionally, productivity was calculated by determining the percentage of harvested area relative to the total planted area.

Based on production data from IDAM and per capita income data (municipal GDP per capita) provided by the Amazonas State Secretariat for Economic Development, Science, Technology and Innovation (SEDECTI-AM), a log-log econometric model (1) was developed using absolute panel data for Brazil nut production by microregion in Amazonas from 2010 to 2023, following the algebraic structure:

$$lnY_{it} = \beta_1 + \beta_2 lnProd_{it} + \beta_3 lnRen_{it} + \beta_4 lnRendProd_{it} + \beta_5 lnPre_{it} + u_{it} \quad (1)$$

Where:

lnY = natural logarithm of Brazil nut production;

lnProd = natural logarithm of the number of active producers in the activity;

lnRen = natural logarithm of the average per capita income of the municipalities;

lnRendProd = natural logarithm of the productive yield of the activity;

lnPre = natural logarithm of the average price paid to the producer.

Note: The subscript *i* represents the *i*-th observation (municipality) and *t* refers to time (years). The coefficients β are the parameters estimated by the econometric regression model.

This model was based on a panel data analysis, which allows a given cross-sectional unit (such as a country, state, or firm) to be observed over time. As such, panel data analysis incorporates both spatial and temporal dimensions (Wooldridge, 2005; Gujarati and Porter, 2011). The econometric model was initially specified in three primary forms using Gretl software (Gnu Regression, Econometrics and Time-series Library, v.2023): the pooled OLS model, the fixed effects model, and the random effects model.

To determine the most appropriate specification and the one that best fit the data behavior, Chow, Breusch-Pagan, and Hausman tests were applied at a 5% significance level, as recommended by Gujarati and Porter (2011). Multicollinearity was assessed using the Variance Inflation Factor (VIF), where values greater than 10 may indicate collinearity problems (Wooldridge, 2005; Gujarati and Porter, 2011), and through the construction of the correlation matrix among the analyzed variables. Heteroskedasticity was tested using the White test at a 5% significance level. It is important to highlight that, due to the log-log specification of the model, the coefficients of the independent variables represent the percentage change in productivity for each 1% increase in the corresponding independent variable (Gujarati and Porter, 2011).

To support the analysis, particularly with regard to the market dynamics of the Brazil nut production chain in Amazonas, additional qualitative and quantitative data were collected from reports and technical staff of the following institutions: the Brazilian Agricultural Research Corporation (EMBRAPA – Western and Eastern Amazon units), the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA), the Brazilian Institute of Geography and Statistics (IBGE), and the Federation of Agriculture and Livestock of the State of Amazonas (FAEA). These secondary data sources were used to provide insight into the structure of the Brazil nut production chain, including production flow, key territories, standard production processes, and target markets (commercial reach).

3. Results

3.1. Production, Producers and Productive yield

The analysis of the territorial distribution of Brazil nut production in the state of Amazonas from 2010 to 2023 reveals a significant concentration in three main microregions: Purus, Rio Negro/Solimões, and Jutaí/Solimões/Juruá. The Purus microregion stood out as the leading producer during most of the analyzed period, with notable peaks in 2014 (44.51%), 2015 (43.98%), and 2023 (41.47%) of the state's total production (Table 1). In parallel, the Rio Negro/Solimões microregion showed a relevant increase in participation starting in 2012, reaching 44.00% in 2017 and maintaining averages above 20% in subsequent years. The Jutaí/Solimões/Juruá microregion, in turn, displayed progressive growth and regained prominence in 2022 (19.02%).

Table 1
Percentage of each microregion in total Brazil nut production in the state of Amazonas, Brazil, from 2010 to 2023.[1]

Microregion[2]	Percentage share of each microregion in the total Brazil nut production of Amazonas by year													
	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
ARN	3.81	3.44	4.30	1.68	2.30	2.24	0.14	0.16	3.31	3.31	5.49	1.31	0.10	0,02
ASL	1.19	7.52	2.32	2.89	3.72	4.07	7.73	7.54	7.25	7.25	11.83	7.13	4.54	17,88
BAM	12.87	13.72	10.69	1.86	3.69	8.94	3.02	3.01	1.13	1.13	1.42	2.54	1.41	0,98
JUR	0.21	0.19	0.28	0.11	0.07	0.14	2.23	0.11	0.21	0.21	0.47	0.01	0.02	0,01
JSJ	10.09	9.54	17.81	12.74	10.24	5.31	8.67	8.85	8.66	8.66	10.33	8.23	19.02	8,6
MAD	19.74	13.07	11.81	18.08	2.04	2.07	1.67	3.94	5.87	5.87	7.32	13.25	17.02	14,96
MAM	5.68	7.74	5.19	7.52	14.57	14.55	3.46	5.77	7.65	7.65	9.59	7.80	5.75	1,59
PUR	30.19	24.58	17.81	18.18	44.51	43.98	34.81	26.62	41.33	41.33	22.23	36.42	33.11	41,47
RNS	16.22	20.20	29.79	36.94	18.86	18.70	38.27	44.00	24.59	24.59	31.31	23.31	19.03	14,49
Total[3]	20.97	23.27	16.28	17.90	27.37	28.08	21.53	18.82	19.03	21.89	15.18	20.29	19.38	23.08

[1] Source: Instituto de Desenvolvimento Agropecuário e Florestal Sustentável do Estado do Amazonas (IDAM). Data collected between 2010 and 2023 and processed in 2025.

[2] Note: ARN = Alto Rio Negro. ASL = Alto Solimões. BAM = Baixo Amazonas. JUR = Juruá. JSJ = Jutaí/Solimões/Juruá. MAD = Madeira. MAM = Médio Amazonas. PUR = Purus. RNS = Rio Negro/Solimões.

[3] Volume presented in thousand tons.

Regarding the number of active producers, a more balanced distribution across microregions was observed, although Baixo Amazonas recorded the highest participation rates over the years, surpassing 14% between 2013 and 2023 (Table 2). Microregions such as Alto Solimões, Médio Amazonas, and Rio Negro/Solimões also maintained steady participation in the number of extractivists, suggesting a relatively stable productive base despite fluctuations in actual output.

Table 2
Percentage of producers in each microregion relative to the total number of active producers in the Brazil nut supply chain in Amazonas, Brazil, from 2010 to 2023.[1]

Microregion[2]	Percentage share of each microregion in the total number of Brazil nut producers in Amazonas by year													
	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
ARN	0.63	0.75	11.27	2.64	2.65	2.64	2.63	2.61	2.61	2.61	2.60	2.60	2.59	2.59
ASL	3.73	5.90	3.59	5.27	5.27	5.26	5.26	5.25	5.24	5.26	5.26	5.25	5.25	5.24
BAM	11.09	17.69	7.41	14.62	14.62	14.63	14.62	14.62	14.62	14.68	14.68	14.67	14.68	14.67
JUR	2.20	2.62	1.97	11.34	11.33	11.33	11.33	11.32	11.32	11.03	11.03	11.03	11.02	11.02
JSJ	16.39	14.55	13.41	17.26	17.27	17.27	17.27	17.27	17.27	17.34	17.34	17.34	17.35	17.36
MAD	24.04	2.34	19.54	0.22	0.21	0.22	0.21	0.22	0.21	0.20	0.20	0.21	0.21	0.22
MAM	4.23	6.36	2.80	8.02	8.02	8.02	8.02	8.02	8.03	8.05	8.05	8.04	8.04	8.04
PUR	24.09	24.56	13.41	36.25	36.26	36.28	36.30	36.31	36.33	36.47	36.48	36.49	36.51	36.52
RNS	13.60	25.23	26.60	4.38	4.37	4.35	4.36	4.38	4.37	4.36	4.36	4.37	4.35	4.34
Total[3]	6,376	5,342	7,099	4,576	4,801	5,039	5,287	5,546	5,819	6,085	6,385	6,700	7,031	7,380

[1] Source: Instituto de Desenvolvimento Agropecuário e Florestal Sustentável do Estado do Amazonas (IDAM). Data collected between 2010 and 2023 and processed in 2025.

[2] Note: ARN = Alto Rio Negro. ASL = Alto Solimões. BAM = Baixo Amazonas. JUR = Juruá. JSJ = Jutaí/Solimões/Juruá. MAD = Madeira. MAM = Médio Amazonas. PUR = Purus. RNS = Rio Negro/Solimões.

[3] Volume presented in thousand tons.

Average productive yield, calculated based on the proportion of harvested area relative to the total planted area, varied considerably over the years and among microregions (Table 3). Noteworthy yields were observed in Alto Solimões in 2023 (73.8%), as well as in the Jutaí/Solimões/Juruá microregion, which recorded values above 65% in several years. Conversely, regions such as Baixo Amazonas and Alto Rio Negro showed lower yield levels, indicating possible challenges related to forest management, harvest accessibility, or collection seasonality.

Table 3
Productive yield of the Brazil nut supply chain in each microregion of Amazonas, Brazil, from 2010 to 2023.[1]

Microregion[2]	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	Average[3]
ARN	38.91	31.12	26.19	37.43	33.25	42.24	39.07	43.67	38.75	44.51	41.87	55.34	45.47	36.53	52.80
ASL	32.26	39.19	68.08	63.10	36.23	35.71	35.77	31.55	24.24	26.45	24.39	26.28	30.68	30.74	36.05
BAM	17.09	33.32	24.91	27.57	41.71	34.91	62.62	67.10	49.67	41.96	43.37	49.79	40.61	34.81	40.67
JUR	20.92	38.49	29.27	26.48	18.98	28.72	28.88	22.83	25.19	31.57	34.35	36.23	39.32	38.31	29.97
JSJ	32.35	23.51	13.98	21.91	16.11	31.54	35.26	41.59	38.94	31.42	28.74	24.58	22.61	25.78	27.74
MAD	15.21	17.03	20.98	12.87	25.69	16.64	33.67	38.15	36.82	32.86	27.83	30.64	30.67	30.15	26.37
MAM	34.33	43.90	32.63	40.73	33.91	44.63	40.28	37.37	32.61	28.63	31.82	26.64	42.89	42.98	49.53
PUR	12.92	10.67	17.27	16.68	39.75	39.76	39.69	29.35	31.34	34.85	32.36	35.86	30.63	30.48	28.69
RNS	28.77	18.81	13.92	14.96	22.32	24.33	24.29	26.02	26.97	29.85	30.41	30.49	30.13	30.16	25.10
Average[4]	31,75	29.60	32.88	31.58	35.45	36.95	42.51	39.13	35.27	35.22	34.34	37.14	36.46	34.68	35.21

[1] Source: Instituto de Desenvolvimento Agropecuário e Florestal Sustentável do Estado do Amazonas (IDAM). Data collected between 2010 and 2023 and processed in 2025.

[2] Note: ARN = Alto Rio Negro. ASL = Alto Solimões. BAM = Baixo Amazonas. JUR = Juruá. JSJ = Jutaí/Solimões/Juruá. MAD = Madeira. MAM = Médio Amazonas. PUR = Purus. RNS = Rio Negro/Solimões.

[3] Average productive yield of each microregion over the historical series.

[4] Average productive yield of the state in each year evaluated.

3.2. Econometric analysis

The results of the econometric analysis (Tables 4 and 5) indicate that Brazil nut production in Amazonas is significantly influenced by both economic and structural variables. Based on the specification tests (Chow, Breusch-Pagan, and Hausman), the fixed effects model proved to be the most appropriate, offering the best fit for the longitudinal panel data.

Table 4
Econometric model of total Brazil nut production in Amazonas from 2010 to 2023.

Variable	Coefficient	Standard Error	p-value	VIF
Constant (β_1)	2.38870	4.16160	0.05	-
Number of producers	1.56277	0.28556	0.05	1.075
Productive yield	1.00615	0.27608	< 0.01	1.088
Per capita GDP / Income	-0.62423	0.44122	< 0.01	1.755
Average price paid to producers	0.95506	0.41831	0.05	1.791
Model p-value	< 0.01			
R^2	0.94			
Chow test p-value[1]	0.87			
Breusch-Pagan test p-value[2]	0.93			
Hausman test p-value[3]	0.85			
White test p-value [4]	0.32			
Durbin-Watson test p-value – positive autocorrelation[5]	0.37			
Durbin-Watson test p-value – negative autocorrelation[5]	0.77			

[1] H_0: the pooled model is preferable to the fixed effects model.

[2] H_0: the pooled model is preferable to the random effects model.

[3] H_0: the random effects model is preferable to the fixed effects model.

[4] H_0: there is no heteroskedasticity in the model.

[5] H_0: there is no autocorrelation in the model.

Table 5
Correlation matrix of the variables included in the econometric model of total Brazil nut production in Amazonas from 2010 to 2023.

Production	Producers	Production yield	Per capita GDP / Income	Price paid to producers	Variables
1.00	0.68	0.65	-0.39	0.67	Production
	1.00	0.59	-0.37	0.65	Producers
		1.00	0.51	0.52	Production yield
			1.00	0.61	Per capita GDP / Income
				1.00	Price paid to producers

Among the independent variables, the number of active producers exerted the strongest statistically significant and positive influence on Brazil nut production ($p = 0.05$), where a 10% increase in the number of producers was associated with an estimated 15.62% increase in total output, *ceteris paribus*. This result highlights the continued dependence of the extractivist production system on human labor, reinforcing the limited presence of mechanization and the key role of collective harvesting practices in remote forest areas. The second most influential factor was productive yield ($p \leq 0.01$), with a 10% increase in yield corresponding to a 10.06% rise in total production. This underscores the strategic importance of improving harvest efficiency, minimizing post-harvest losses, and implementing enhanced forest management techniques as central pathways to boost sector performance.

Furthermore, the average price paid to producers also demonstrated strong relevance and a statistically significant influence on production levels ($p \leq 0.01$). Specifically, a 10% increase in the price paid to producers was associated with a 9.55% increase in total output. This finding suggests that, in concordance to other extractive chains, the Brazil nut sector in Amazonas may exhibit higher supply elasticity, likely due to the responsiveness of forest gatherers to price incentives. It also indicates the importance of strengthening market transparency, shortening supply chains, and increasing local bargaining power to ensure that price signals are transmitted more effectively to primary producers.

In contrast, municipal per capita income exhibited a negative effect on Brazil nut production ($p = 0.05$), with a 10% increase in local income associated with an estimated 6.24% reduction in total output. This inverse relationship may reflect a structural trade-off in forest-based economies, where higher income levels tend to correlate with reduced dependence on extractivist activities. As households gain access to alternative income sources, such as formal employment, social programs, or agricultural intensification, they may gradually disengage from labor-intensive, low-profit forest extraction. Additionally, the reduced production in higher-income municipalities may also signal a shift toward other land uses or economic priorities that marginalize traditional forest product chains. These findings underscore the importance of targeted policies that recognize the socio-economic diversity of rural Amazonian communities and promote inclusive value-added strategies that make extractivism a viable livelihood even in evolving local economies.

3.3. Organizational structure of the supply chain

The Brazil nut value chain in Amazonas exhibits considerable territorial heterogeneity and is predominantly based on traditional extractivist practices. The flow of production is largely dependent on river routes, which connect harvesting areas to commercial hubs such as Manaus, Manacapuru, and Tefé. However, significant logistical weaknesses were identified, particularly the lack of adequate storage and processing infrastructure in producing regions. These shortcomings contribute to substantial post-harvest losses and reduced value addition.

Furthermore, the data reveal limited institutional coordination across the chain's segments, with low participation of cooperatives and organized associations in most of the surveyed municipalities. This disarticulation hinders access to public policies, credit lines, and certification programs, thereby weakening the competitiveness of the Amazonian product in comparison to countries like Bolivia, which displays higher levels of industrialization and product standardization.

In addition, informality continues to dominate commercial relations within the chain, especially in more isolated areas. Many forest gatherers sell their production through intermediaries, which reduces their profit margins and increases the economic vulnerability of these communities. The absence of formal contracts, regular access to market information, and technical training limits the producers' bargaining power and perpetuates a cycle of dependency. This condition also hampers traceability and certification efforts, attributes that are increasingly demanded by both domestic and international markets. Therefore, public policies aimed at strengthening local productive arrangements, promoting digital inclusion among extractivists, and establishing community-based processing units are essential to foster greater equity, value addition, and sustainability within the Brazil nut value chain in Amazonas.

4. Discussion

Firstly, the distribution of Brazil nut production in Amazonas, highlighting the leadership of the Purus, Rio Negro/Solimões, and Jutaí/Solimões/Juruá microregions, reveals that this production chain is closely linked to areas rich in native Brazil nut groves, with the presence of traditional populations with a history of extractivism and a river network that facilitates the outflow of production (Homma, 2012; Gomes, 2018). In the cases of Purus and Jutaí, community organization and local knowledge appear to contribute to production regularity, while proximity to Manaus favors logistics and institutional support in the Rio Negro/Solimões region (Silva et al., 2013; Teixeira de Sousa and Rocha, 2025). In contrast, microregions with lower participation, such as Alto Rio Negro and Baixo Amazonas, face challenges such as limited access to Brazil nut groves, low population density, or disorganized production, which undermine their competitiveness (Mariosa et al., 2022; Marin et al., 2023).

The analysis of the number of extractivists revealed a more homogeneous distribution among the microregions, but not always associated with high production volumes. This indicates that, in some areas, there are many producers with low individual efficiency due to logistical, technical, or economic constraints (Gomes, 2018; Silva and Dias, 2020). This pattern reflects the labor-intensive nature of the chain, which still lacks formal structuring, cooperativism, and access to technologies that could improve productivity and remuneration for those involved (Evangelista-Vale et al., 2021; Merino, 2024; de Oliveira et al., 2025). Regarding productive yield, there was strong variation between regions and over time, influenced by climatic, ecological, and operational factors (Evangelista-Vale et al., 2021; Merino, 2024). Regions with higher yield indices, such as Jutaí/Solimões/Juruá, possibly combine well-established traditional practices with conservation of the Brazil nut groves (Giatti et al., 2021; Mariosa et al., 2022). On the other hand, regions with low yields, such as Baixo Amazonas, may face issues such as disorganized harvesting, an aging workforce, and post-harvest losses (Denny et al., 2021; de Oliveira et al., 2025).

By linking these results to the econometric analysis, it becomes evident that, as observed in other production chains in the Amazon that are strongly tied to and dependent on an extractivist model, the number of producers and productive yield are the most decisive variables affecting production (Teijlingen, 2016; Gomes, 2018; de Oliveira et al., 2025). This reflects a proportional increase in production that is dependent on labor to sustain the activity, an extensively documented characteristic of non-timber forest products, such as Brazil nuts (Homma, 2012; Vieira, 2023). In this context, the fact that the average price paid to the producer also shows a significant positive impact on production suggests that policies aimed at increasing the value paid to extractivist producers, as well as certification programs and value-adding initiatives, can directly contribute to production growth by attracting more labor to the activity (Rêgo et al., 2021; Gasparinetti et al., 2022).

In this regard, the observed negative correlation between municipal per capita income and production volume, which indicates that more economically developed areas tend to abandon extractivist activities in favor of less strenuous and more profitable income sources, suggests that the lack of technological advancement in this production chain, making it more labor-dependent, is a major bottleneck for expanding its production frontier (Barletti, 2016; Said et al., 2021; Rosa et al., 2024). Again, the literature reports that this phenomenon is commonly observed in other Amazonian production chains, indicating that extractivist systems require public policies that enable them to break this vicious cycle. The most promising short-term solutions pointed out involve the integration of appropriate technology with proper training, along with income improvement and environmental conservation (Evangelista-Vale et al., 2021; Vieira, 2023).

When seeking to understand the role of the Brazil nut value chain within the broader structure of Brazil's agribusiness sector, it becomes apparent that, although Brazil holds the largest global production of in-shell Brazil nuts, it has a low level of industrialization and value addition compared to countries such as Bolivia, which predominantly exports shelled, deodorized, and internationally certified products (Soriano et al., 2021; Vieira, 2023). This is largely due to institutional disarticulation and informality within the Brazilian supply chain, particularly in the Amazon, as identified in this study and reinforced by

Gasparinetti et al. (2022). In fact, Merino (2024) points out that the low adherence to cooperatives and the lack of coordination among productive links contribute to limited access to public policies, processing technologies, credit lines, and more demanding international markets, thereby stagnating the development of this value chain.

From a market perspective, this inefficiency within the Brazil nut production chain is also reflected in the underutilization of the entire fruit. Only about 10% of the Brazil nut pod is commercially exploited, the edible kernels, while the husks, shells, and press cakes are byproducts with potential uses that remain largely underexploited (Petrechen et al., 2019). The press cake, resulting from cold or hot pressing for oil extraction, for instance, contains high levels of protein (37.5 g/100 g) and fiber (9.6 g/100 g), making it a promising ingredient for food formulations or animal feed (Zanqui et al., 2020; Abrantes et al., 2024). The Brazil nut oil, when cold-pressed, can present high concentrations of selenium, vitamin E, and essential fatty acids, allowing it to be targeted to premium food and cosmetics markets (Castro et al., 2024).

In general terms, the Brazil nut value chain, as illustrated in Fig. 1, begins with the collection of the ouriço, the heavy, woody fruit that can weigh up to 2 kg and must be gathered soon after falling to prevent contamination by fungi and aflatoxins (Kainer et al., 2007; Kluczkovski et al., 2020; da Costa et al., 2022), as shown in Fig. 2. The following stages include transportation to collection points, opening of the fruits, drying, and sorting, all of which are essential to ensure the quality of the nuts, also as shown in Fig. 1. The bottlenecks within this chain, as shown in Fig. 2, begin with the lack of basic infrastructure in these regions, which results in significant losses and limits value addition at the point of origin, leading to commercialization through intermediaries who capture disproportionate profit margins (Gomes, 2018; Denny et al., 2021; Merino, 2024). Additionally, the Brazil nut tree presents significant challenges to cultivation due to its ecological requirements and long reproductive cycle, making the productive intensification of the chain dependent on the valorization of traditional extractivism and the integration of technologies that respect socio-biodiversity (Zanqui et al., 2020; Rêgo et al., 2021; Vieira, 2023; de Oliveira et al., 2024).

From a production standpoint, the Brazil nut tree has a long maturation cycle: it begins to fruit around 8 years of age and reaches full production only at about 12 years, yielding an average of 470 nuts per tree per year (de Oliveira et al., 2024). This low individual productivity, combined with ecological dependency and irregular fruiting, strongly conditions the extractivist dynamic, which is vulnerable to climate variability, wildfires, and changes in land use patterns (Petrechen et al., 2019; Evangelista-Vale et al., 2021). Such vulnerability was reflected in the variation in productive yields among microregions in Amazonas, as reported in this study’s results, with regions such as Jutaí/Solimões/Juruá and Purus achieving better production performance in recent years.

On the other hand, the experience of other Amazonian value chains, such as cocoa and cupuaçu, shows that the transition from extractivist models to organized and sustainable agroforestry systems can boost productivity while preserving the forest and improving the social indicators of the communities involved (Schroth et al., 2001; Rosa et al., 2024). This again underscores the need for public policies that integrate territorial development, environmental conservation, and value addition at the origin (Jurema and Oliveira, 2023; Merino, 2024). The creation of community-based processing units, promotion of organic certification and traceability, and the fostering of cooperative local production arrangements are essential strategies to enhance the sustainability and competitiveness of the Brazil nut chain (Homma, 2012; Baletti, 2014; Leifsen, 2020). Furthermore, technological exploitation of byproducts and incentives for research into new industrial applications for the press cake, oil, and shell can transform environmental liabilities into high-value economic assets, further enhancing the dynamics of this value chain (Kainer et al., 2007; Zanqui et al., 2020; Rêgo et al., 2021; Abrantes et al., 2024).

5. Conclusion

This study provides a comprehensive diagnosis of the Brazil nut value chain in the state of Amazonas, revealing a production system still strongly rooted in traditional extractivism, structurally marked by territorial inequalities, labor intensity, and limited value addition. The econometric evidence underscores the crucial role of human labor and productive yield as key drivers of output, while also highlighting the inhibiting effect of rising local income levels on extractivist engagement, an indicator of the socioeconomic vulnerability of the chain in the face of broader development trends. Market analysis revealed critical weaknesses such as institutional disarticulation, informality, and underutilization of byproducts, which collectively undermine competitiveness and resilience, especially when compared to more industrialized models like Bolivia's. Nonetheless, the chain harbors untapped potential, particularly in its sociobiodiversity, nutritional richness, and environmental sustainability. Advancing this potential requires integrated public policies that bridge infrastructure gaps, foster cooperative organization, promote technological innovation, and incentivize local processing and product diversification. Drawing lessons from other Amazonian agroforestry experiences, a gradual transition from subsistence-based extraction toward organized, inclusive, and sustainable production systems appears not only viable but urgent for ensuring economic inclusion, forest conservation, and the long-term viability of the Brazil nut economy in Amazonas.

From an empirical standpoint, the study identified that Brazil nut production is highly concentrated in three microregions, Purus, Rio Negro/Solimões, and Jutaí/Solimões/Juruá, where factors such as traditional knowledge, community organization, and logistical access help sustain output over time. The econometric model demonstrated that a 10% increase in the number of producers leads to a 15.62% rise in total production, while a 10% gain in productive yield corresponds to a 10.06% increase in output, underscoring the chain's deep reliance on labor and harvest efficiency. Furthermore, the average price paid to producers significantly influenced production, indicating that better market incentives may mobilize labor and reduce abandonment of extractivism. Conversely, higher municipal income levels were negatively associated with Brazil nut output, suggesting that socioeconomic development, when not accompanied by modernization and diversification of the chain, may lead to reduced engagement in extractive activities. These findings reinforce the need for region-specific strategies that improve productivity and remuneration without disconnecting producers from forest-based livelihoods.

Declarations

Author contribution

The experimental plan and design were conceived, planned, and developed by xxxxx. The primary research draft was written by xxxxx. xxxxx prepared materials and methods. xxxxx collected data. xxxxx performed laboratory analysis. xxxxx performed statistical analysis and result interpretation. The manuscript was reviewed and edited by all the authors. The ultimate manuscript was read and approved by all the authors.

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Data availability

The data of this study are available from the corresponding author upon reasonable request.

Consent for publication

All authors give consent for publication.

Consent to participate

Not applicable.

Conflict of interest

The authors declare no competing interests.

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Figures

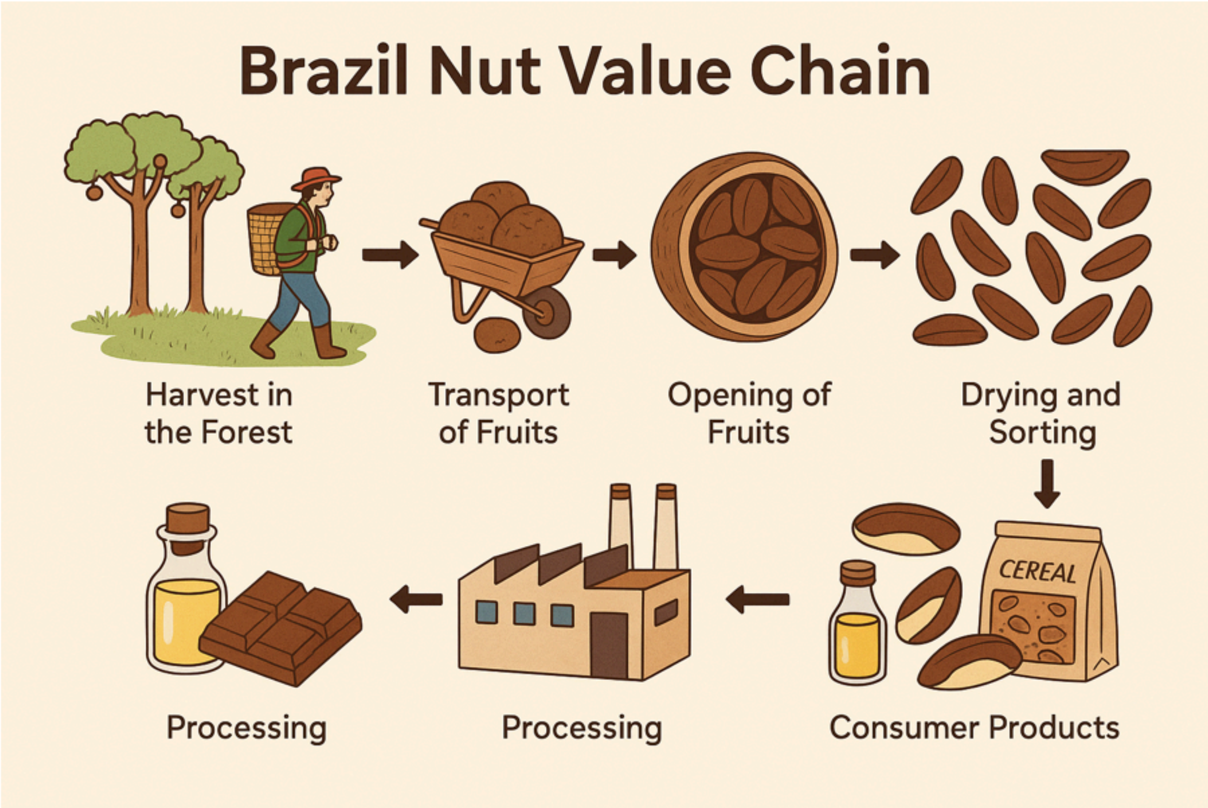

Figure 1

Step-by-step illustration of the Brazil nut value chain in the Amazon, from forest harvest to final consumer products, highlighting the stages of fruit collection, transport, opening, drying, processing, and commercialization.

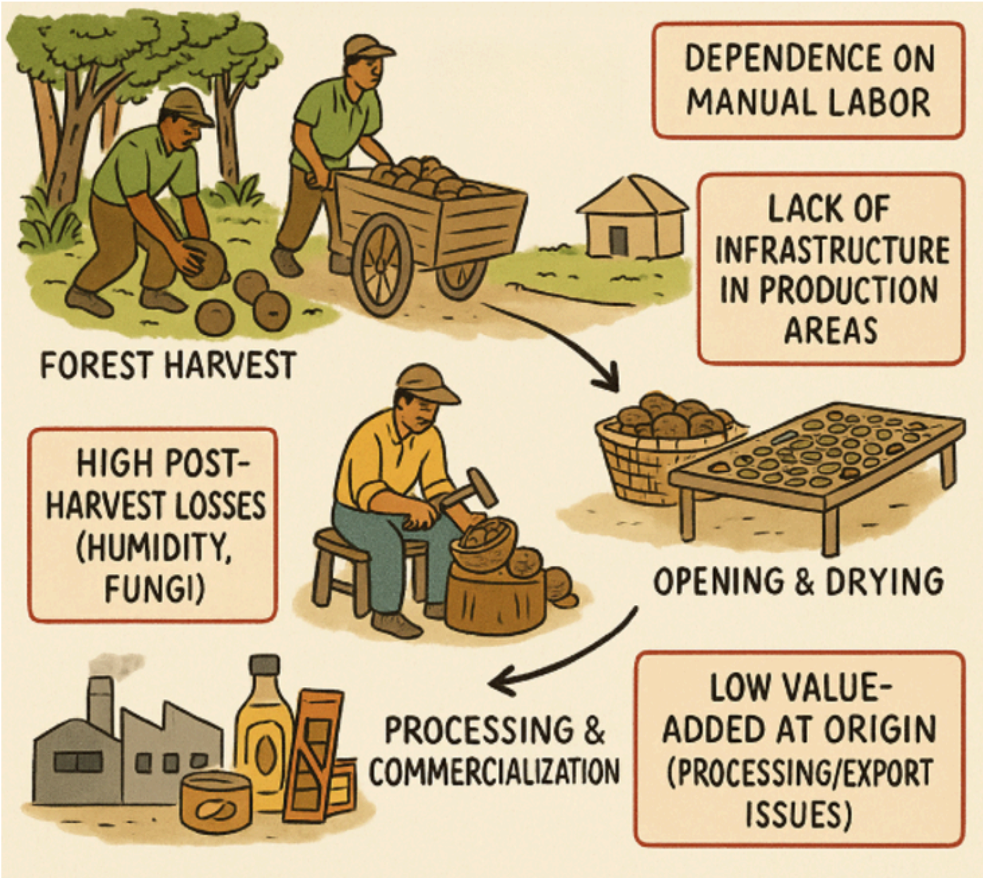

Figure 2

Bottlenecks in the Brazil nut value chain in the Amazon.