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DYNAMICS OF THE LAYER POULTRY PRODUCTION CHAIN IN AMAZONAS: ECONOMETRIC ANALYSIS AND CHARACTERIZATION OF THE PRODUCTIVE PROFILE

HILÁRIO RAMIRO DE ABREU FILHO

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Dissertation submitted to the Graduate Program in Animal Science and Fishery Resources (PPGCARP) at the Federal University of Amazonas (UFAM) as a requirement for obtaining the degree of Master in Animal Science and Fishery Resources, with an emphasis on Animal Production.

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RESUMO

A avicultura de corte e postura representa um dos pilares do agronegócio brasileiro, posicionando o país entre os maiores produtores e exportadores de carne de frango e ovos. No Amazonas, o setor vem se expandindo gradualmente, impulsionado pela crescente demanda por alimentos de origem animal com alto valor nutricional. Este trabalho tem como objetivo analisar a cadeia produtiva avícola no Estado, estruturando-se em quatro capítulos interligados que exploram diferentes dimensões econômicas, sociais, ambientais e produtivas. O Capítulo 1 introduz os objetivos, a justificativa e a revisão de literatura, ressaltando a relevância da avicultura para o desenvolvimento regional e apontando entraves como os elevados custos de insumos, limitações logísticas e carências estruturais típicas da região Amazônica. Também enfatiza a necessidade de políticas públicas, inovação tecnológica e estratégias de manejo sustentável para promover competitividade e segurança alimentar. No Capítulo 2, artigo publicado na revista *World Poultry Science Journal*, são discutidos os desafios ambientais e de bem-estar animal na produção avícola latino-americana. A revisão sistemática aborda o uso racional de recursos naturais, as práticas de manejo sustentável e a urgência de alinhar eficiência produtiva à responsabilidade socioambiental, destacando avanços e barreiras ainda presentes na região. O Capítulo 3, publicado no livro *Science and Technology in Studies with Animals in the Amazon*, foca nos aspectos comerciais e produtivos da avicultura Amazônica. Analisa o papel das microrregiões produtoras, o consumo de ovos e carne de frango, e a inserção da produção regional nos mercados locais e interestaduais, evidenciando oportunidades, fragilidades e a disparidade em relação aos grandes polos nacionais. Por fim, o Capítulo 4 apresenta um diagnóstico da cadeia de postura no Amazonas, com análise econométrica baseada em séries históricas de 2000 a 2023. Os resultados mostram instabilidade na produção de ovos, influenciada por custos, demanda, logística e fatores climáticos. A microrregião do Rio Negro/Solimões destacou-se como principal polo produtivo, sendo o tamanho do plantel identificado como fator determinante para o aumento da produção. De forma integrada, os achados indicaram que a avicultura no Amazonas possui potencial estratégico, mas sua consolidação depende de investimentos em infraestrutura, capacitação técnica e políticas públicas que reduzam gargalos logísticos e custos de produção, fomentando a atividade.

Palavras-chave: Avicultura, Bioeconomia, Sistemas de produção, Sustentabilidade.

ABSTRACT

Broiler and layer poultry farming represents one of the pillars of Brazilian agribusiness, positioning the country among the world's largest producers and exporters of chicken meat and eggs. In Amazonas, the sector has been gradually expanding, driven by the growing demand for animal-based foods with high nutritional value. This study aims to analyze the poultry production chain in the State, structured into four interconnected chapters that explore different economic, social, environmental, and productive dimensions. Chapter 1 introduces the objectives, justification, and literature review, highlighting the relevance of poultry farming for regional development and pointing out obstacles such as high input costs, logistical limitations, and structural shortcomings typical of the Amazon region. It also emphasizes the need for public policies, technological innovation, and sustainable management strategies to promote competitiveness and food security. In Chapter 2, published as an article in the World Poultry Science Journal, environmental and animal welfare challenges in Latin American poultry production are discussed. The systematic review addresses the rational use of natural resources, sustainable management practices, and the urgency of aligning productive efficiency with socio-environmental responsibility, highlighting both advances and persistent barriers in the region. Chapter 3, published in the book Science and Technology in Studies with Animals in the Amazon, focuses on the commercial and productive aspects of Amazonian poultry farming. It analyzes the role of producing microregions, patterns of egg and chicken meat consumption, and the integration of regional production into local and interstate markets, evidencing opportunities, weaknesses, and disparities in relation to major national poultry hubs. Finally, Chapter 4 presents a diagnosis of the layer poultry chain in Amazonas, with an econometric analysis based on historical series from 2000 to 2023. The results reveal instability in egg production, influenced by costs, demand, logistics, and climatic factors. The Rio Negro/Solimões microregion stood out as the main production hub, with flock size identified as a key factor for increased output. Taken together, the findings indicate that poultry farming in Amazonas has strategic potential, but its consolidation depends on investments in infrastructure, technical training, and public policies aimed at reducing logistical bottlenecks and production costs, thereby fostering the activity.

Keywords: Bioeconomy, Poultry farming, Production systems, Sustainability.

LIST OF FIGURES

LIST OF TABLES

SUMMARY

CHAPTER 1 – INTRODUCTION, OBJECTIVES, AND LITERATURE REVIEW

1. INTRODUCTION

Broiler and layer poultry farming is an economic activity of great importance in Brazil, standing out for its advancement and productive efficiency, which have contributed to consolidating the country as one of the main producers and exporters of poultry and eggs in the global scenario (CRUZ *et al*., 2016; MENDES, 2021). In the state of Amazonas, poultry farming has been gradually developing, driven by the increasing demand for food resulting from population growth and local consumers' requirements for animal products with nutritional quality. The sector is primarily characterized by the production of commercial eggs, which are considered an affordable source of high biological value protein, in addition to containing essential lipids (CRUZ *et al*., 2013).

This activity has gained relevance as an alternative for regional socioeconomic development, promoting the generation of direct and indirect jobs, increasing household income, and stimulating the local economy. Although the state of Pará stands out as the largest poultry producer in the Northern Region, according to the Agricultural Census of IBGE, Amazonas presents expansion potential, especially in the municipalities of Manaus, Rio Preto da Eva, Iranduba, Manacapuru, and Careiro, where commercial layer poultry farming has been concentrated (CRUZ *et al*., 2016).

The Amazonas state, composed of 62 municipalities, has demonstrated significant expansion in the poultry sector, consolidating itself as an economic activity of regional importance. Among the productive segments, Commercial Layer Poultry Farming stands out, showing remarkable growth, especially in strategically located municipalities. Cities such as Manaus, Rio Preto da Eva, Iranduba, Manacapuru, and Careiro emerge as productive hubs, substantially contributing to the local and regional supply of eggs. This progress reflects the potential of the poultry chain in generating employment, income, and food security, in addition to highlighting the importance of investment in technologies and sustainable practices for strengthening the sector in the Amazon region (CRUZ *et al*., 2016).

In general, poultry production in Amazonas is limited due to a series of structural, sanitary, and environmental constraints that hinder its expansion. The activity faces restrictions resulting from current environmental legislation in the Amazon region, as well

as hygienic barriers related to the lack of adequate infrastructure for control and inspection (CRUZ *et al*., 2016).

Another factor that hinders sector development is the shortage of formalized industries, with few units operating under state regulation, which limits large-scale processing and marketing. Added to this is the difficulty of accessing specific credit lines for small producers, which makes investments in technology, management, and biosecurity unfeasible. In this context, small-scale, family-based, free-range poultry farming plays a central role in the regional economy, especially in rural areas, where it serves as an essential source of subsistence, income generation, and food security (CRUZ *et al*., 2021).

Free-range poultry farming has played a relevant role in diversifying poultry production in Amazonas, breaking paradigms by consolidating itself as a viable alternative for the production of both commercial and free-range eggs. This activity is largely carried out by small producers, using simple facilities, with low levels of mechanization and scarce technological resources. The lack of investment is aggravated by limited or nonexistent specialized technical assistance, which hinders the adoption of good management, health, and nutrition practices (CRUZ *et al*., 2016).

Despite these challenges, free-range poultry farming has attracted a growing number of consumers, driven by a positive perception regarding product quality. The system is often associated with healthier and more sustainable food, as it involves less intensive practices, lower use of artificial inputs, and greater animal welfare. This appreciation of free-range products represents a strategic opportunity to strengthen family farming and promote sustainable rural development in the State (RUFINO *et al*., 2024).

Despite the advances observed in the sector, poultry farming in Amazonas still faces significant obstacles that limit its full development. One of the primary challenges is the high reliance on the importation of basic feed inputs, particularly corn and soybeans, which are the primary components of poultry diets. As these grains are not produced on a large scale in the State, it is necessary to acquire them from other regions of the country, which makes the production process more expensive due to high logistical costs and supply instability (CRUZ *et al*., 2016).

This difficulty in locally obtaining raw materials directly impacts feed formulation, which accounts for, on average, about 70% of the total cost of poultry production. This

condition limits the competitiveness of local producers compared to other regions with greater autonomy in input production (RUFINO *et al*., 2024).

Strengthening poultry farming in the Amazon region can play a strategic role in promoting food security and improving the socioeconomic conditions of the local population. The production of eggs and poultry meat, through systems adapted to regional realities, contributes to regular access to animal-source foods with high nutritional value, especially proteins and essential lipids, at affordable prices. Furthermore, poultry farming represents an important source of income generation and employment in rural areas, promoting sustainable development and reducing food vulnerability (LAIA *et al*., 2021).

However, for this potential to be fully achieved, more in-depth studies are needed on the economic feasibility and profitability of the activity in the region, considering production costs, distribution logistics, and the specificities of the local market. It is also urgent to incorporate appropriate technologies and sustainable practices capable of increasing productivity, reducing environmental impacts, and ensuring the biosecurity of poultry farming (CRUZ *et al*., 2021).

The strengthening of regional poultry farming has the potential to promote food security, improve population quality of life, and foster local socioeconomic development through job creation, production diversification, and the dynamization of rural economies. However, there are still a few studies focused on analyzing the profitability of the activity, productive efficiency at different scales, and the adoption of sustainable practices adapted to the Amazonian reality (SILVA *et al*., 2020; CRUZ *et al*., 2021).

2. OBJECTIVES

2.1.General objective

To diagnose the dynamics of the poultry production chain in Amazonas through econometric tools.

2.2.Specific objectives

- To prepare a systematic review on environmental, technological, and animal welfare challenges in Latin American poultry production;
- To conduct a narrative review on commercial and productive aspects of poultry farming in the Legal Amazon;
- To describe the productive and economic profile of the layer poultry production chain in Amazonas during the period from 2000 to 2023;
- To perform an economic analysis of the layer poultry production chain in Amazonas during the period from 2000 to 2023.

3. LITERATURE REVIEW

3.1.Economic importance and poultry production chain

The poultry production chain plays an essential role in the Brazilian economy, being one of the main sectors of the national agribusiness. Brazil stands out as one of the largest producers and exporters of chicken meat, ensuring food security and generating millions of direct and indirect jobs (ABPA, 2023). In addition, egg production has grown significantly, meeting the increasing domestic and international demand (EMBRAPA, 2021).

According to Silva *et al*. (2020), Brazilian poultry farming benefits from technological advances such as genetic improvement, balanced nutrition, and automation, factors that boost productivity and competitiveness in the global market. However, challenges such as fluctuations in input prices and international sanitary requirements still affect the sector (SOUZA; FERREIRA, 2019). Thus, poultry farming is strategic for Brazil's economic development, contributing to income generation, food supply, and the strengthening of Brazilian agricultural exports.

Poultry farming in Amazonas faces significant challenges related to the supply of inputs, especially corn and soybean meal, which are essential for poultry feed. According to the Federation of Agriculture and Livestock of the State of Amazonas (FAEA), the State demands about 60 thousand tons of corn annually, of which only 33% is produced locally, with the remainder imported from states such as Mato Grosso and Goiás. This external dependence, combined with the increase in corn exports, has resulted in shortages and rising input prices, directly impacting the production costs of poultry farmers in Amazonas (FAEA, 2014).

To mitigate these challenges, initiatives such as the revitalization of the AM-010 highway have been proposed, aiming to improve logistics and reduce transportation costs for local producers. The improvement of access roads is considered crucial to facilitate the flow of production and make poultry farming in Amazonas more competitive compared to other regions of the country (AGRIMÍDIA, 2021). Furthermore, the implementation of public policies that encourage local input production and the modernization of logistical infrastructure are essential measures to strengthen the poultry sector in Amazonas.

3.2.Poultry farming in Amazonas

The poultry production chain in Amazonas plays an essential role in the regional economy and in the food security of the population, presenting particular characteristics that bring both challenges and opportunities for the sustainable development of the sector. Poultry farming in the State has grown to meet the domestic demand for animal protein, but it still faces logistical and structural barriers that affect its competitiveness (IDAM, 2017).

Poultry production in Amazonas is predominantly directed toward the layer segment, with greater concentration in the metropolitan region of Manaus. This sector has been responsible for supplying between 90 and 95% of the local demand for eggs, making it a key element for the state's food security (CRUZ *et al*., 2016). However, one of the main challenges faced by local producers is the dependence on the importation of inputs, especially corn and soybean meal, which are fundamental for feed production. The need to transport these inputs over long distances raises production costs, limiting the competitiveness of poultry farming in Amazonas compared to other regions of Brazil (CRUZ *et al*., 2016; IDAM, 2017).

In contrast, industrial-scale broiler production is virtually nonexistent in the State, leading Amazonas to depend on the importation of chicken from other States to meet domestic consumption. This limitation represents an opportunity for the expansion of broiler farming in the region, primarily through the adoption of production models adapted to local environmental conditions. One alternative that has been growing is free-range poultry farming, which, although still small-scale, has the potential to significantly contribute to food supply and income generation for small producers (CRUZ *et al*., 2016).

Poultry farming in Amazonas has excellent potential to grow and contribute even more to the socioeconomic development of the State. With strategic planning and government support, the production chain can overcome its challenges and become more self-sufficient and competitive (SILVESTRIM *et al*., 2022). Research, such as that by Silva *et al*. (2020), indicates that investments in productive technologies, incentive policies, and the structuring of the logistics chain are fundamental to strengthening poultry farming in Amazonas. Improving infrastructure, reducing production costs, and seeking sustainable alternatives, such as the use of local inputs, can stimulate the expansion of the activity and minimize external dependence (SILVA *et al*., 2020; SILVESTRIM *et al*., 2022).

3.3.Economic analysis in poultry farming

Despite the growing demand for chicken meat, much of the supply still depends on production from other states, highlighting a significant gap in local production. In this context, Amazonas presents enormous potential for investments in broiler farming, mainly due to its favorable environmental conditions, availability of natural resources, and the increasing need to supply the domestic market with its own production. The consolidation of this production chain in the State would not only reduce external dependence but also boost regional development, generating jobs, income, and food security (SILVA *et al*., 2020).

However, the sector faces structural and logistical challenges that impact on the competitiveness of local producers (CRUZ *et al*., 2016). Poultry farming in Northern Brazil still shows low productivity compared to other regions due to logistical difficulties (CRUZ *et al*., 2016; SILVA *et al*., 2020). The demand for chicken meat in Amazonas is growing, driven by population growth and by the consumption of this protein as a more affordable alternative compared to beef and pork. According to Souza and Almeida (2021), chicken meat consumption in the State has increased annually, reinforcing the need to expand local production. However, the internal productive capacity of Amazonas remains below local demand, resulting in a high dependence on chicken meat imports from other regions of the country, particularly the South and Central-West. This interstate dependence leads to increased logistical costs, especially with transportation, which directly raises the final product price for local consumers (OLIVEIRA, 2019).

Production costs in Amazonas poultry farming are higher compared to other regions of the country. This occurs due to the higher prices of inputs such as feed, vaccines, and equipment, which must be transported from different States (FERREIRA *et al*., 2020). In addition, the logistical difficulties imposed by the geography of Amazonas, with much of the transportation carried out by rivers and poorly maintained roads, further increase operational costs.

Broiler production in Amazonas faces additional costs due to the need for infrastructure adapted to the region’s hot and humid climate, which compromises poultry welfare and productive performance. Efficient control of temperature and humidity in poultry houses requires investments in infrastructure, including sheds with a minimum ceiling height of 3 meters equipped with ridge vents, as well as strict sanitary management covering the quality of water, feed, and the internal environment. Furthermore, the adoption of elevated

sheds, thermal roofing, and functional layouts that facilitate air circulation and operational flow is recommended. Such adaptations are essential to reduce production losses and economically sustain poultry farming in the region (SANTOS; LIMA, 2022).

Despite existing challenges, poultry farming in Amazonas shows promising prospects for growth. The adoption of tax incentives and specific public policies can stimulate local production and reduce dependence on imports (MENDES, 2021). The use of regional by-products in feed formulation represents a viable alternative to lower feeding costs and enhance competitiveness (CRUZ *et al.*, 2016). Furthermore, production expansion has the potential not only to meet regional demand but also to create opportunities for exports to neighboring countries. To achieve these advances, however, investments in technology, producer training, and improvements in logistical infrastructure are essential (MENDES, 2021; SANTOS; LIMA, 2022).

3.4. Challenges and perspectives for poultry farming in Amazonas

Poultry farming in Amazonas faces structural and logistical challenges that hinder its growth and competitiveness in the market. According to Silva *et al*. (2020), one of the main obstacles is the high cost of inputs, such as feed and vaccines, which are mostly imported from other regions of the country. In addition, poor infrastructure and transportation difficulties further increase production costs (FERREIRA *et al*., 2020).

Another major challenge for poultry farming in Amazonas is the hot and humid climate, which requires investments in environmental control technologies to ensure bird welfare and maintain productivity (SANTOS; LIMA, 2022). In addition, the lack of government incentives and specific public policies restricts the expansion of the sector (MENDES, 2021).

Despite these constraints, there are opportunities to strengthen the activity. The use of regional inputs in feed formulation can reduce costs and increase competitiveness (CARVALHO *et al*., 2020). Furthermore, investments in infrastructure and producer training can drive sectoral development (PEREIRA, 2018). With appropriate strategies, poultry farming in Amazonas has the potential to reduce external dependence and stimulate the local economy (SOUZA; ALMEIDA, 2021).

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CHAPTER 2 - ENVIRONMENTAL, TECHNOLOGICAL, AND ANIMAL WELFARE CHALLENGES IN LATIN AMERICAN POULTRY PRODUCTION: A SYSTEMATIC REVIEW OF SUSTAINABILITY AND EFFICIENCY

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5. MATERIAL AND METHODS

5.1.Study Selection Criteria

We carried out this systematic literature review following the methodology described by Siddaway *et al*. (2018), which includes the following stages: (i) defining a research question to guide the study; (ii) identifying key thematic aspects to be explored; (iii) implementing a structured data screening process; and (iv) analysing and interpreting the collected data. This approach ensures a thorough synthesis of existing empirical evidence. The research team consisted of two trained reviewers who independently conducted the selection of studies. Disagreements were resolved through consensus.

5.2.Focus question

The central question 'What are the main factors influencing the sustainability and efficiency of the poultry production chain in Latin America, considering nutritional practices, animal welfare, and environmental management?' was developed using the PICOC framework (Population, Intervention, Comparison, Outcome, Context). To answer this question, the following sub-items were formulated: a) How do different nutritional strategies impact the sustainability and efficiency of poultry production in Latin America?; b) What are the key challenges and advancements in animal welfare practices within the region's poultry industry?; c) How does environmental management influence resource efficiency and long-term sustainability in poultry production?.

5.3.Information sources and data curation

The systematic search was performed in October 2024 using the following databases: ScienceDirect, SciELO, Scopus, and Web of Science. The search strategy consisted of four predefined Search Components (SCs):

- SC1: ‘poultry farming’ or ‘poultry production’ or ‘broilers’ or ‘laying hens’
- SC2: ‘nutrition’ or ‘diets’ or ‘feed additives’
- SC3: ‘Latin America’ or ‘Brazil’ or ‘Colombia’ or ‘Peru’
- SC4: ‘sustainability’ or ‘efficiency’ or ‘animal welfare’

These components were combined using the Boolean operator AND to ensure that all retrieved articles addressed the full scope of the research question. Within each component, terms were combined using OR to account for synonymy.

5.4.Inclusion and exclusion criteria

The review was limited to peer-reviewed journal articles published in English between 2013 and 2024. Editorials, letters, reviews and mini-reviews were excluded from the main analysis to avoid duplication of data and ensure the synthesis focused on primary empirical evidence. However, they were consulted in the background phase to help define search terms and contextualization of the research gap. Inclusion criteria were ‘studies that assess sustainability and efficiency in poultry production in Latin America, focusing on at least one of the following aspects: nutritional practices, animal welfare, or environmental management’.

On the other hand, exclusion criteria were:

- Studies on poultry that do not address sustainability or efficiency;
- Studies on animal nutrition not specific to poultry;
- Studies on sustainability in livestock excluding poultry;
- Studies outside Latin America;
- Studies on poultry not addressing the review’s core themes.

5.5.Screening and data extraction

Titles and abstracts were screened independently by the two reviewers using Rayyan software. Full-text articles were then assessed against eligibility criteria. A structured Excel-based data extraction form was used to record the following variables:

- Study identification (authors, year, country);
- Type of poultry system (intensive, semi-intensive, free-range, etc.);
- Focus area (nutrition, welfare, environmental management);
- Type of intervention (e.g. feed additive, housing modification);
- Outcome variables (e.g. feed conversion ratio, mortality, welfare indicators);
- Methodological design (e.g. experimental, observational).

Coding was both quantitative (numerical synthesis of frequencies, proportions, trends) and qualitative (thematic classification and interpretation of key insights). Additionally, the systematic review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (PAGE *et al*. 2021) to ensure methodological rigour and transparency in the selection process.

5.6.Risk of bias assessment

To assess the methodological quality and potential bias in the included studies, we used a simplified checklist based on the Joanna Briggs Institute (JBI) Critical Appraisal Tools for experimental and observational studies. Each study was evaluated according to clarity of objectives, adequacy of methodology, completeness of reporting, and presence of bias. The risk of bias was categorised as low, moderate, or high, and results were crossvalidated by the two reviewers.

6. RESULTS

6.1.Literature search

The study selection process was conducted according to the criteria established in the methodology, including 37 articles for in-depth analysis. The initial search identified a total of 135 articles in the ScienceDirect, Scielo, Scopus, and Web of Science databases. After removing 54 duplicate and rejected articles, 81 studies were selected for title and abstract screening. Following this step, 32 articles were excluded for meeting at least one exclusion criterion. A total of 49 studies proceeded to full-text reading, where additional 18 articles were removed for failing to meet all inclusion criteria or not aligning with study's objectives. Finally, 6 additional articles were included through targeted searches, resulting in a final selection of 37 studies for systematic review (Figure 1).

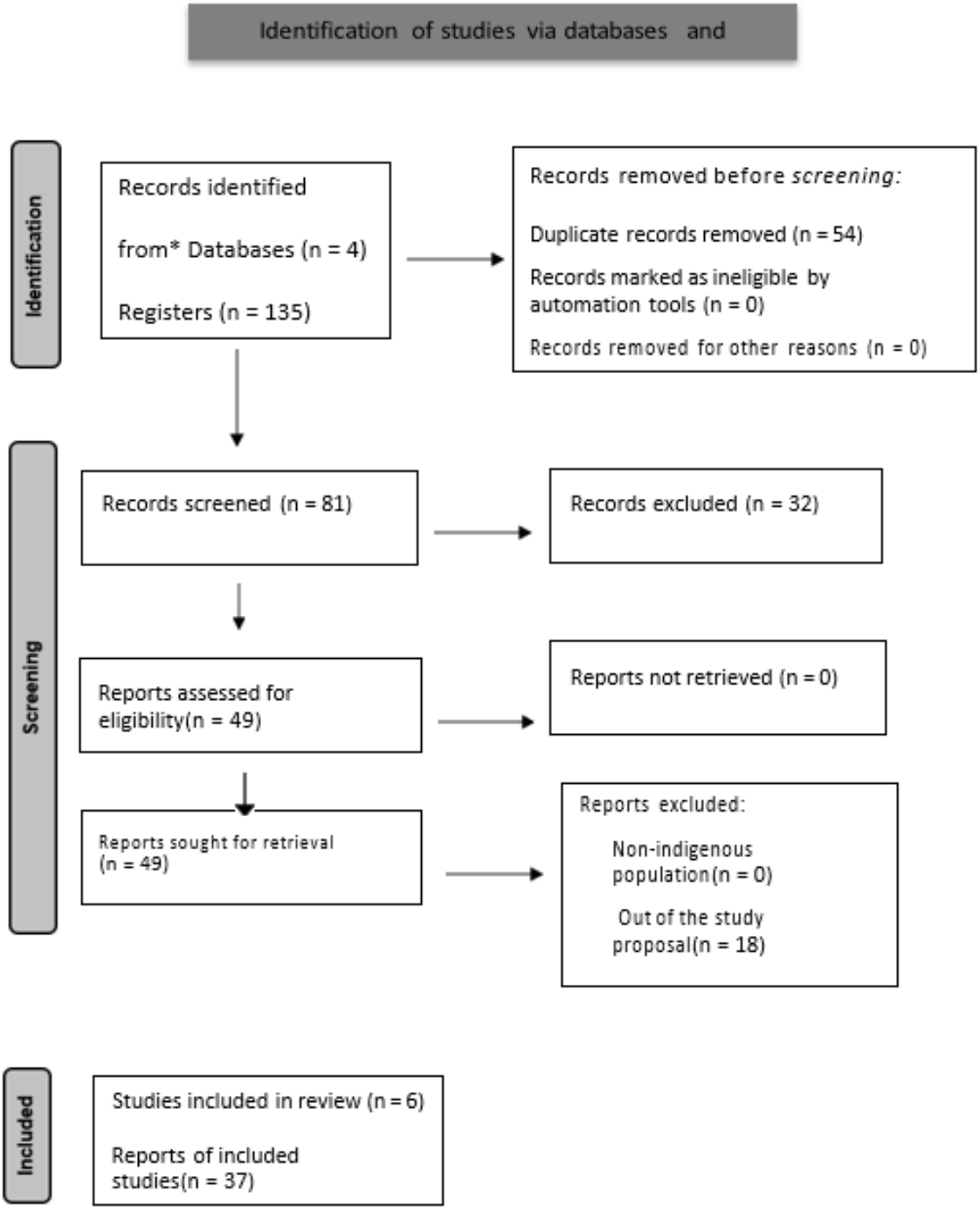

Figure 1. PRISMA flow diagram displays the literature search results.

The included studies encompass a broad range of research conducted in Latin America, with Brazil, Mexico, Chile, and Ecuador being the most frequently studied countries (Figure 2). Brazil accounts for the largest share of the reviewed literature, reflecting the country's

significant role in poultry production research. The geographical distribution of studies highlights disparities in research focus, indicating varying levels of investigation into sustainability and efficiency practices across the region.

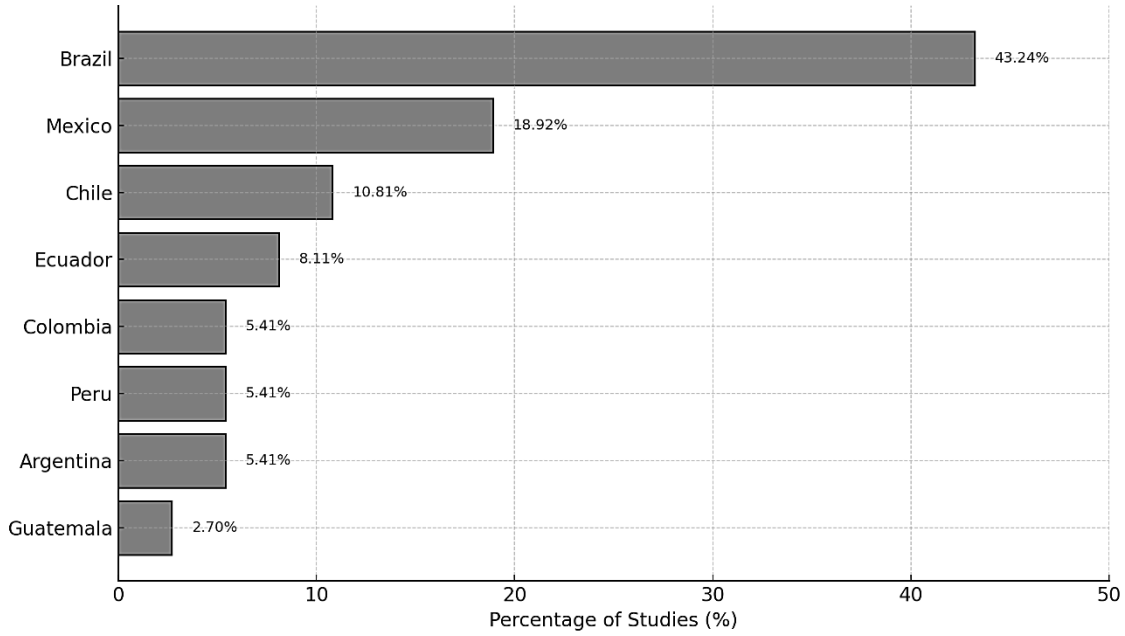

Figure 2. Occurrence of works on poultry production chain in Latin América considering 2013-2014.

A temporal analysis of the included articles (2013–2024) reveals a gradual increase in publications over the years, with peaks in 2024, 2019, and 2014, when the highest number of studies is published (Figure 3). Regarding research themes, the selected studies predominantly focus on nutritional strategies (36.2%), disease prevention and welfare practices (32.9%), and environmental sustainability (30.9%). Notable research efforts explore alternative feed ingredients' role, feed additives' impact on poultry performance, and the implementation of circular economy principles to enhance resource efficiency. Additionally, trend was observed suggesting growing scientific interest in optimising poultry production through nutritional innovations, animal welfare improvements, and environmental management strategies.

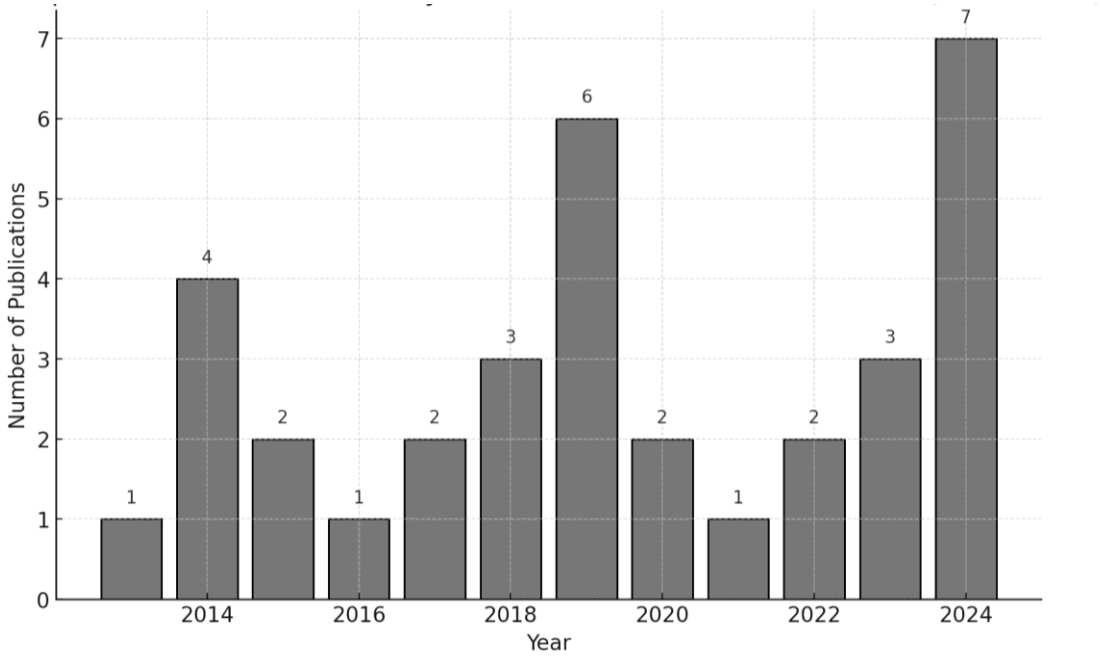

Figure 3. Temporal distribution of publications during the period evaluated (2013-2024).

Data visualisation tools, including QGIS, were used to generate maps and graphical representations illustrating the geographical and thematic distribution of studies. The final distribution of the reviewed articles is summarised in Figure 1 provides a PRISMA diagram detailing the study selection workflow.

6.2.Key findings

The systematic review of poultry production systems (Tables 1 and 2) in Latin America revealed a complex and evolving industry characterised by diverse farming models, genetic specialisation, and an increasing focus on sustainability. The findings indicate that poultry production in the region is largely dominated by industrial or intensive broiler farming, which accounts for 36.73% of the total systems analysed. Similarly, industrial layer farming represents 18.29% of poultry production, reinforcing the predominance of high-output systems designed to meet the increasing demand for poultry products. This trend is driven by the need for efficiency, economic viability, and the ability to maintain competitiveness in global markets. However, the study also highlights the continued relevance of semi-intensive and alternative production systems (22.53%), alongside small-scale family poultry farming (8.16%), which remain significant, particularly in rural areas where poultry farming serves as

a major economic activity for smallholders. These alternative models contribute to local food security and offer opportunities for more sustainable and welfare-oriented production practices.

Table 1. Poultry farming systems and facilities most used in Latin America.

Category of the production system	Percentage (%)*
Industrial or intensive broiler farming	36.73
Industrial layer farming	18.29
Semi-intensive or alternative broiler farming	12.33
Semi-intensive or alternative layer farming	10.20
Mixed, family or small-scale poultry farming	8.16
Other unspecified systems	14.29
Category to facilities	**Percentage (%)***
Conventional poultry houses	25.53
Rustic and backyard poultry houses	13.65
Climate-controlled and automated systems	24.71
Cage systems	23.71
Adapted or alternative poultry houses	9.88
Other unspecified facilities	2.52

* The percentages presented were calculated based on 37 records after applying the selection criteria.

Table 2. Poultry strains are categorized as used in poultry systems of Latin America.

Category related to production system	Percentage (%)*
Broiler chickens with defined lineage (Cobb, Ross and so on)	34.49
Layer chickens with defined lineage (Hy-Line, Lohmann and so on)	33.29
General Layer chickens	10.02
Mixed poultry farming (broilers and layers)	8.16
General broiler chickens	7.43
Poultry farming without specified lineage	5.23
Other poultry production (experimental, wild or unspecified)	1.38

* The percentages presented were calculated based on 37 records after applying the selection criteria.

In terms of infrastructure, the study found considerable variability in the types of housing systems employed across Latin America. Conventional poultry houses are the most frequently

used (25.53%), followed closely by climate-controlled and automated systems (24.71%), demonstrating a transition towards technological advancement in poultry farming. The implementation of climate-controlled systems is particularly relevant in countries with extreme temperature variations, as they contribute to better environmental control, reduced mortality rates, and improved feed conversion efficiency.

However, the persistence of rustic and backyard poultry houses (13.65%) suggests that traditional, small-scale poultry production continues to be an important component of the industry, particularly in rural areas where access to advanced technology is limited. Additionally, cage systems (23.71%) remain widely used in layer production, reflecting the industry's reliance on high-density production methods despite growing concerns about animal welfare and regulatory changes favouring cage-free systems in some markets.

Another critical aspect of the poultry sector in Latin America is the genetic specialisation of poultry strains, which plays a key role in maximising production efficiency. The study revealed that commercial broiler strains (34.49%), such as Cobb and Ross, and commercial layer strains (33.29%), including Hy-Line and Lohmann, dominate the industry, reflecting a strong preference for genetically optimised birds that provide superior feed conversion rates and consistent product quality. However, 10.02% of poultry farms still rely on general layer chickens, and 7.43% on general broilers, indicating that there is still room for improvement in terms of genetic selection and optimisation. The existence of mixed poultry farming systems (8.16%), where broilers and layers coexist, further highlights the diversity of production strategies, particularly in small and medium-scale operations.

Beyond production efficiency, sustainability challenges remain a key concern for the industry. The study underscores the importance of feed optimisation and waste management as central issues that impact both economic viability and environmental sustainability. While the adoption of agricultural byproducts and alternative feed ingredients has been identified as a promising strategy to reduce feed costs and mitigate environmental impact, its implementation remains uneven across the region. Factors such as availability, processing infrastructure, and regulatory frameworks influence the degree to which such sustainable feeding strategies can be integrated into commercial poultry production. Furthermore, animal welfare considerations are gaining traction, particularly within alternative and small-scale production systems, where more extensive farming conditions allow for higher welfare standards. Nevertheless, in intensive systems, the challenge remains to balance high-density

production with improved welfare protocols, particularly concerning space allowance, environmental enrichment, and humane handling practices.

In this scenario, Brazil stands out as the dominant force in poultry production in Latin America and one of the leading global players in the industry. The country benefits from a combination of favourable climatic conditions, vast agricultural resources, and a well-developed production infrastructure, which allow for high productivity and cost-efficient operations. With a strong emphasis on technological innovation, genetic improvement, and optimised nutrition, Brazil has achieved remarkable feed conversion rates and superior poultry growth performance, ensuring its competitiveness in both domestic and international markets. The presence of vertically integrated production systems, which enhance biosecurity, supply chain efficiency, and product standardisation, further reinforces Brazil's leadership in the sector. Additionally, the country plays a crucial role in exporting poultry meat to over 150 countries, with key markets including China, the European Union, and the Middle East, benefiting from rigorous sanitary protocols and compliance with international trade standards. Beyond economic advantages, Brazil has been at the forefront of sustainability initiatives, incorporating circular economy principles, waste reutilisation, and precision farming techniques to mitigate the environmental impact of large-scale poultry farming. These factors collectively position Brazil as a benchmark for efficiency, sustainability, and innovation in global poultry production, setting a model that influences the entire Latin American poultry industry.

7. DISCUSSION

7.1.Dominance of intensive systems and the rise of alternatives

The findings of this systematic review reinforce the predominance of intensive poultry systems in Latin America, particularly industrial broiler (36.73%) and layer farming (18.29%), which are characterised by high productivity, genetic specialisation, and increasing automation (UZUNDUMLU; DILLI, 2023; MARMELSTEIN *et al*., 2024). These systems have driven economic growth in the sector, leveraging improvements in feed conversion, disease control, and infrastructure. However, they also face persistent challenges related to environmental impact, animal welfare, and dependence on conventional feed inputs such as corn and soybean (SILVA *et al*., 2023; RIBEIRO *et al*., 2024).

Despite the dominance of intensive systems, semi-intensive and alternative production models (22.53%), as well as small-scale family farming (8.16%), remain relevant across the region (DIAS *et al*., 2016; ASENCIO *et al*., 2023). These systems are particularly important in rural areas, contributing to food security and income diversification. Moreover, increased consumer awareness regarding sustainable and ethical production practices has led to growing interest in free-range, organic, and agroecological models (CHÁVEZ *et al*., 2017; BRITO *et al*., 2019; SANDRA *et al*., 2023), which, although less productive, align with environmental and welfare standards and show potential for niche market expansion (CORDERO *et al*., 2024; MACHADO *et al*., 2024).

7.2.Infrastructure, welfare conditions, and production contexts

Infrastructure variability is a central feature of the Latin American poultry sector. Conventional housing systems (25.53%) and climate-controlled facilities (24.71%) indicate a movement towards technological modernisation and thermal comfort (COELHO *et al*., 2019), which are especially relevant in regions with high climatic variability (QUEIROZ *et al*., 2017; OLIVEIRA *et al*., 2024). Nevertheless, the persistence of rustic and backyard facilities (13.65%) in remote or underserved regions highlights structural disparities and barriers to innovation (ASENCIO *et al*., 2023).

Welfare concerns are most evident in high-density systems, particularly those using cages (23.71%), where spatial restrictions limit natural behaviours (PAVAN *et al*., 2022). In response, strategies such as environmental enrichment and improvements in housing design are increasingly being explored to mitigate stress and enhance welfare (BARBOSA FILHO *et al*., 2014; NAZARENO *et al*., 2022; RIBEIRO *et al*. 2024). Precision livestock farming technologies, including sensor-based environmental control and automated monitoring systems, also offer promising tools to reconcile welfare and productivity (GAZONI *et al*., 2015; LINS *et al*., 2021; BALTHAZAR *et al*., 2024).

7.3.Genetic specialization and the role of local adaptation

Genetic selection is a fundamental pillar in optimising poultry production efficiency across Latin America. The predominance of specialised commercial broiler strains, notably Cobb and Ross, which together account for 34.49% of broiler systems, reflects a clear industry preference for birds with superior feed conversion rates and rapid growth performance

(REATI *et al*., 2020). Similarly, the widespread adoption of Hy-Line and Lohmann layer strains, present in 33.29% of layer operations, highlights the focus on achieving high productivity and uniform egg quality through genetic standardisation (COELHO *et al*., 2019; REATI *et al*., 2020; LINS *et al*., 2021). These trends are closely linked to the intensification of poultry farming and the demands of large-scale production systems, where genetic uniformity contributes to greater predictability in management and processing.

Nevertheless, the continued presence of general-purpose breeds and mixed farming systems, together representing over 25% of the analysed poultry production models, indicates the persistence and relevance of more diversified genetic profiles, especially among small and medium-scale producers (SÁ *et al*., 2015). These systems are often preferred in extensive or semi-intensive settings due to their adaptability and robustness under variable environmental and nutritional conditions (TAVARES *et al*., 2015). Under such contexts, non-specialised breeds may demonstrate greater resilience to heat stress, disease challenges, and limited feed availability, factors that are particularly relevant in rural or resource-constrained regions (ABREU *et al*., 2019). Thus, while genetic specialisation enhances efficiency in intensive systems, genetic diversity remains an important asset for the sustainability and adaptability of alternative poultry production models.

7.4.Sustainability bottlenecks and circular opportunity

Feed optimisation and waste management are among the most critical sustainability challenges. The reviewed studies point to the potential of agro-industrial byproducts and alternative ingredients to reduce feed costs and mitigate environmental impact (COSTA *et al*., 2015; ESPARZA *et al*., 2019; FERREIRA *et al*., 2019; GROFF-URAYAMA *et al*., 2022; DALÓLIO *et al*., 2024). However, adoption remains uneven, hampered by factors such as processing limitations, supply logistics, and regulatory frameworks (SILVA *et al*., 2016; GUTIERREZ *et al*., 2023; PAVLAK *et al*. 2023). Circular economy practices, such as transforming poultry litter into biofertilizers or energy, represent promising strategies to enhance sustainability and economic efficiency (ALVES *et al*., 2023).

Animal welfare has emerged as a growing concern, particularly as intensive systems face scrutiny over stocking densities, environmental enrichment, and handling practices (BARBOSA FILHO *et al*., 2014; NAZARENO *et al*., 2022; RIBEIRO *et al*., 2024). While alternative farming systems generally provide better welfare conditions, large-scale producers

are increasingly exploring strategies to improve housing, reduce stress, and enhance bird health (PROKOSKI *et al*., 2021; TELES *et al*., 2021; MORGAN *et al*., 2022; BALTHAZAR *et al*., 2024). The implementation of precision livestock farming technologies, such as real-time monitoring of environmental parameters and automated health tracking, offers a promising avenue for maintaining welfare standards in intensive systems without compromising productivity (GAZONI *et al*., 2015; SILVA *et al*. 2015; GAZONI *et al*., 2017; RODRÍGUEZ VERA; HIDALGO BRAVO, 2019; LINS *et al*., 2021).

7.5.Regional disparities and the Brazilian benchmark

A major pattern emerging from the literature is the concentration of scientific production in countries with strong poultry sectors, such as Brazil, Mexico, Chile, and Ecuador (PRINZ *et al*., 2020). Conversely, nations in Central America and the Andean region are underrepresented in the academic landscape, indicating a need for greater research investment and capacity-building (BRAYKOV *et al*. 2016; BARCIA-ANCHUNDIA; MENDOZA-RIVADENEIRA, 2021). Promoting regional integration through collaborative research networks, knowledge exchange, and shared innovation platforms is crucial to democratise access to sustainable poultry technologies (SANTOS *et al*., 2021).

Technological innovation is a key driver of transformation in the poultry sector. The increasing use of automated climate control systems, artificial intelligence for disease detection, and precision nutrition models indicates a shift towards data-driven decision making (LINS *et al*. 2021; MARMELSTEIN *et al*. 2024). However, the review also highlights the barriers to technology adoption, particularly for small and medium-sized producers who lack financial resources and technical expertise (SIDINEI *et al*. 2021). Bridging this gap requires policy interventions, training programs, and public–private partnerships to ensure equitable access to emerging technologies and management practices (SANTOS *et al*., 2021; HORTÊNCIO *et al*., 2022).

Brazil emerges as a central force in Latin American and global poultry production. The country's competitive advantage stems from a combination of abundant feed resources, technological adoption, vertical integration, and genetic improvement (COSTA *et al*., 2015; DALÓLIO *et al*., 2024; MARMELSTEIN *et al*., 2024). Nevertheless, environmental challenges remain, including the management of high volumes of waste, climate-induced stress, and food safety concerns (BRAYKOV *et al*. 2016; ABREU *et al*., 2019; ALVES *et al*.,

2023). While larger companies have implemented advanced solutions in biosecurity and automation, small and medium-scale producers still face constraints in accessing these technologies (SIDINEI *et al*., 2021; HORTÊNCIO *et al*., 2022).

Brazil holds a strategic position as a leader in poultry production and has the potential to drive sustainable development across Latin America by reinforcing its investments in circular economy models, alternative feed strategies, and precision farming (SANTOS *et al*., 2021; PAVAN *et al*., 2022). Through the adoption of innovative practices, such as the use of non-conventional feed ingredients, bioenergy generation, and waste reutilisation, the country can reduce both environmental impacts and production costs, establishing a replicable model for neighbouring nations (FERREIRA *et al*., 2019; ALVES *et al*., 2023). These practices not only align with global sustainability goals but also enhance animal welfare and production efficiency, contributing to a more responsible poultry sector.

Looking ahead, Brazil's continued advancement in biosecurity protocols and disease surveillance is crucial for safeguarding flock health, expanding export capabilities, and opening access to new international markets (HORTÊNCIO *et al*., 2022). At the same time, by sharing technological innovations, genetic improvements, and best management practices, Brazil can promote regional integration and modernisation throughout Latin America's poultry industry (SANTOS *et al*., 2021; PAVAN *et al*., 2022). This collaborative approach fosters economic development while strengthening the region's resilience to market and environmental challenges. Ultimately, Brazil's focus on innovation, sustainability, and market diversification will be key to maintaining its global competitiveness and ensuring long-term viability in poultry production.

8. CONCLUSION

This systematic review highlights the complexity and diversity of poultry production in Latin America. Intensive systems dominate broiler and layer production, driven by specialised genetics, vertical integration, and technological investments. However, alternative models, including family farming and agroecological systems, remain significant, particularly in rural areas. Production infrastructure is highly variable, reflecting regional disparities in technological access. Sustainability remains a cross-cutting challenge, with particular emphasis on waste management, feed formulation efficiency, and improvements in animal welfare. Brazil emerges as the regional leader, demonstrating high productivity and export

capacity, yet facing environmental and structural bottlenecks similar to those of its neighbouring countries.

Ensuring the sustainability of the poultry production chain requires integrated solutions that combine technological innovation, public policy, and context-specific production practices. The adoption of alternative feed ingredients, waste reutilisation, and precision technologies are viable strategies to reduce environmental impacts and production costs. The heterogeneity among production systems calls for differentiated approaches, ranging from training programs for smallholders to incentives for infrastructure modernisation. For policymakers, this review underscores the importance of supporting applied research, promoting sustainable transitions, and enforcing animal welfare regulations. Researchers should explore regional knowledge gaps and deepen integrative approaches. Farmers, in turn, can benefit from context-appropriate best practices aligned with their technological level and socioeconomic conditions.

Despite following robust methodological guidelines, this review has limitations. Restricting the analysis to English-language articles may have excluded relevant studies published in Spanish or Portuguese, introducing potential language bias. Furthermore, most studies originated from Brazil, Mexico, Chile, and Ecuador, with limited data from Central America and the Andean region. Although risk of bias was assessed, variations in methodological quality across included studies may influence the strength of the conclusions drawn.

Future research should prioritise underrepresented countries to provide a more equitable overview of poultry production in Latin America. Comparative studies between intensive and alternative systems could yield valuable insights on productivity, welfare, and sustainability. Cost-benefit analyses of adopting emerging technologies, such as precision nutrition and automated housing systems, are essential to inform strategic investments in the sector. Finally, thematic meta-analyses quantifying the impact of sustainable feeding and management practices on zootechnical, environmental, and economic indicators are encouraged to support evidence-based policymaking.

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CHAPTER 3 - COMMERCIAL AND PRODUCTIVE ASPECTS OF POULTRY FARMING IN THE LEGAL AMAZON

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10. BACKGROUND

The changes in the global macroeconomic environment resulting from market liberalization and globalization have been crucial for stabilizing various economies, particularly in countries of the so-called "Global South" (CLAPP 2009; GERDES *et al*., 2022). These changes have heightened internal competition in these countries due to the opening up to imports and the influx of a wide range of lower-priced and higher-quality products (CLAPP, 2009). However, this stabilization has also challenged the financial gains derived from the speculative market and required companies to focus on achieving profits through productivity gains (PADAYACHEE, 2019; EMENEKWE *et al*., 2022).

Bringing this context to the Brazilian market, the federal units that make up the so-called "Legal Amazon" or "Brazilian Amazon" are characterized by being part of a commercial zone with low or medium participation in the country's Gross Domestic Product (GDP) (NAHUM, 2012; PEREIRA *et al*., 2019; SANTOS *et al*., 2023). Particularly considering the Northern Region of Brazil, where most of the Amazon is within Brazilian territory, it represents approximately 9% of the national GDP (IBGE 2021), showing considerable economic and demographic growth over the past decades. Among the federal units in the Legal Amazon (Figure 1), the states of Pará, Amazonas, and Mato Grosso stand out with the highest participation, with the municipality of Manaus, in particular, having the 5th largest total municipal GDP in Brazil and the 5th highest Brazilian per capita GDP (IBGE 2021; SANTOS *et al*., 2023).

The growth of the primary sector in the Legal Amazon naturally follows this economic and demographic expansion, especially due to the increased regional demand for food and the potential for expanding its commercial frontier, which is dramatically reflected in the local economy (BELUSSO; HESPANHOL, 2010; RODRIGUES *et al*., 2014; CRUZ *et al*., 2016). Bringing this to the context of the poultry production chain, since the 1980s, this activity has been an important segment of the Amazonian primary sector (CRUZ *et al*., 2016; CRUZ *et al*., 2021).

Figure 1. Map illustrating the states that are part of the Legal Amazon, with other biomes (Cerrado and Pantanal) that are also part of them. Legend: AC = Acre; AM = Amazonas; AP = Amapá; MA = Maranhão; MT = Mato Grosso; PA = Pará; RO = Rondônia; RR = Roraima; TO = Tocantins. Source: Santos *et al*. (2021)

Initially, poultry farming met a significant piece of the regional demand for broiler meat and chicken eggs. However, the territories of the Legal Amazon have historically faced various logistical challenges related to the transportation of goods, both for acquiring inputs

and for distributing products (JAFARI *et al*., 2006; CRUZ *et al*., 2016; CRUZ; RUFINO, 2017). For the poultry sector, as with other animal production activities, this becomes a significant issue, as feed accounts for approximately 70% of the total production cost, and many Amazonian territories have to import feedstuffs for animal feed production from other regions, with this dependency potentially reaching 100% importation, naturally increasing production costs even further (SANTOS; GRANJEIRO, 2012; CRUZ; RUFINO, 2017; ANDRADE *et al*., 2023).

As a result, coupled with the expansion of the production frontier in the Central-West, Southeast, and South Brazilian regions, the importation of frozen broiler meat from these regions progressively reduced Amazonian production until it became relatively insignificant in Brazilian production (RODRIGUES *et al*., 2014; CRUZ *et al*., 2016). This development had two important consequences: first, the shift of local producers to other agricultural activities or concentrating solely on egg production, whose peculiarities were more favorable to local development due to the perishable nature of eggs, which require production closer to consumer centers; and second, the change in consumer habits, with the population increasingly opting for frozen chicken due to its advantages and conveniences related to storage and preservation (BELUSSO; HESPANHOL, 2010; CRUZ *et al*., 2013; CRUZ *et al*., 2016; CRUZ *et al*., 2021).

However, with the advent of the 2000s, poultry farming has regained prominence in the Amazonian primary sector. This resurgence is due to both the increased accessibility to technological tools, which help expand the agricultural frontier and seek solutions to logistical problems and production barriers, and the change in the profile of producers, who now focus on meeting growing local demand, and consumers, who value local production for its accessibility to higher-quality, fresher products more quickly, even if at a higher price (CRUZ *et al*., 2013; RODRIGUES *et al*., 2014; CRUZ *et al*., 2021).

11. DISTRIBUTION OF POULTRY PRODUCTION IN THE LEGAL AMAZON

The data from the latest agricultural census conducted by the Brazilian Institute of Geography and Statistics (IBGE 2017) reveal an interesting overview of poultry farming in the Amazon region. Table 1 shows that the Legal Amazon has a total of 54,918 poultry farms, representing a small fraction (1.9%) of the 2,847,573 farms in Brazil. Among the States of the Legal Amazon, Pará leads with 14,765 farms, followed by Maranhão with 13,904 and Mato

Grosso with 7,376. These numbers indicate a significant concentration of poultry farming activities in states such as Pará and Maranhão, while states like Amapá and Roraima have considerably fewer farms, reflecting regional differences in the distribution and organization of this economic activity.

Still in Table 1, when analyzing the poultry flock (that is, the number of birds), Mato Grosso stands out with more than 5.3 million gallinaceous birds, which represents almost half of the total flock in the Legal Amazon. Pará follows with approximately 2.9 million gallinaceous birds. Compared to the Brazilian total, which is over 1.36 billion birds, the flock in the Legal Amazon is relatively small, representing only 8.34%. This suggests that despite the large number of farms, the productive capacity in the region is still limited compared to other regions of the country.

Table 1. Number of farms involved in poultry farming and the number of birds in the poultry flock in the states of the Legal Amazon and the total for Brazil[1].

Species	States	Farms[2]	Birds[2]
Gallinaceous Birds	RO	57.82	6,262.21
	AC	30.29	2,348.65
	AM	36.67	4,279.93
	RR	12.02	1,021.57
	PA	147.65	29,305.17
	AP	3.52	212.30
	TO	48.41	7,097.91
	MA	139.04	9,605.24
	MT	73.76	53,452.17
	Amazon	549.18	113,585.20
	Brazil	2,847.57	1,362,253.51
Quails	RO	0.37	74.04
	AC	0.07	15.43
	AM	0.14	44.50
	RR	0.06	8.35
	PA	0.40	11.21

	AP	0.02	1.77
	TO	0.33	6.11
	MA	0.23	13.21
	MT	0.51	215.97
	Amazon	2.13	390.59
	Brazil	17.63	15,281.68
Turkeys	RO	0.88	4.53
	AC	0.48	2.48
	AM	0.52	3.22
	RR	0.63	3.80
	PA	4.96	38.12
	AP	0.11	0.70
	TO	1.14	6.35
	MA	2.41	13.53
	MT	1.23	7.09
	Amazon	12.36	79.82
	Brazil	82.61	15,636.99
Others[3]	RO	3.90	50.74
	AC	6.53	86.60
	AM	8.96	186.93
	RR	2.98	49.35
	PA	25.70	341.63
	AP	1.33	31.19
	TO	4.04	46.09
	MA	17.30	225.60
	MT	5.48	76.15
	Amazon	76.22	1,094.28
	Brazil	250.36	3,779.13

[1] Data extracted from the 2017 Brazilian Agricultural Census (IBGE 2017).

[2] Values expressed in 1,000 units.

[3] Muscovy ducks, geese, ducks, partridges, and pheasants.

In addition to gallinaceous birds, the Legal Amazon also houses quails, turkeys, and other species such as ducks and geese. However, the number of these birds is quite small compared to gallinaceous birds. For example, the number of quails in the Legal Amazon is only 39,059, representing just 2.56% of the Brazilian total. The low participation of quails and turkeys in the national context reflects a lower diversification in poultry production in the region, possibly due to market limitations or the adaptation of these birds to local conditions.

The percentage analysis (Table 2) shows that while the Legal Amazon has a significant number of farms, its participation in national poultry and egg production is still limited. For example, the region contributes only 1.95% of the country's poultry farms but produces 8.34% of gallinaceous birds, which suggests that, on average, the farms in the Legal Amazon may be smaller or less productive compared to other regions of Brazil.

Table 2. Percentage participation of farms and number of birds of different poultry species in the Legal Amazon relative to the total in Brazil[1].

Species	Farms, %	Birds, %
Gallinaceous Birds	19.29	8.34
Quails	12.08	2.56
Turkeys	14.95	0.51
Others[2]	30.44	28.96

[1] Data extracted from the 2017 Brazilian Agricultural Census (IBGE 2017).

[2] Muscovy ducks, geese, ducks, partridges, and pheasants.

In terms of egg production (Table 3), the Legal Amazon produces about 361.4 million dozen, representing approximately 7.7% of the national production of 4.67 billion dozen. Mato Grosso is the largest producer in the region, with 145 million dozen, followed by Pará with 77 million. These two States together account for more than half of the egg production in the Legal Amazon, indicating that while poultry farming is dispersed, egg production is more concentrated in specific areas.

Table 3. Quantity of eggs produced by chickens in the states of the Legal Amazon and the total for Brazil[1].

States	Quantity (in thousand dozen)
RO	52,943
AC	5,961
AM	42,059
RR	4,492
PA	77,338
AP	302
TO	22,228
MA	11,053
MT	145,073
Amazon	361,449
Brazil	4,672,363

[1] Data extracted from the 2017 Brazilian Agricultural Census (IBGE 2017).

These observed results regarding the distribution of poultry farms and flocks in the Legal Amazon can be explained by a series of socioeconomic, environmental, and logistical factors that influence the concentration of poultry activities in certain territories, especially in the states of Pará, Maranhão, and Mato Grosso. Firstly, the climatic and environmental conditions of these states, with milder temperatures, are more favorable for poultry farming, unlike States such as Amapá, Amazonas, and Roraima, which may face more severe climatic challenges, such as more extreme temperatures and more severe rainfall seasonality, impairing poultry productivity due to the need for more costly resources for artificial environmental control of the poultry houses (SILVA *et al*., 2019; PROCÓPIO; LIMA, 2020).

However, the main factor explaining the prominence of these States is related to the more developed infrastructure and transportation logistics, as Pará, Maranhão, and Mato Grosso have the most developed road networks, ports, and airports in the Legal Amazon, facilitating access to inputs and the marketing of production, making poultry farming a more economically viable activity in these states (RODRIGUES *et al*., 2014; SILVA *et al*., 2019; PROCÓPIO; LIMA 2020). Additionally, the fact that Brazil's agricultural frontier for grain production, such as soybeans and corn, is highly concentrated in these territories also benefits

them, as this availability significantly reduces the cost of diets (BELUSSO; HESPANHOL, 2010; RODRIGUES *et al*., 2014; SILVA *et al*., 2019). Furthermore, the existence of state public policies and tax incentives directed towards agribusiness, stemming from the long tradition in agribusiness that Mato Grosso, Pará, and Maranhão have, may also have favored the expansion of poultry activities in these territories, while the absence of such policies in smaller or more remote states may explain the lower number of poultry farms (BELUSSO; HESPANHOL, 2010; RODRIGUES *et al*., 2014).

In contrast, smaller and more geographically isolated markets such as Amapá, Acre, and Roraima face greater difficulties in making large investments in poultry farming due to logistical challenges caused by their relative geographic isolation and small population, which results in a limited internal consumer market (RODRIGUES *et al*., 2014; PROCÓPIO; LIMA, 2020; SANTANA *et al*., 2020). This results in fewer farms and smaller flocks. The states of Tocantins and Rondônia, despite not facing these significant logistical challenges and being very close to Brazil's major agricultural frontier, which provides them with a natural ability for primary sector activities, face difficulties due to their late development (NAHUM, 2012; PEREIRA *et al.*, 2019). Tocantins only became an official state of the Brazilian federation in 1988, while Rondônia was established in 1956. This late development resulted in a relative delay in the formation of infrastructure that could support a large poultry market (NUNES *et al*., 2011; PEREIRA; NASCIMENTO, 2014; PEREIRA *et al*., 2019; CRUZ *et al*., 2021). However, these states are currently in the process of expanding their poultry production, with significant advances in infrastructure and productivity over the past decades (NUNES *et al*., 2011; CRUZ *et al*., 2021).

Finally, the state of Amazonas presents a unique case in this scenario. While it faces considerable logistical challenges similar to Amapá, Acre, and Roraima, it has a very large internal consumer market, particularly concentrated in Manaus, making it attractive for developing local poultry activities. In this context, large-scale production aimed at export is not attractive to producers in Amazonas due to the high costs associated with the nearly total importation of inputs used in the activity and difficulties in exporting production outside the state (CRUZ *et al*., 2016; SILVA *et al*., 2019; ANDRADE *et al*., 2023), which makes them less competitive compared to producers in Mato Grosso, Pará, and Maranhão. However, the presence of the largest metropolitan area in the Legal Amazon, the city of Manaus with its 2.2

million inhabitants (IBGE 2022), has created a substantial internal demand, stimulating the development of a relatively consistent poultry industry to meet this demand.

As mentioned above, while poultry production from Amazonas may not be competitive in exports, it is highly competitive in its internal market. This is because, just as there are high costs for importing inputs, there are also high costs in importing finished products that could compete with those from local poultry production (CRUZ *et al*., 2016; SILVA *et al*., 2019). The key advantage for local producers in this scenario is the quality of their products, which reach consumers fresher due to the proximity between the farms and local markets (CRUZ *et al*., 2016).

12. PARTICIPATION OF LEGAL AMAZON IN BRAZILIAN POULTRY PRODUCT EXPORTS

When analyzing the data from the annual reports of the Brazilian Animal Protein Association (ABPA) between the years 2014 and 2023 (ABPA, 2014; 2015; 2016; 2017; 2018; 2019; 2020; 2021; 2022; 2023), focusing on the participation of the States of the Legal Amazon in the total number of broilers slaughtered in slaughterhouses with national certification (SIF) in Brazil (Figure 2), which are effectively directed towards export, it is observed that the state of Mato Grosso stands out significantly compared to the others. Mato Grosso shows the highest contribution among the Legal Amazon States, although with a downward trend, decreasing from approximately 4.7% in 2013 to around 3.5% in 2022. However, this decline in the relative participation of Mato Grosso may be related to increased competitiveness from other regions of Brazil, which have also invested in infrastructure and technology for poultry production.

The prominence of Mato Grosso, as previously mentioned in this study, is primarily due to its advanced agricultural infrastructure and its integration into Brazil's major agricultural frontier, such as soybean and corn production, which are essential for feeding broilers, with feed costs representing up to more than two-thirds of total costs (BELUSSO; HESPANHOL, 2010; RODRIGUES *et al*., 2014; SILVA *et al*., 2019). Additionally, Mato Grosso has a more developed transportation infrastructure, facilitating the distribution of its production to both domestic and international markets, strongly positioning it on the map of Brazilian exports (RODRIGUES *et al*., 2014; SILVA *et al*., 2019; PROCÓPIO; LIMA, 2020).

The other States in the Legal Amazon have much lower participation than Mato Grosso, with Rondônia and Pará standing out slightly among them, but still with participation below 1% in most of the analyzed period. The growth in Rondônia and Pará, although locally relevant, still faces significant challenges, such as less developed infrastructure and logistical limitations, which hinder greater growth in the participation of certified slaughters (BELUSSO; HESPANHOL, 2010; NUNES *et al*., 2011; PEREIRA; NASCIMENTO, 2014; RODRIGUES *et al*., 2014; PEREIRA *et al*., 2019; CRUZ *et al*., 2021).

States of Amapá, Acre, and Amazonas have almost insignificant participation, reflecting the lower relevance of these States in the national scenario of slaughtered, certified, and exported broilers. This phenomenon can be attributed to geographical isolation, limited access to inputs and markets, and lower investments in the poultry sector for meat production in these markets (RODRIGUES *et al*., 2014; CRUZ *et al*., 2016; PROCÓPIO; LIMA, 2020; SANTANA *et al*., 2020). It is also important to mention that Maranhão and Roraima have appeared in the statistics after 2020, indicating a movement, although still very small, towards the growth of the poultry sector in these States. This suggests that there is an opportunity for the growth of the poultry sector in these States, especially if investments are directed towards improving infrastructure and incentive policies that make poultry farming more competitive (PEREIRA *et al*., 2019; CRUZ *et al*., 2021). Expanding the domestic market and developing technologies that enable more efficient and sustainable production can also open new opportunities for these States.

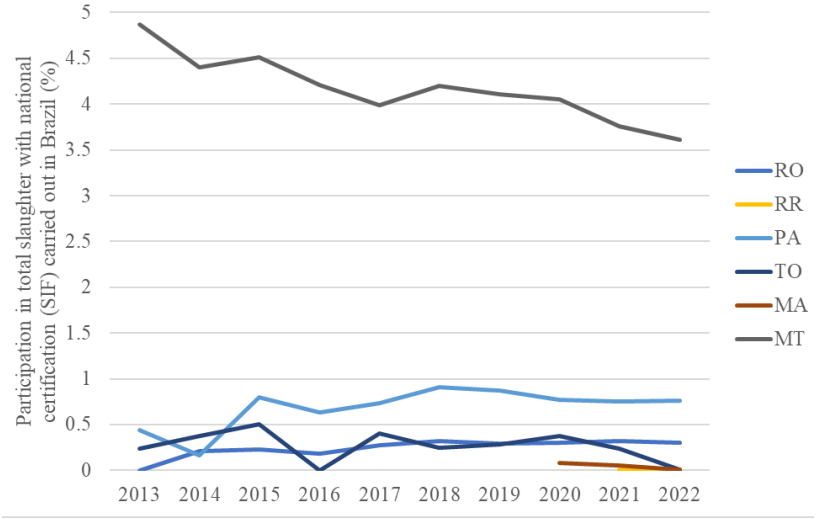

Figure 2. Graph illustrating the participation of the states of the Legal Amazon in total slaughter of broilers with national certification (SIF) carried out in Brazil (%). Source: Annual Reports from ABPA (2014; 2015; 2016; 2017; 2018; 2019; 2020; 2021; 2022; 2023)

When analyzing the participation of the Legal Amazon States in the total number of birds housed for egg production in Brazil from 2013 to 2022 (Figure 3), which is a significant indicator for egg production, it is observed that the state of Mato Grosso also stands out significantly compared to the others. Mato Grosso shows the highest individual contribution among the Amazon states, maintaining a certain stability over the years. As seen in the broiler segment, this is primarily due to the advanced agricultural infrastructure in the state, which facilitates access to essential inputs such as high-quality feed, as well as efficient logistics for production outflow (BELUSSO; HESPANHOL, 2010; RODRIGUES *et al*., 2014; SILVA *et al*., 2019; PROCÓPIO; LIMA, 2020). The stability observed over the years may reflect the maturity of the poultry sector in the state, where producers have already consolidated their operations and found ways to maintain competitiveness, mainly specializing in exports. Annual reports from ABPA show that Mato Grosso is the only state in the Legal Amazon contributing to national egg exports, and it also has a significant share in this statistic.

The state of Amazonas, despite facing logistical challenges similar to other States in the Amazon, such as geographic isolation and high input costs (CRUZ *et al*., 2016; SILVA *et al*., 2019; ANDRADE *et al*., 2023), manages to maintain a consistent share in egg production. This is mainly due to the large internal consumer market, especially in the metropolitan region of Manaus, which drives local demand (CRUZ *et al*., 2016). The emergence of the state of Pará in national statistics from 2020 indicates recent development in egg production, possibly driven by investments in infrastructure and incentive policies (SILVA *et al*., 2019). For States with lower participation, such as Acre, Roraima, and Amapá, there are growth opportunities if improvements are made in transportation infrastructure and incentives for sector development. Additionally, adopting technologies that allow for more efficient production and strengthening local markets can open new opportunities for these States to expand their participation in the national scenario.

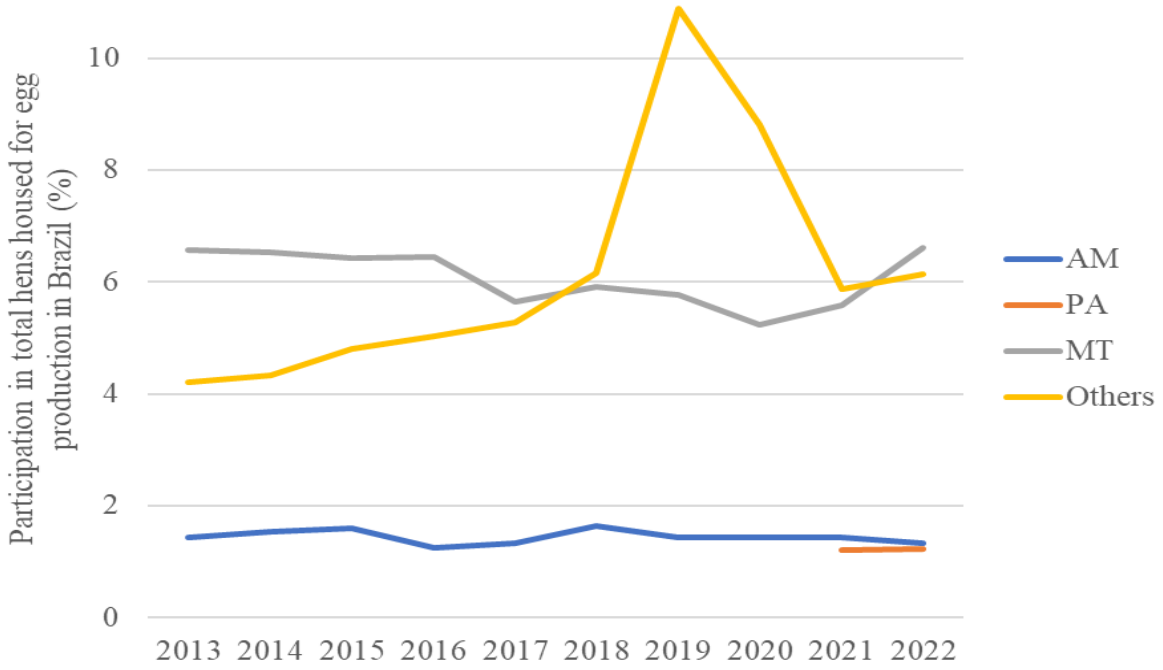

Figure 3. Graph illustrating the participation of the States of the Legal Amazon in total hens housed for egg production in Brazil (%). Source: Annual Reports from ABPA (2014; 2015; 2016; 2017; 2018; 2019; 2020; 2021; 2022; 2023)

13. MAIN CHALLENGES AND OPPORTUNITIES IN POULTRY FARMING IN THE LEGAL AMAZON

Poultry farming in the Legal Amazon presents a unique combination of challenges and opportunities that impact its development and sustainability. One of the main positive aspects is the possibility of integrating poultry production with the region's sustainable development (CRUZ *et al*., 2016; CRUZ *et al*., 2021). This integration can be made possible by combining traditional agricultural practices with advanced management techniques and technologies, allowing for environmental preservation while maintaining high productivity (NUNES *et al*., 2011; PROCÓPIO; LIMA, 2020; CRUZ *et al*., 2021). However, the ecological sensitivity of the Legal Amazon requires a careful approach to avoid environmental damage, particularly regarding waste management and the use of natural resources (MONTEIRO NETO, 2001; CRUZ *et al*., 2013; CRUZ *et al*., 2016; SANTANA *et al*., 2020).

The inadequate infrastructure in the Legal Amazon represents one of the biggest challenges for poultry farming in the region, as issues related to the transportation and distribution of poultry products are frequent due to the lack of an efficient logistics network, including roads and storage systems (PASQUIS 2003; SOUZA *et al*., 2011; PASSOS, 2013;

BARBOSA; PRADO, 2014). This deficiency not only increases operational costs but also affects the competitiveness of products in both national and international markets (CRUZ *et al*., 2016; PROCÓPIO; LIMA 2020; CRUZ *et al*., 2021; ANDRADE *et al*., 2023). Overcoming these logistical barriers is fundamental for Amazonian poultry production to compete on equal terms with other regions of Brazil.

The commercial challenges faced by poultry farming in the Legal Amazon also include strong competition with other regions of Brazil, where the sector is more developed and consolidated. To overcome this disadvantage, producers in the Legal Amazon need to find ways to add value to their products, for example, through production diversification with the offering of eggs and special cuts of meat (BELUSSO; HESPANHOL, 2010; OLIVEIRA *et al*., 2015; CRUZ *et al*., 2016; CRUZ *et al*., 2021). This strategy can help differentiate the region's products and increase their profitability.

However, in the national market, poultry farming in the Legal Amazon has significant potential, especially for supplying its local consumer market. There are promising opportunities for expanding both its production frontier and consumer market, provided there are investments in certifications and improvements in production processes, which are essential to gain and maintain consumer confidence (BELUSSO; HESPANHOL, 2010; NUNES *et al*., 2011; PEREIRA; NASCIMENTO, 2014; RODRIGUES *et al*., 2014; PEREIRA *et al*., 2019; CRUZ *et al*., 2021).

In this context, implementing public policies is crucial for developing poultry farming in the Legal Amazon (BENATTI *et al*., 2003; BECKER, 2010). Measures such as subsidies for small producers, tax incentives, and investments in infrastructure and technology can help overcome some of the challenges faced by the sector (FRANCO *et al*., 2014; ARANDA *et al*., 2017). These policies should aim at creating a more favorable environment for the growth of poultry production, promoting the competitiveness and sustainability of the activity in the region (DEMATTÊ FILHO; MARQUES, 2015; CRUZ *et al*., 2016; CRUZ *et al*., 2021).

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CHAPTER 4 - DIAGNOSIS OF THE LAYER POULTRY PRODUCTION CHAIN IN AMAZONAS, BRAZIL: AN ECONOMETRIC AND MARKET ANALYSIS

15. METHODOLOGY

The profile of the layer poultry production chain in the state of Amazonas was initially characterized according to the territorial division by microregions adopted by the Institute of Sustainable Agricultural and Forestry Development of the State of Amazonas (IDAM), as presented in Figure 1. The period considered was from 2000 to 2023, taking into account the accumulated values from January to December in each of these years. The choice of this time frame was due to the availability of data.

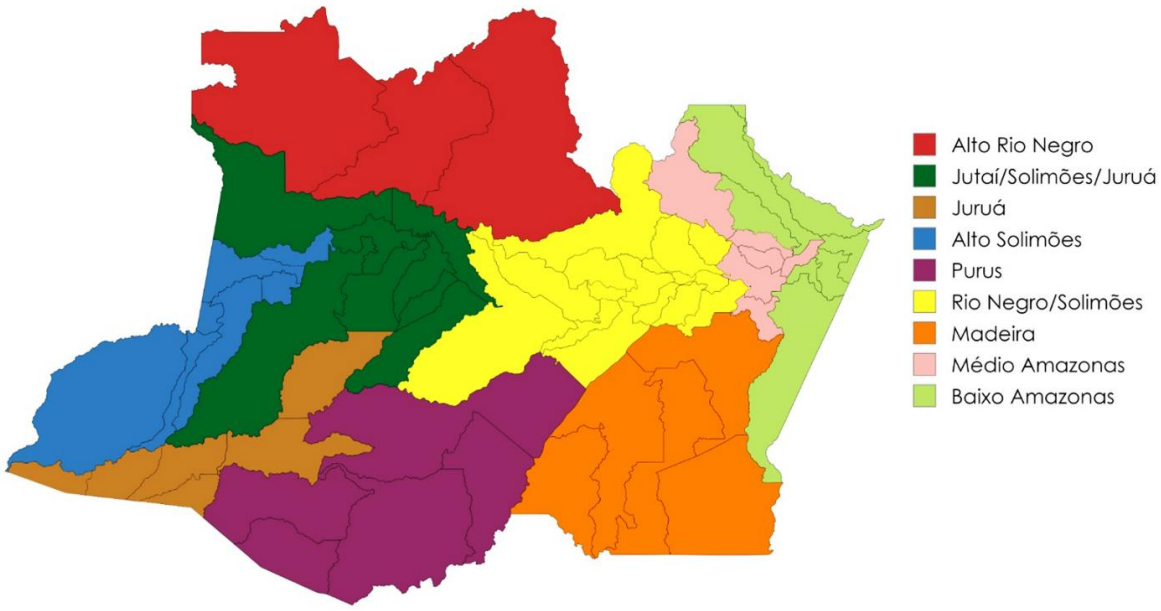

Figure 1. Territorial division adopted by IDAM considering the distribution of municipalities along the river basins. Source: Own elaboration.

The data used in this research are secondary in nature and were obtained from IDAM, which collected them through questionnaires applied to active producers in the layer poultry chain located in all municipalities of Amazonas and affiliated with its local units. It is important to emphasize that IDAM is the institution responsible for collecting data from the primary sector of Amazonas, with offices and technical staff present in all its municipalities. The data collected were obtained by the researchers for processing and analysis of the material under study.

The data were initially grouped by municipality from the samples collected through the questionnaires, considering production, the number of active producers, and flock size, and were then aggregated by microregion according to the territorial division adopted by IDAM, as described above. In the descriptive presentation of the data, the annual production of layer poultry in each microregion of Amazonas was evaluated as a percentage of the total production (in millions of units) for each year analyzed. The number of active producers in this production chain was evaluated in absolute terms, as was the flock size (in thousand units). The productive yield of the activity was also calculated based on the percentage of eggs produced in relation to the flock size throughout the year (365 days).

Finally, based on the data obtained from IDAM, along with per capita income data (per capita GDP of each municipality) obtained from the Secretariat of Development, Science, Technology, and Innovation of the State of Amazonas (SEDECTI-AM), a log-log econometric model was built with absolute data structured in panel form, referring to egg production by microregion of Amazonas from 2000 to 2023, according to the following algebraic structure:

$$lnY_{it} = \beta_1 + \beta_2 lnProd_{it} + \beta_3 lnAnim_{it} + \beta_4 lnRen_{it} + \beta_5 lnRendProd_{it} + \beta_6 lnPre_{it} + u_{it} \quad (1)$$

Where:

lnY = natural logarithm of egg production.

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

lnAnim = natural logarithm of the number of birds housed 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 product and *t* represents time (years), while β denotes the parameters estimated by the econometric regression model.

This model was based on panel data analysis. This choice was made because panel data analysis allows the same cross-sectional unit (a country, a state, or a company) to be monitored over time. Thus, panel data analysis provides two dimensions: spatial and temporal

(WOOLDRIDGE, 2005; GUJARATI; PORTER, 2011). The econometric model was initially designed in three primary specifications using the Gretl software (Gnu Regression, Econometrics and Time-series Library v. 2023): the pooled model (Ordinary Least Squares – OLS), the fixed effects model, and the random effects model. To select the model that best fit the data and expressed its behavior, the Chow, Breusch-Pagan, and Hausman tests were performed, as described by Gujarati and Porter (2011), at a 5% significance level. Multicollinearity was assessed through the Variance Inflation Factor (VIF) analysis, where values greater than 10 could indicate a collinearity problem (WOOLDRIDGE, 2005; GUJARATI; PORTER, 2011), and by constructing the correlation matrix among the analyzed variables. Heteroskedasticity was evaluated using White's test at a 5% significance level. It is worth noting that, as this is a log-log model, the coefficients of the independent variables represent the percentage change in productivity for each 1% increase in the proposed independent variable (GUJARATI; PORTER, 2011).

To support the analysis, particularly regarding market perspectives of the layer poultry production chain in Amazonas, additional data were also gathered from reports and technical staff of the following institutions: Brazilian Agricultural Research Corporation (EMBRAPA – Western and Eastern Amazon Units), Brazilian Institute of the Environment and Renewable Natural Resources (IBAMA), Brazilian Institute of Geography and Statistics (IBGE), and the Federation of Agriculture and Livestock of the State of Amazonas (FAEA). These secondary data were used to understand the production chain in terms of its structure, production flow, key territories, standard production process, and target markets (commercial reach).

16. RESULTS AND DISCUSSION

Evaluating the annual results of layer poultry production in Amazonas (Table 1, Figure 2), it is possible to observe an unstable pattern over the years, with periods of increase and decline depending on the year analyzed. This instability may be related to several factors, such as variations in input costs, adverse climatic conditions, fluctuations in market demand, common in agricultural chains, and logistical challenges characteristic of the Amazon region (CRUZ *et al*., 2016; DIAS; CARVALHO, 2017; WILLERDING *et al*., 2020; MEDINA; CRUZ, 2021; CABRAL *et al*., 2023). It was also observed that there was a significant concentration of production in the Rio Negro/Solimões microregion throughout the period from 2000 to 2023, with this microregion showing the highest production in the state in all the years evaluated. Other microregions that also

stood out either in specific periods or through consistent production across the historical series analyzed were Médio Amazonas, Alto Solimões, and Baixo Amazonas.

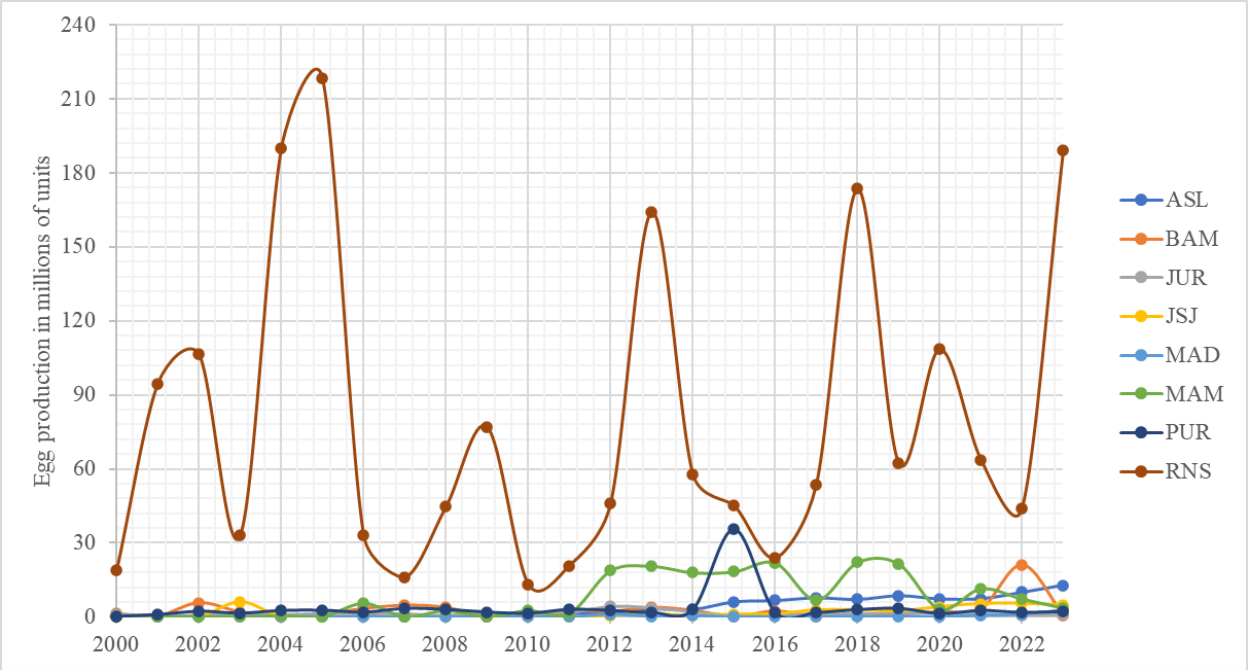

Figure 2. Annual egg production (in millions of units) in the microregions of Amazonas from 2000 to 2023. Legend: ARN = Alto Rio Negro; ASL = Alto Solimões; BAM = Baixo Amazonas; JUR = Juruá; JSJ = Jutaí/Solimões/Juruá; MAD = Madeira; MAM = Médio Amazonas; PUR = Purus; RNS = Rio Negro/Solimões.

Table 1. Percentage share of each microregion in layer poultry production in Amazonas between 2000 and 2023.

Year	Microregions									Total (in millions of units)
	Alto Rio Negro	Alto Solimões	Baixo Amazonas	Juruá	Jutaí/Solimões/ Juruá	Madeira	Médio Amazonas	Purus	Rio Negro/Solimões	
2000	0.00	0.00	5.86	4.70	0.00	0.00	0.33	0.98	88.13	21.51
2001	0.00	0.00	0.35	0.27	0.00	0.00	0.03	0.96	98.39	96.17
2002	0.00	0.00	4.97	0.43	0.00	0.01	0.02	1.97	92.60	114.80
2003	0.00	0.98	4.32	2.13	13.71	0.07	0.00	3.43	75.36	43.76
2004	0.00	0.16	0.04	0.36	0.01	0.03	0.22	1.33	97.85	194.24
2005	0.00	0.01	0.43	0.54	0.00	0.00	0.07	1.19	97.76	223.27
2006	0.09	0.68	7.29	2.93	0.02	0.22	12.15	4.18	72.44	45.42
2007	0.00	0.63	18.38	4.21	0.39	0.12	0.35	13.42	62.50	25.41
2008	0.00	0.13	6.92	0.83	0.02	0.02	4.70	5.51	81.87	54.45
2009	0.05	0.12	0.00	1.90	0.00	0.00	0.12	2.39	95.42	80.59
2010	0.00	2.47	0.00	5.32	0.00	0.00	13.82	7.80	70.59	18.60
2011	1.46	4.96	7.77	5.16	0.35	0.06	4.46	9.68	66.10	31.42
2012	0.39	2.38	2.79	5.40	0.59	1.40	24.28	3.35	59.42	77.39
2013	0.02	1.60	1.90	1.85	0.63	0.11	10.37	0.88	82.64	198.63
2014	0.00	3.45	2.97	2.22	0.49	0.63	20.62	3.47	66.15	87.20
2015	0.00	5.71	0.01	0.51	0.97	0.02	17.20	33.26	42.32	106.55
2016	0.00	11.29	3.96	1.81	2.03	0.02	37.44	2.99	40.46	58.62
2017	0.01	10.47	0.07	1.14	3.73	0.00	9.10	2.37	73.11	73.51
2018	0.02	3.36	0.34	0.57	1.36	0.00	10.52	1.39	82.44	210.45
2019	0.00	8.52	0.88	1.34	2.39	0.19	21.36	3.39	61.93	100.78
2020	0.00	5.69	1.66	1.20	3.15	0.09	2.45	1.05	84.71	128.10
2021	0.00	7.75	3.44	1.16	5.57	0.59	12.00	2.70	66.79	95.34
2022	0.00	10.88	23.15	0.78	5.88	1.18	7.96	1.96	48.21	91.53
2023	0.16	5.91	0.31	0.48	2.18	1.33	1.64	0.99	87.00	217.44

Source: Institute of Sustainable Agricultural and Forestry Development of the State of Amazonas. Data collected between 2000 and 2023 and processed in 2024.

According to Cruz *et al*. (2016), the fact that egg production in Amazonas is concentrated mainly in the Rio Negro/Solimões microregion is due to this microregion encompassing the city of Manaus, the largest metropolis in the Amazon region and the capital of Amazonas. Manaus concentrates a large share of the population as well as the state's financial, commercial, and logistical resources, in other words, it represents the largest local consumer market.

Furthermore, the authors point out that, given this market attraction, layer farms were established in the rural areas of Manaus, in the rural areas of surrounding municipalities that form the metropolitan region, or in the rural areas of municipalities with favorable logistical connections to Manaus for both product distribution and input acquisition, which is the case for those located in other highlighted microregions. These results highlight three key factors that help explain the concentration of egg production in Amazonas, particularly in the Rio Negro/Solimões microregion: 1) the geolocation of the municipalities that make up these microregions, which account for the state's largest population concentration and, consequently, the greatest potential consumer market; 2) these municipalities possess the best infrastructure in the state for obtaining inputs and accessing the consumer market through terrestrial or river transport, the main modes used in the region, thereby providing greater opportunities for the development and expansion of the production chain; and 3) government incentives and public policies targeted to this production chain, especially within these territories (CRUZ *et al*., 2016; TREMEA; SILVA, 2020; CAVALCANTE *et al*., 2024).

It is important to note, however, that even with significant development and expressive production levels in these microregions, the layer sector still faces bottlenecks that hinder further expansion. These include problems with energy supply in northern Brazil (CRUZ *et al*., 2016), environmental challenges and climate change in the Amazon region (MALHI *et al*., 2008; MARENGO *et al*., 2018), the lack of an accessible network of specialized laboratories for pathological and nutritional analyses (CRUZ *et al*., 2016), extremely high production costs due to dependence on imported inputs (CRUZ *et al*., 2016; CRUZ; RUFINO, 2017), the limited availability of specialized public technical assistance for small and medium-sized producers (CRUZ *et al*., 2013; CRUZ *et al*., 2016), insufficient infrastructure for grain storage and stock formation (CRUZ *et al*., 2016; CRUZ; RUFINO, 2017; ANDRADE *et al*., 2023), and difficulties in accessing inputs during the off-season (ANDRADE *et al*., 2023).

Another important factor influencing egg production in Amazonas is the saturation of the production chain. Since the layer poultry chain is almost exclusively oriented toward supplying the domestic market, once demand was fully met, production expansion faced natural limitations (MANKIW, 2013a; VARIAN, 2023). As a result, growth in production does not necessarily translate into higher profits for producers, because supply matches or even exceeds regional demand, often putting downward pressure on prices (MANKIW, 2013a,b; PINDYCK; RUBINFELD, 2014).

This scenario hinders new investments in modernization and expansion of productive capacity (PINDYCK; RUBINFELD, 2014), which is reflected in the relatively stable totals recorded year after year in Table 1. Moreover, Manaus, which for a long time ranked among the five largest egg-producing municipalities in Brazil (CRUZ *et al.,* 2016), has been outside the top ten for more than five years (IBGE, 2022).

This situation also appears to have influenced the number of active producers in the chain (Table 2), which grew during the period evaluated, especially in the Rio Negro/Solimões and Médio Amazonas microregions, and more recently in Alto Solimões. This suggests a certain attractiveness of the sector for new producers in these territories, although the number of producers remains lower than in other Amazonian primary-sector chains that are more labor-intensive (DIAS; CARVALHO, 2017; CABRAL *et al.,* 2023). However, it is important to highlight that layer poultry farming is a highly technical production chain, in which productive capacity is not necessarily linked to the number of active producers but rather to the adoption of technology, efficient management, and economies of scale (SILVA, 2015; TREMEA; SILVA, 2020).

Thus, a relatively small number of highly skilled producers operating with modern and technological infrastructure, as is the case in the leading microregions, particularly Rio Negro/Solimões, can maintain or even expand production without requiring a large contingent of producers. This contrasts with other Amazonian primary-sector chains that are highly dependent on labor (DIAS; CARVALHO, 2017; WILLERDING *et al.,* 2020; CABRAL *et al.,* 2023). Such a scenario favors the concentration of activity in larger companies, which can optimize resources and achieve high levels of productivity through better management practices, process automation, and investments in bird nutrition and genetics (CRUZ *et al.,* 2016; MANKIW, 2013a; VARIAN, 2023).

This is further evidenced by the results of the number of housed birds (Table 3), showing that the majority of Amazonas' poultry stock is also concentrated in the Rio Negro/Solimões

microregion, with notable participation from Médio Amazonas and, more recently, Alto Solimões. The analysis of average productive yields across the microregions (Table 4) reinforces this finding, as the main producing microregions have maintained average yields above 50% in recent years, demonstrating significant improvements in productive efficiency. It is also important to note that fluctuations in yields during the evaluated period may be associated with factors such as the average price paid to producers and the ease of access to resources in these microregions (MANKIW, 2013a,b).

Therefore, the trend of concentrating production in more structured territories, such as the municipalities of the Rio Negro/Solimões microregion, supports the idea that egg production in Amazonas, similar to other major Brazilian poultry centers, is tied to operational efficiency and distribution logistics rather than simply the number of active producers. Proximity to consumer markets, availability of inputs, and access to more efficient logistics infrastructure are decisive factors for sustaining production growth, even amid fluctuations in the number of producers (PINDYCK; RUBINFELD, 2014; VARIAN, 2023). This context further suggests that both public policies and private initiatives aimed at strengthening the competitiveness of the production chain can be effective when they prioritize measures such as producer training, access to credit for modernization, and incentives for adopting economically sustainable practices, all focused on reducing costs and increasing productive efficiency (SILVA, 2015; CRUZ *et al.,* 2016; TREMEA; SILVA, 2020).

Table 2. Number of active producers in the layer poultry production chain in the microregions of Amazonas between 2000 and 2023.

Year	Microregions									Total (in absolute numbers)
	Alto Rio Negro	Alto Solimões	Baixo Amazonas	Juruá	Jutaí/Solimões/ Juruá	Madeira	Médio Amazonas	Purus	Rio Negro/Solimões	
2000	0	0	2	11	0	0	1	53	66	133
2001	0	0	1	4	0	0	8	23	29	65
2002	0	0	8	5	0	1	2	5	37	58
2003	0	1	19	7	1	2	0	9	17	56
2004	0	1	3	7	2	1	4	21	7	46
2005	0	1	3	12	0	0	3	4	29	52
2006	1	6	2	6	1	4	4	13	47	84
2007	0	3	2	6	1	2	3	10	43	70
2008	0	4	3	10	1	3	3	11	45	80
2009	1	5	0	10	0	0	2	8	60	86
2010	0	41	0	5	0	0	4	8	55	113
2011	6	4	4	4	1	1	3	4	61	88
2012	6	7	1	5	5	1	17	2	24	68
2013	5	17	12	5	7	2	15	5	50	118
2014	0	9	1	2	2	3	12	22	54	105
2015	0	15	9	6	8	1	11	6	72	128
2016	0	12	5	2	5	1	25	4	60	114
2017	1	13	3	3	7	0	17	39	88	171
2018	1	14	5	2	11	0	31	6	148	218
2019	0	12	6	3	4	36	13	13	57	144
2020	0	11	7	4	7	17	12	4	168	230
2021	0	14	16	1	11	2	26	3	132	205
2022	0	14	4	4	9	4	42	4	123	204
2023	5	24	1	8	11	8	37	2	195	291

Source: Institute of Sustainable Agricultural and Forestry Development of the State of Amazonas. Data collected between 2000 and 2023 and processed in 2024.

Table 3. Flock size of birds housed in the layer poultry production chain in the microregions of Amazonas between 2000 and 2023.

Year	Microregions									Total (in thousand birds)
	Alto Rio Negro	Alto Solimões	Baixo Amazonas	Juruá	Jutaí/Solimões/ Juruá	Madeira	Médio Amazonas	Purus	Rio Negro/Solimões	
2000	0.00	0.00	10.00	10.50	0.00	0.00	0.70	5.52	903.10	929.82
2001	0.00	0.06	2.60	9.00	0.00	0.00	51.10	12.00	448.30	523.06
2002	0.00	0.00	18.20	5.50	0.00	1.50	28.30	8.50	1,027.80	1,089.80
2003	0.00	7.00	62.50	11.90	2.00	1.75	0.00	9.50	611.16	705.81
2004	0.00	5.00	22.00	12.00	2.90	0.50	37.50	15.38	907.20	1,002.48
2005	0.00	5.00	38.50	11.00	0.00	1.50	35.50	12.00	979.50	1,083.00
2006	0.30	8.24	40.00	8.00	0.20	0.89	38.00	17.64	174.40	287.67
2007	0.00	2.61	35.00	11.00	2.00	0.84	43.50	20.00	305.95	420.90
2008	0.20	1.22	43.50	10.06	1.70	1.11	46.00	20.00	532.75	656.53
2009	1.00	4.10	0.00	14.50	0.00	0.00	33.80	23.00	470.05	546.45
2010	0.00	11.81	0.00	14.50	0.00	0.00	79.50	17.00	595.62	718.43
2011	6.00	11.00	45.19	13.00	2.10	0.30	26.00	19.31	533.00	655.90
2012	5.69	8.50	10.00	19.40	2.86	5.00	87.00	12.00	212.90	363.35
2013	0.18	14.71	17.52	17.00	5.80	1.00	95.37	8.04	759.97	919.59
2014	0.00	13.93	12.00	9.00	2.00	2.55	83.26	14.05	266.98	403.76
2015	0.00	27.98	0.15	2.59	4.83	0.08	85.01	16.40	209.08	346.12
2016	0.00	29.92	10.46	4.80	5.39	0.03	99.16	7.88	107.20	264.85
2017	0.05	34.76	0.21	3.80	12.36	0.02	30.22	7.87	242.73	332.02
2018	0.22	31.92	3.22	5.40	12.91	0.00	99.96	13.20	783.67	950.50
2019	0.00	38.81	4.04	6.10	10.90	0.86	97.23	15.46	281.83	455.23
2020	0.00	32.91	9.60	6.94	18.20	0.52	14.17	6.05	490.09	578.48
2021	0.00	33.39	14.82	5.00	24.02	2.52	31.67	11.60	287.62	410.65
2022	0.00	44.97	9.57	3.20	24.32	4.88	32.95	24.32	199.31	343.52
2023	1.53	57.37	3.00	4.62	21.12	12.93	15.88	9.66	844.21	970.31

Source: Institute of Sustainable Agricultural and Forestry Development of the State of Amazonas. Data collected between 2000 and 2023 and processed in 2024.

Table 4. Productive yield of the layer poultry production chain in the microregions of Amazonas between 2000 and 2023.

Year	Microregions									Annual average (in %)
	Alto Rio Negro	Alto Solimões	Baixo Amazonas	Juruá	Jutaí/Solimões/ Juruá	Madeira	Médio Amazonas	Purus	Rio Negro /Solimões	
2000	0.00	0.00	34.52	26.40	0.00	0.00	28.18	10.20	5.75	11.67
2001	0.00	0.00	35.41	7.92	0.00	0.00	0.14	20.99	57.83	13.59
2002	0.00	0.00	85.85	24.51	0.00	2.37	0.17	72.72	28.34	23.77
2003	0.00	16.91	8.28	21.40	8.22	5.41	0.00	43.26	14.79	13.14
2004	0.00	17.16	0.88	15.82	1.93	30.25	3.16	45.96	57.40	19.17
2005	0.00	1.22	6.83	29.89	0.00	2.30	1.25	60.82	61.05	18.15
2006	32.88	10.18	22.68	45.62	8.22	29.42	39.80	29.54	51.68	30.00
2007	0.00	17.01	36.52	26.68	13.61	8.61	0.57	46.68	14.22	18.21
2008	0.00	15.94	23.73	12.26	2.41	1.48	15.22	41.11	22.92	15.01
2009	9.86	6.50	0.00	28.82	0.00	0.00	0.79	22.94	44.81	12.64
2010	0.00	10.65	0.00	18.72	0.00	0.00	8.84	23.38	6.04	7.51
2011	21.21	38.82	14.79	34.15	14.79	14.79	14.79	43.15	10.68	23.02
2012	14.45	59.18	59.18	58.97	44.49	59.18	59.18	59.18	59.18	52.55
2013	59.18	59.18	59.18	59.18	59.18	59.18	59.18	59.18	59.18	59.18
2014	0.00	59.18	59.18	59.18	59.18	59.18	59.18	59.18	59.18	52.60
2015	0.00	59.56	18.83	57.21	58.64	59.18	59.07	59.20	59.10	47.87
2016	0.00	60.66	60.66	60.66	60.66	59.18	60.66	60.66	60.63	53.75
2017	60.67	60.66	60.66	60.66	60.66	0.00	60.66	60.66	60.66	53.92
2018	60.66	60.66	61.42	60.66	60.66	0.00	60.66	60.66	60.66	54.00
2019	0.00	60.66	60.66	60.66	60.66	60,66	60.66	60.66	60.66	53.92
2020	0.00	60.66	60.74	60.77	60.66	60.65	60.66	60.66	60.66	53.94
2021	0.00	60,66	60.66	60.66	60.56	60.67	98.96	60.66	60.66	58.16
2022	0.00	60.66	60.66	60.66	60.66	60.66	60.66	20.20	60.66	49.42
2023	61.38	61.39	61.41	61.40	61.40	61.40	61.39	61.40	61.40	61.40
Annual average (in %)	13.34	35.73	39.70	42.20	31.52	28.94	36.41	47.63	45.75	35.69

Source: Institute of Sustainable Agricultural and Forestry Development of the State of Amazonas. Data collected between 2000 and 2023 and processed in 2024.

When analyzing the econometric model (Table 5) obtained from production chain data together with per capita income data for each municipality within each microregion (which considered Gross Domestic Product – GDP per capita data) and the average price paid to producers, it was observed that the model was overall significant ($p < 0.05$). The included variables built a model that accurately reflects the reality of the layer poultry production chain in Amazonas. In this model, the null hypothesis was rejected ($p < 0.01$) for all applied tests, indicating that the fixed effects model was the most appropriate panel data specification. Furthermore, the estimated model showed no evidence of heteroskedasticity or positive/negative autocorrelation.

Table 5. Econometric model for total egg production in Amazonas between 2000 and 2023.

Variable	Coefficients	Standard error	p-value	VIF
Constant (β_1)	0.063228	0.280314	0.82	-
Producers	-0.047280	0.010121	0.03	2.435
Animals	1.112290	0.018925	<0.01	4.000
Productive yield	1.073420	0.025557	<0.01	2.157
GDP per capita/Income	-0.008046	0.039648	0.84	1.808
Average price paid to the producer	0.073157	0.016129	<0.01	1.684
Model p-value		<0.01		
R^2		0.99		
p-value of the Chow Test[1]		<0.01		
p-value of the Breusch-Pagan Test[2]		<0.01		
p-value of the Hausman Test [3]		<0.01		
p-value of the White Test [4]		0.06		
p-value of the Durbin-Watson Test - positive[5]		0.98		
p-value of the Durbin-Watson Test - negative[5]		0.99		

[1] H_0: pooled model is better than the fixed effects model.

[2] H_0: pooled model is better than the random effects model.

[3] H_0: random effects model is better than fixed effects.

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

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

Among the variables evaluated, the one that showed the greatest econometric influence on egg production in Amazonas was the number of animals, that is, the volume of the flock available for laying. The coefficient of 1.112 indicates that a 10% increase in flock size results in an 11.12% increase in production, keeping other variables constant. In the same sense, it was also observed that productive yield is crucial for egg production in

Amazonas, with a coefficient of 1.073 indicating that a 10% increase in yield results in a 10.73% increase in production, keeping other variables constant.

These econometric results further reinforce the findings of the descriptive analysis, highlighting the importance of investments in technologies and management practices to improve productivity in the laying poultry chain. Such measures can significantly enhance producer engagement in the activity and, consequently, increase local production (SHUNDALOV, 2022; DUPAS *et al*., 2023). However, it is vital that these advances remain economically sustainable in the medium and long term and that the trade frontier expands in sync with the production frontier to foster the chain and prevent stagnation (DUPAS *et al*., 2023).

As for the price paid to producers, although it also has a positive impact on egg production in Amazonas, its effect is minimal or almost negligible. A 10% increase in the price paid to producers results in less than a 1% (0.73%) increase in production. In other words, even if producers receive more money for their output, it does not lead to a significant rise in the number of eggs produced. This indicates that the price paid to producers is not the main motivating factor for increasing egg production in Amazonas, possibly due to the structural characteristics of the local production chain, which operates with stable and predictable profit margins.

The laying poultry chain in the state demonstrates a strong dependence on productive factors, such as flock availability and bird performance, which have a more direct impact on production than price variations. This can be attributed to the fact that egg production is a continuous-cycle activity, with high fixed costs and a constant need for inputs, such as feed and infrastructure, which are not directly influenced by the final sale price (MANKIW, 2013a; PINDYCK; RUBINFELD, 2014).

Thus, even in the face of product appreciation, producers may face difficulties in expanding their production capacity due to structural limitations such as access to inputs, skilled labor, and adequate logistics infrastructure (SAPSFORD; BALASUBRAMANYAM, 1994; MANKIW, 2013a,b). Furthermore, the supply elasticity of eggs in Amazonas tends to be relatively low compared to other primary sector products, since the decision to increase production involves long-term investments in infrastructure and management, making it difficult to respond quickly to price stimuli (BASU, 2020; VARIAN, 2023).

From another perspective, the influence of the number of active producers on production showed a negative pattern, where each 10% increase in the number of producers leads to a reduction of about 0.47% in egg production in Amazonas, which is a peculiarity of this chain. This behavior can be explained by production fragmentation, where the entry of small producers with lower productive capacity dilutes the total contribution of eggs and reduces average production per producer (MANKIW, 2013a,b).

These new producers, operating on a smaller scale and with less access to modern technologies, face difficulties in achieving the efficiency of large established producers, which negatively impacts average production (PINDYCK; RUBINFELD, 2014). In addition, logistical and infrastructure limitations in Amazonas hinder access to inputs and markets for small producers, which may restrict their ability to compete and produce sustainably. The entry of new producers also increases competition for scarce resources, raising costs and reducing margins, which particularly affects smaller producers and may limit their productive capacity. These factors, coupled with a lack of qualification and technical knowledge among new entrants, create a peculiarity in the laying poultry chain in Amazonas: an increase in the number of producers, instead of boosting production, can lead to a decline in efficiency and a reduction in total production (VARIAN, 2023).

As for the results regarding the income variable, it is important to first consider that this is a relevant measure of the wealth level of a productive population. In the model, the fact that local income shows a negative impact, where each 10% increase in income results in about a 0.08% reduction in egg production, indicates a very small influence of this variable on production.

This effect may be related to technological migration and urban modernization throughout Amazonas. In the microregions that include municipalities with the highest per capita GDP in the state, there is naturally a preference for activities geared toward producing higher value-added goods, to the detriment of primary sector activities and lower value-added goods. Thus, as the per capita income of municipalities and their respective microregions increases, primary sector production, such as eggs, tends to decline, due to labor migration to production chains offering higher remuneration.

Another point to consider is that Amazonas generally shows a per capita income below the national average (IBGE, 2022), with significant problems of unequal income distribution, resulting in a disproportionate concentration of wealth in major urban centers, mainly Manaus and its surrounding municipalities. From the perspective of productive

analysis, this low per capita income in Amazonas may, to some extent, limit producers', especially smallholders', access to inputs, equipment, and technologies, as previously mentioned. This could naturally reduce their egg production or even discourage them from remaining in the activity.

These relationships observed in the econometric model are also corroborated in the analysis of the correlation matrix of these variables (Table 6), where egg production shows a high positive correlation with the number of animals (0.96) and with productive yield (0.81), confirming that flock size and production efficiency are directly associated with production growth. The moderate relationship between production and the number of producers (0.70) reinforces the idea that, although more producers may be associated with production, this variable alone has a negative effect on average efficiency, as observed in the econometric model.

Table 6. Correlation matrix of the variables included in the econometric model for egg production in Amazonas from 2000 to 2023.

Production	Producers	Animals	Prod. yield	Income	Price	Variables
1.00	0.70	0.96	0.81	0.46	0.33	Production
	1.00	0.73	0.48	0.45	0.16	Producers
		1.00	0.63	0.38	0.41	Animals
			1.00	0.54	0.01	Prod. Yield
				1.00	-0.25	Income
					1.00	Price

The per capita income of municipalities shows a moderate correlation (0.46) with production, suggesting that although it contributes to understanding market dynamics, this variable is not as decisive as flock size and productive yield. On the other hand, the average price paid to producers shows a lower correlation (0.33) with production, indicating that it plays a secondary role in directly increasing production, likely influencing more the economic sustainability of the activity than the actual volume produced.

17. CONCLUSION

The research results indicate that the laying poultry production chain in the state of Amazonas is undergoing a process of consolidation as a strategic activity for the regional supply of eggs, playing a relevant role in promoting food security and strengthening local socioeconomic development. Data analysis revealed a high concentration of production in

the Rio Negro/Solimões microregion, mainly attributed to its proximity to the main consumer center (Manaus), the existence of relatively more developed logistics infrastructure, and the presence of public incentive policies, which together create a more favorable environment for the expansion and sustainability of poultry farming in the region.

The analyzed data show that the main determinant factor for increasing egg production in the state of Amazonas is flock size, associated with the zootechnical performance of the birds. These findings suggest that investments in genetic improvement, adequate management practices, and optimized nutritional formulations are fundamental strategies for enhancing sector productivity. However, the high costs of inputs and logistics, resulting from dependence on suppliers located in other regions of the country, remain significant barriers to the competitiveness of egg production in Amazonas, undermining its ability to compete with the country's main production hubs.

Additionally, the study results indicated an inverse relationship between the number of producers and production volumes, suggesting that the high fragmentation of the activity may compromise the sector's productive efficiency. This finding highlights the importance of developing and implementing public policies aimed at technical training, access to continuous technical assistance, and modernization of production infrastructure. Such measures are essential to promote efficiency gains and ensure the economic viability and sustainability of small and medium-sized production units.

Another critical aspect identified refers to the saturation of the domestic market, which imposes limitations on the growth of local production and demands the adoption of strategies aimed at expanding commercial reach into new regional and national markets. In this context, optimizing logistics conditions and diversifying distribution channels are viable alternatives to enable the commercial expansion of the sector. Given this scenario, it is recommended that actions be formulated and implemented to reduce production costs, foster technological development, and design public policies that sustainably strengthen the laying poultry production chain in Amazonas. Such measures are fundamental to promoting the competitiveness and resilience of the sector in the face of structural and cyclical challenges imposed by the regional and national context.

For future research, it is recommended to conduct in-depth studies on the feasibility of using local feed alternatives, with emphasis on the utilization of regional agro-industrial residues, as a strategy to reduce dependence on inputs from other regions and mitigate production costs. Furthermore, it is crucial to explore the potential insertion of the production

chain into external markets by analyzing the main logistical, sanitary, and commercial barriers that may restrict this expansion. Such approaches can contribute to strengthening the economic and environmental sustainability of laying poultry farming in the state of Amazonas.

Another relevant aspect to be considered in future research concerns the analysis of the impacts of climate change on poultry production in the Amazon region, given the growing environmental challenges and the need for adaptation to the region's specific ecological conditions. In addition, research focused on the adoption of emerging technologies, such as automation and the digitalization of production processes, appears promising for improving operational efficiency and promoting the long-term sustainability of the poultry sector.

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19. FINAL CONSIDERATIONS

This dissertation analyzed the dynamics of the layer poultry production chain in the state of Amazonas from multiple perspectives, environmental, technological, zootechnical, economic, and market-related, through an integrated approach that combined a systematic review of poultry production in Latin America, an analysis of the commercial and productive aspects of the Legal Amazon, and an econometric diagnosis of the Amazonas poultry chain based on historical series from 2000 to 2023.

Overall, the results reinforce that poultry farming is a strategic activity for food security and socioeconomic development in the Amazon region. However, the local production chain remains strongly dependent on external inputs, burdened by high logistical costs and structural bottlenecks that limit its competitiveness when compared to other major poultry hubs in Brazil.

The systematic review highlighted the main challenges faced by Latin American poultry production, particularly those related to animal welfare, environmental sustainability, and efficient use of resources. Intensive systems were found to predominate, but alternative models, such as family and free-range production, continue to play an important role in ensuring food security, particularly in rural and peripheral areas.

The analysis of the Legal Amazon showed that poultry production is highly concentrated in certain states, particularly Mato Grosso, Pará, and Maranhão, reflecting better logistical conditions and greater availability of feed grains. This contrasts with the challenges faced in States such as Amazonas, Acre, Amapá, and Roraima. Even so, the region demonstrates growth potential, especially in the layer segment, where proximity to local consumer markets provides a competitive advantage.

The diagnosis of the layer poultry chain in Amazonas confirmed the concentration of production in the Rio Negro/Solimões microregion, where the presence of Manaus as the largest urban and logistical center of the State creates favorable conditions for the development of the activity. The econometric model identified flock size and productive yield as the main determinants of egg production, while the number of producers had a negative effect on efficiency, showing that fragmentation of the activity may compromise economies of scale. Per capita income and producer price had little influence, suggesting that production is more dependent on structural and zootechnical factors than on short-term market stimuli.

From these findings, three strategic axes emerge as fundamental for strengthening the chain: (i) infrastructure and logistics, to reduce transport costs and ensure regular access to inputs; (ii) technological innovation and training, focusing on genetic improvement, nutrition, biosecurity, and adoption of digital technologies; and (iii) public policies and institutional support, expanding credit, encouraging regional feed production, strengthening technical assistance, and promoting value addition and market diversification.

Layer poultry farming in Amazonas shows potential for expansion and consolidation as a strategic activity within the regional bioeconomy, but its long-term sustainability depends on overcoming historical barriers related to dependence on imported inputs, climatic vulnerability, and infrastructure limitations. The future of the sector necessarily requires investments in science, technology, and innovation, as well as alignment with public policies that promote competitiveness while respecting the environmental and social particularities of the Amazon.

Future research should focus on: (a) the use of local agro-industrial byproducts as feed alternatives; (b) the impacts of climate change on poultry production in the region; and (c) the feasibility of integrating Amazonas production into external markets, considering logistical and sanitary barriers. The study of more resilient, efficient, and regionally adapted production systems may contribute to the strengthening of sustainable, economically viable, and socially inclusive poultry farming in the state of Amazonas.