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ADRIELLE RODRIGUES COSTA

ADVANCEMENTS IN BIOLOGICAL SCIENCES

FOR ENVIRONMENTAL AND TECHNOLOGICAL PROGRESS

Atena Editora
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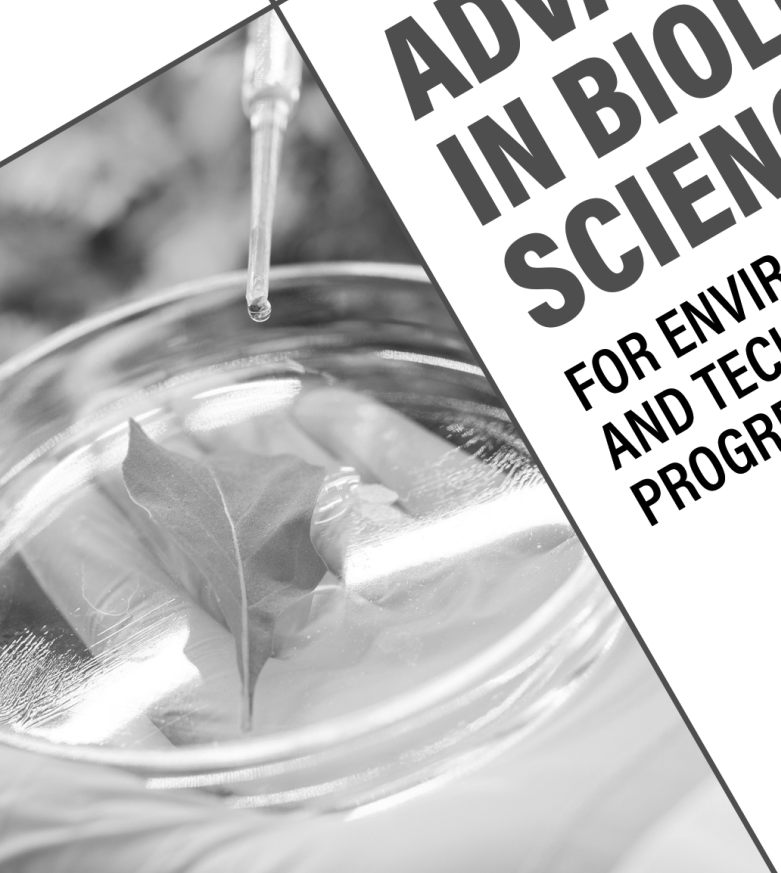

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Este livro reúne uma coleção de estudos interdisciplinares que buscam aprofundar a compreensão sobre temas centrais para a saúde pública, aquicultura e a qualidade ambiental dos ecossistemas aquáticos no Brasil. Organizado em quatro capítulos, a obra aborda desde as questões epidemiológicas e socioeconômicas associadas à esquistossomose no estado do Maranhão até o manejo sustentável em sistemas de aquicultura e pesque-pagues.

O livro é uma colaboração de diversos pesquisadores, unindo esforços para analisar as interfaces entre parasitoses negligenciadas, qualidade da água e práticas de cultivo em ambientes aquáticos, em um esforço para contribuir tanto com a pesquisa científica quanto com a formulação de políticas públicas e estratégias de manejo sustentável.

No primeiro capítulo, os autores apresentam uma análise detalhada da esquistossomose mansoni no estado do Maranhão, com foco no período de 2007 a 2016. A partir de dados epidemiológicos, socioeconômicos e ambientais, são discutidas as tendências de prevalência da doença e os desafios enfrentados para seu controle. O capítulo destaca as regiões mais afetadas e analisa a correlação entre as condições de saneamento básico, coleta de lixo e os índices de infecção. Este estudo é crucial para entender o impacto da esquistossomose em populações vulneráveis e oferecer caminhos para políticas de saúde pública mais eficazes.

Este segundo capítulo complementa a análise epidemiológica do primeiro ao aprofundar a discussão sobre os fatores socioeconômicos que influenciam a disseminação da esquistossomose mansoni no Maranhão. Os autores exploram a relação entre condições de saneamento inadequadas, falta de acesso a água potável e os índices de infecção pela parasitose. Além disso, o capítulo oferece uma reflexão sobre as disparidades regionais e o impacto das políticas de controle da doença nas diferentes microrregiões do estado.

Neste capítulo, o foco desloca-se para a área de produção animal sustentável, explorando o uso de insetos e subprodutos como alternativas para a alimentação de codornas. O estudo apresenta uma análise inovadora do potencial nutritivo e econômico dessas fontes alimentares alternativas, que podem reduzir o impacto ambiental da produção animal convencional. O capítulo aborda a viabilidade técnica e os benefícios ambientais dessa prática, mostrando como a introdução de insetos na dieta de aves pode contribuir para um modelo mais sustentável de produção.

O último capítulo foca na aquicultura e na importância do manejo adequado da qualidade da água em sistemas de pesque-pague no Brasil. Os autores discutem o papel do fitoplâncton na manutenção da saúde dos ecossistemas aquáticos e no sucesso da aquicultura. A qualidade da água emerge como um

elemento essencial para a sustentabilidade desses sistemas, que demandam monitoramento rigoroso para evitar eutrofização e outros desequilíbrios ecológicos. O capítulo também explora as boas práticas de manejo que podem garantir o sucesso econômico e ambiental de pesque-pagues, com base em estudos realizados em várias regiões do país.

A coletânea apresentada neste livro oferece uma visão abrangente de questões fundamentais para a saúde pública, a produção sustentável e o manejo ambiental no Brasil. Através da integração de estudos epidemiológicos, socioeconômicos e ecológicos, a obra pretende ser uma referência para pesquisadores, gestores de políticas públicas e profissionais da área de saúde e meio ambiente que buscam soluções sustentáveis e eficazes para os desafios enfrentados nas suas respectivas áreas.

Adrielle Rodrigues Costa
José Weverton Almeida-Bezerra

SUMMARY

SUMMARY

CHAPTER 1

SCHISTOSOMIASIS MANSONI IN THE STATE OF MARANHÃO, BRAZIL, FROM 2007 TO 2016: TEMPORAL ANALYSIS AND SOCIOECONOMIC FACTORS

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ABSTRACT: Objective: Our aim is to carry out a temporal analysis of the percentage of positivity for schistosomiasis mansoni in the state of Maranhão, Brazil, from 2007 to 2016, highlighting the socioeconomic factors related to the positivity of schistosomiasis in Maranhão. **Methodology**: The indicators of the Control Program on Schistosomiasis were gathered and secondary data on Health Regions and their municipalitieswereanalyzed.The percentage of positivity of the examined population and the coverage of the program were calculated: number of people studied and examined, proportion of endemic/studied municipalities (%) and treatment coverage (%).For the analysis of the positivity trend of schistosomiasis cases over the period, annual percentage change (APC) was calculated. A trend analysis of schistosomiasis correlated with other intestinal parasitic diseases was also carried out.In order to analyze the relationship between the socioeconomic variables of the Health Districts and the positivity rates, the Spearman correlation test was performed. **Results**: In the period, 1,024,413 individuals were surveyed, with 899,672coproscopic exams performed. 34,806 people positive for *S. mansoni* were diagnosed, resulting in a positivity rate of 3.87, which was considered stable over the period.The Health Regions including the municipalities of Baixada Maranhense microregion presented the highest positivity rates. Garbage collection showed a weak correlation with the positivity rate of schistosomiasis. **Conclusions**: Through the data analyses, it was found out that the state showed a tendency towards stability in the positivity rate of schistosomiasis in the period. The microregion known as Baixada Maranhense constitutes an important hostspot of the disease in the state, due to biotic factors associated with precarious environmental conditions and low socioeconomic indicators of the population living in this region, collaborating for this scenario. Therefore, an integrated approach may be necessary for the effective control of the disease in the State.
KEYWORDS: Neglected Tropical Diseases, Epidemiology, Schistosomiasis, Temporal trend.

INTRODUCTION

Schistosomiasis is a helminthiasis transmitted by freshwater snails, whose genera *Biomphalaria* Preston, 1910, *Oncomelania* Gredler, 1881 and *Bulinus* Müller, 1781 are distributed mainly in countries in Africa, Asia and Latin America, including Brazil and affects about 250 million people worldwide[1-3]. Its etiological agent belongs to the genus *Schistosoma* Weinland, 1858, a trematode that, combined with the snail (intermediate host), man (main definitive host) and socio-environmental determinants, establishes a strong epidemiological cycle for the transmission of the parasitosis[4].

It is estimated that the transmission of schistosomiasis in Brazil promotes the infection of 6 million people and that 25 million are exposed to the vulnerability of contracting the disease[5]. The National Survey of Prevalence of Schistosomiasis and Geohelminthiasis, conducted from 2010 to 2014, revealed that the large Southeast and Northeast regions of the country have higher positivity rates, 2.35% and 1.27% respectively. Sergipe (10.7), Pernambuco (3.8), Alagoas (3.4), Minas Gerais (5.8) and Bahia (2.9) showed the highest proportions of positive cases in areas with population of up to 500,000 inhabitants[6].

It is a fact that schistosomiasis is present in Brazil in a more intensified way in the 19 Federated Units, seven of which are located in the Northeast (Pernambuco, Sergipe, Alagoas, Bahia, Paraíba, Maranhão and Rio Grande do Norte). This high prevalence and permanence of the cycle in this region is related to poor basic sanitation, poor access to health centers and delays in diagnosis and treatment[7]. One of the states in the Northeast that has a high occurrence of this parasitosis is Maranhão, where it has been reported since 1920[8]. Of the 217 of its municipalities, it is endemically present in 20 of them and with a focus on 29. The high prevalence is concentrated mainly in the North Coast and Baixada Maranhense region[9].

As it is a disease linked to underdevelopment, the occurrence of schistosomiasis is directly related to its high prevalence in low-income populations, accompanied by factors such as poor sanitation, lack of health education, poor hygiene conditions and the presence of the intermediate host in water collections[10]. With the aim of controlling the spread of the disease in Brazil, the Special Program for the Control of Schistosomiasis (PECE) was created in 1975, replaced in the 1980s by the Program for the Control of Schistosomiasis (PCE), which became a regular initiative of the Ministry of Health (MS)[11]. Currently, disease control occurs through actions carried out at the municipal level, such as demographic delimitation, census coproscopic surveys, treatment of infected people, epidemiological surveillance and annual feed of the PCE Information System (SISPCE)[12].

Given the few epidemiological studies on schistosomiasis in the state of Maranhão, as well as works that carry out a temporal analysis of the disease and the factors that interfere with it, it is extremely important to carry out a thorough verification of the relationship between environmental, social and economic indicators and the number of positive cases of the disease in the state. Thus, the present study aims to carry out a temporal analysis of the percentage of positivity for schistosomiasis mansoni in the state of Maranhão, Brazil, from 2007 to 2016, highlighting the socioeconomic factors related to the positivity of schistosomiasis in Maranhão.

METHODS

An observational analytical study was carried out, with an ecological design, in which secondary data sources were used.

STUDY AREA

The area considered for this study was the state of Maranhão, which has 217 municipalities, spread over an area of 331,936.949 km², being considered the second largest state in the Northeast region and the eighth largest in Brazil. Its population was 6,574,789 people, according to the census carried out in 2010. The composition of the population was 63.08% urban and 36.92% rural. The state's Human Development Index (HDI) is 0.639. The monthly household income per capita is R$ 597.00[13].

Regarding the basic sanitation service, only 19.3% of households in the state had adequate sewage, that is, they use a septic tank or a sewage collection and treatment network[13].

The state is divided into 19 Health Regions (also called Health Regions). The São Luís Region is made up of the state capital and the four municipalities that make up its Metropolitan Region: Alcântara, Paço do Lumiar, Raposa and São José de Ribamar. The Pinheiro and Zé Doca Health Regions cover the largest number of cities: 17 municipalities each. These two regions, together with the Viana Region, cover the municipalities located in the Baixada Maranhense micro-region. For initial analysis, the 19 Health Regions were considered, which constituted the unit of analysis of this study.

STUDY POPULATION

The population included in the analysis was the "population surveyed", denomination given by the PCE-MA, which consists of the number of people who are considered for the coproscopic survey carried out by the program, that is, those who received the container for collecting the material for examination. This population is reached by the active search carried out by the program. Cases notified by SINAN were also included, which are registered by passive demand, that is, when the infected person seeks the health service for diagnosis and treatment of the disease.

VARIABLES ANALYZED

Dependent variable

Within the scope of the PCE, positivity for schistosomiasis is considered the percentage of positive cases recorded over a period of time. For the analysis of the historical series of positive cases of the disease in the Health Regions of Maranhão, the total number of tests performed and the number of people with eggs (1-4, 5-16, ≥17) in the period from 2007 to 2016 were considered.

For the calculation of positivity it was considered:

$$\frac{\textit{number of people with eggs}}{\textit{total number of exams performed}} \times 100$$

The positivity of each Region corresponds to the ratio of the number of cases to the number of tests carried out in the municipalities belonging to it and which had this data. Municipalities that did not present a positivity rate were excluded from the study.

In addition to positivity, the other operational indicators of the PCE were also considered: population surveyed, population examined (exams performed), municipalities studied and endemic, people to be treated between the years 2007 and 2016.

DATA SOURCE

Data reported by the Schistosomiasis Control Program (PCE-MA) of the State Health Secretariat (SES) were collected, between the years 2007 and 2016, made available through the Schistosomiasis Control Program Information System (SISPCE. http: //tabnet.datasus.gov.br/cgi/deftohtm.exe?sinan/pce/cnv/pcema.def). The data are the results of coproscopic surveys and malacological surveys in endemic areas of the State.

The socioeconomic data related to the municipalities included in the Health Regions considered for this research came from the censuses of the Brazilian Institute of Geography and Statistics (IBGE. https://www.ibge.gov.br/pt/inicio.html), through the following platforms: IBGE Automatic Recovery System – SIDRA, IPEADATA and Atlas of Human Development in Brazil. These banks calculate their variables based on microdata from various IBGE surveys (National Household Sample Survey, Demographic Census).

STATISTICAL ANALYSIS

Initially, the operational indicators of the PCE were surveyed, from which the percentage of positivity of the examined population and the coverage of the program were calculated: number of people studied and examined, proportion of endemic/studied municipalities (%) and treatment coverage (%).

For the analysis of the positivity trend of schistosomiasis cases over the period, annual percentage change (APC) was calculated with a confidence interval (CI) of 95%, using the Joinpoint method for modeling, where positivity was considered as a response variable and years as a regression variable. Models were only obtained from those Regionals that had data for the complete series of years.

A trend analysis of schistosomiasis correlated with other intestinal parasitic diseases was also carried out. For this purpose, the Prais-Winsten regression model was considered. To adjust the model, the percentage of positivity on a logarithmic scale was considered as the dependent variable, and the period of the series as the independent variable.The trend was considered stable when the regression coefficient did not differ from zero ($p > 0.05$).

In order to analyze the relationship between the socioeconomic variables of the Health Districts and the positivity rates, the Spearman correlation test was performed, since the data distribution was not normal.

The schistosomiasis trend analysis tests were performed using the Joinpoint Regression Program software, Version 4.7.0.0. (National Cancer Institute. https:// surveillance.cancer.gov/joinpoint/). Correlated trend data (Prais-Winsten regression) were analyzed using the STATA program, version 14.0. The other tests were carried out using the Statistical Package for the Social Sciences software (SPSS. International Business Machines - IBM) and plotted in Microsoft Office package Excel (version 2201, Microsoft, USA).

ETHICAL CONSIDERATIONS

The data used in this research were obtained from secondary sources and in the public domain, in which there is no nominal identification of patients, thus respecting the ethical aspects of Resolution No. 466/2012 of the National Health Council.

Indicator	Description
IDHM	Municipal Human Development Index. Geometric mean of the indexes for the dimensions of Income, Education, and Longevity, with equal weights (Source: Human Development Atlas in Brazil).
Percentage of Urban Population	Ratio between the population living in urban areas and the total population, multiplied by 100 (Source: IBGE, 2010 Demographic Census).
Households with Inadequate Water Supply and Sanitation	Ratio between the number of people living in households where the water supply is not from a general network and the sanitation is not done by a sewerage system or septic tank, and the total resident population in permanent private households, multiplied by 100. Only permanent private households are considered (Source: IPEADATA).
Type of Sanitation	Ratio between the population living in permanent private households according to the type of sanitation and the total resident population in permanent private households, multiplied by 100. The following types of sanitation were considered: General network, Septic tank, Rudimentary cesspit, Ditch, river, lake or sea, and No sanitation (Source: IBGE, 2010 Demographic Census).
Water Supply	Ratio between the population living in permanent private households according to the type of water supply and the total resident population in permanent private households, multiplied by 100. The following forms of water supply were considered: General network, Well or spring on the property, River, dam, lake, etc. (Source: IBGE, 2010 Demographic Census).
Garbage Collection	Ratio between the population living in households with garbage collection and the total resident population in permanent private households, multiplied by 100. Situations where garbage collection is done directly by a cleaning service or collected in a service cleaning bin were included (Source: IBGE, 2010 Demographic Census).
Health and Sanitation Expenditures	Average annual expenditure (in BRL) per municipality between the years 2007 and 2011 on the health and sanitation sectors (Source: IPEADATA).

Table 1. Socioeconomic and Health Indicators of Health Regions

RESULTS

Temporal analysis of *Schistosoma mansoni* positivity from 2007 to 2016 in the state of Maranhão

From 2007 to 2016, the PCE-MA listed 1,024,413 individuals as population surveyed. A total of 899,672 coproscopic examinations were carried out during the period (corresponding to 87.82% of this population). 34,806 people positive for *S. mansoni* were diagnosed in the state of Maranhão between 2007 and 2016. Detailed information on operational indicators can be found in a previously published table.[14].Adopting the positivity calculation, a percentage of 3.87 was obtained for the period under analysis. The highest prevalence rate (4.97) was recorded in 2010 and the lowest (2.54) in 2016 (Figure 1).

The state of Maranhão showed a stable trend in the schistosomiasis mansoni positivity rate (APC = 4.11; CI = -8.5 to 0.5; p > 0.05). The State of Maranhão has always been below the positivity in Brazil, except for 2015, when it was observed that the state positivity (3.23) was slightly above the national positivity (3.16) (Figure 1).

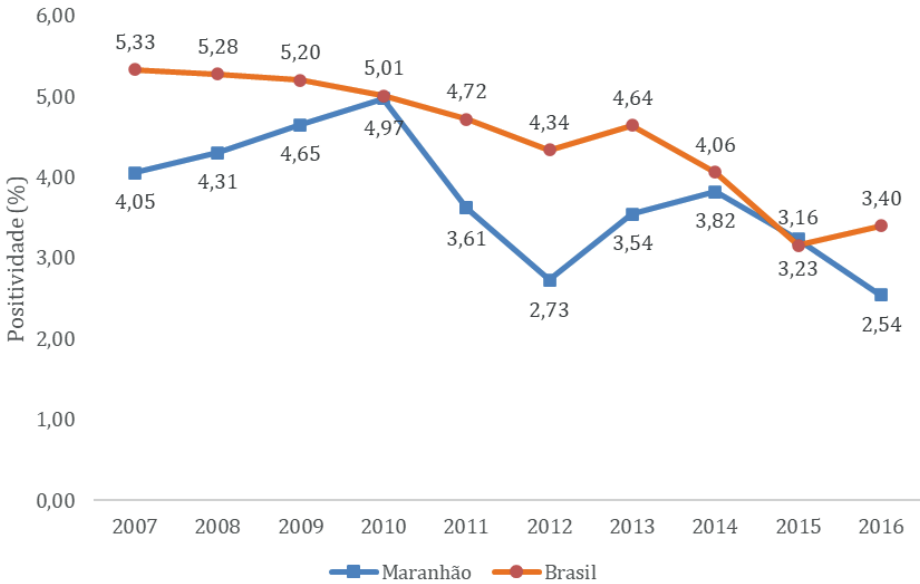


Figure 1. Positivity rates for schistosomiasis in Maranhão and Brazil, 2007-2016

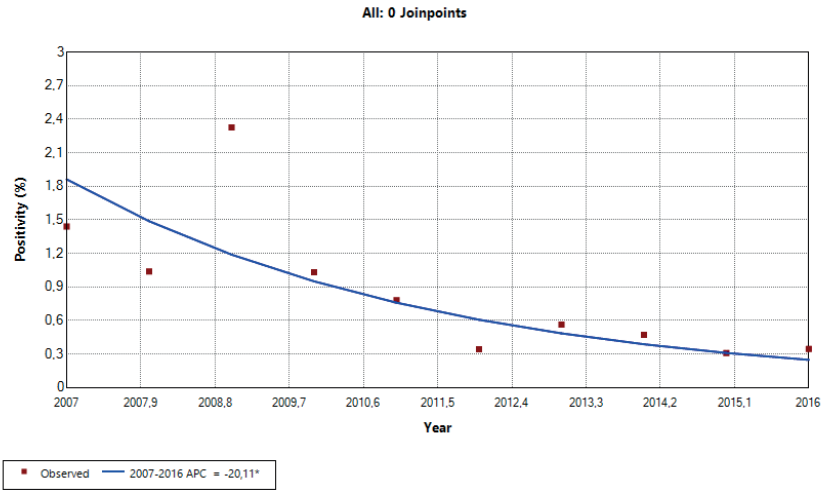
Among the municipalities worked, 87.37% registered positive cases of *S. mansoni* during the period. On average, 77.71% of municipalities recorded positivity rate <5%. The proportion of municipalities that presented positivity ≥5% and <25% was 20.53%. Municipalities with positivity ≥25% and <50% were 1.48%. Only one municipality (Bequimão – HR Pinheiro) had positivity greater than 50% in 2009.

During the period under study, some HR presented significant prevalence rates, as is the case of the Pinheiro Region, followed by the Viana and ZéDoca Regions. The Caxias and Itapecuru Regions had the lowest positivity rates. The Units of Açailândia, Bacabal, Balsas, Codó, Imperatriz, Pedreiras, Presidente Dutra, Santa Inês, and Timon were excluded from the present study due to incomplete or non-computable data.

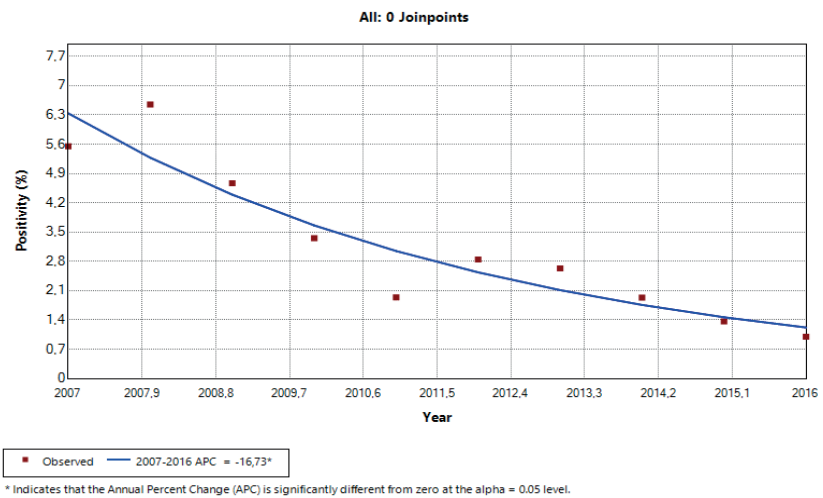
When positivity was analyzed by Health Region, two Regions showed a tendency towards a decrease of cases statistically significant ($p < 0.05$). The São Luís Region demonstrated the greatest downward trend (APC = -20.11; CI= -30.7 to -7.8; $p < 0.05$) (Figure 2a), followed by the ZéDoca Region (APC = -16.72; CI = -22.0 to -11.1; $p < 0.05$) (Figure 2b).

The Regions of Chapadinha, Pinheiro, São João dos Patos and Viana, although showing a reduction in the number of cases, have a stable trend, indicating that these Regions actually have a stationary series. The annual variation rates for these Regions were: Chapadinha (APC = -6.01; CI = -15.9 to 5.0; p > 0.05); Pinheiro (APC= -4.16; CI = -8.6 to 0.5; p > 0.05); São João dos Patos (APC= -4.75; CI= -10.5 to 1.4; p > 0.05); Viana (APC= -2.77; IC= -7.9 to 2.7; p > 0.05) (Figures 2c to 2f). For the other Regions (Barra do Corda, Caxias, Itapecuru-Mirim, Rosário) it was not possible to generate a temporal trend due to insufficient data for the period.

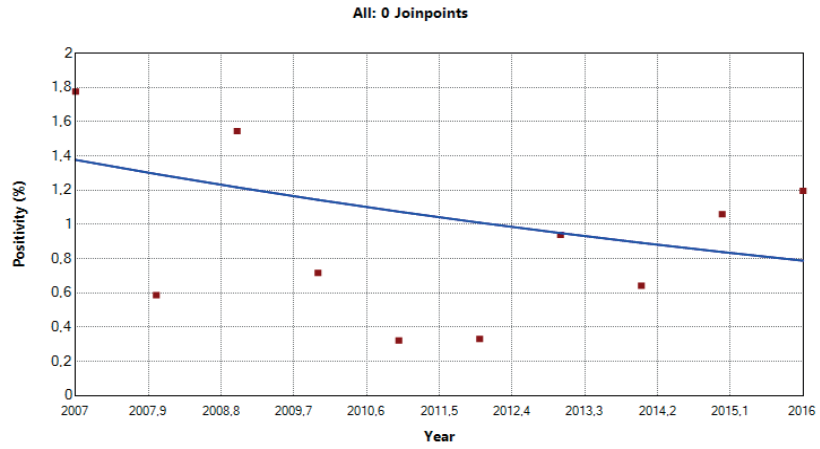
2a) São Luís Regional



2b) Zé Doca Regional

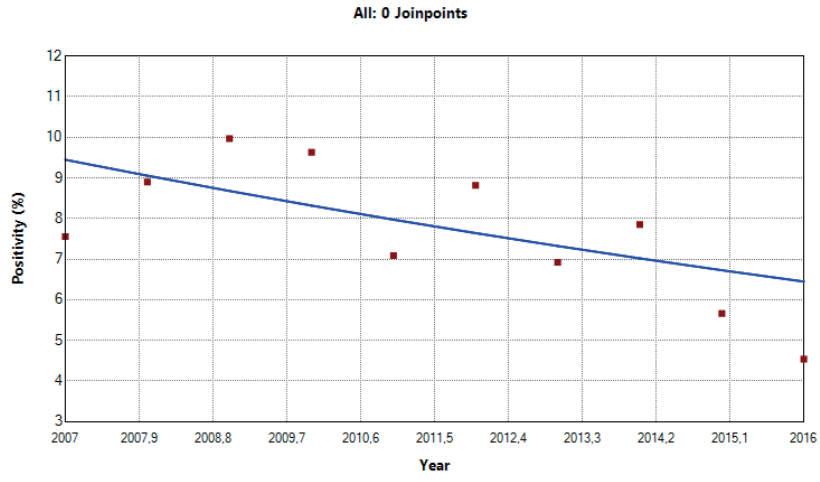


2c) Chapadinha Regional



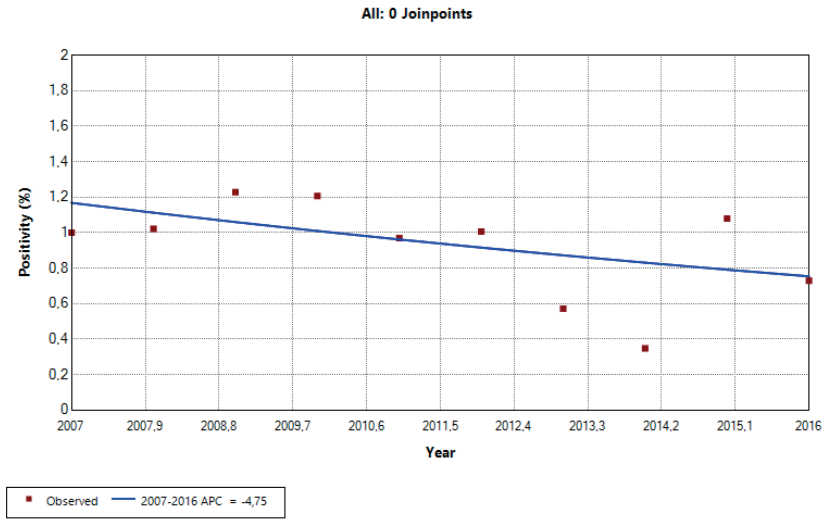
* Indicates that the Annual Percent Change (APC) is significantly different from zero at the alpha = 0.05 level.
Final Selected Model: 0 Joinpoints.

2d) Pinheiro Regional



* Indicates that the Annual Percent Change (APC) is significantly different from zero at the alpha = 0.05 level.
Final Selected Model: 0 Joinpoints.

2e) São João dos Patos Regional



2f) Viana Regional

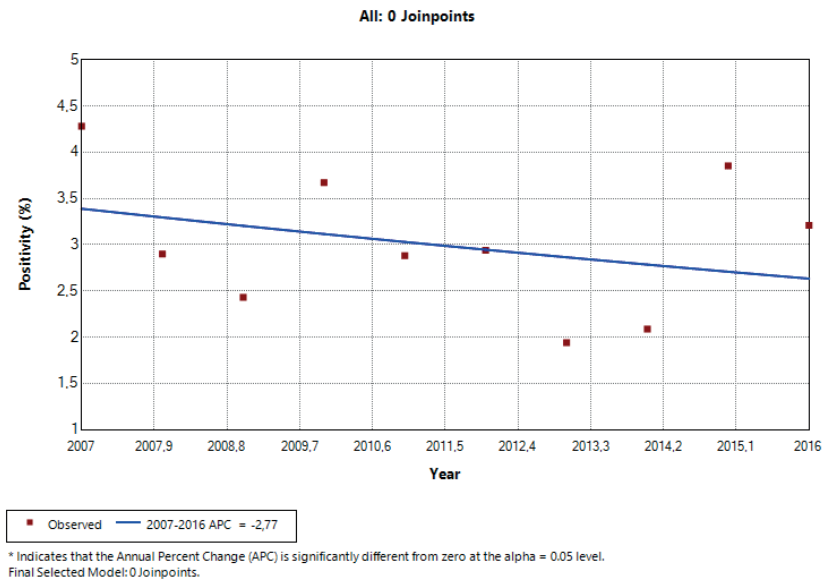


Figure 2. Observed and expected positivity rates by Health Regions of the state of Maranhão, 2007-2016.

When analyzing the trend of schistosomiasis correlated with other parasitic diseases (geohelmintoses) worked on by the PCE in each year of the time series, a change in the disease trend was observed. In this model, an increasing trend was noted in the state of Maranhão (Coef = 0.042; p < 0.001), with an increase rate of 10.27% (Table 2).

The highest rate of positivity growth occurred in the Viana Region, which was 18.61% (Coef = 0.074; p = 0.004), followed by the Regions of São Luís with 14.92% (Coef = 0.603; p = 0.001), Chapadinha, with 14.13% (Coef = 0.057; p < 0.001), Rosário, with 9.47% (Coef = 0.279; p = 0.001), Pinheiro, with 6.18% (Coef = 0.026; p < 0.002) and São João dos Patos, with 4.76% (Coef = 0.129; p < 0.001) (Table 2).

The Regions that showed a stable trend were Caxias (Coef = -0.109; p = 0.084), Itapecuru-mirim (Coef = 0.094; p = 0.077) and Zé Doca (Coef = 0.019; p = 0.673). The only Region that showed a decreasing trend was Barra do Corda, with -6.54% (Coef = -0.029; p < 0.001) (Table 2).

Regionals	Prevalence of schistosomiasis			
	Coefficient	p-valor*	Trend **	Rate of change
São Luís	0.6039	0,001	growing	14,92%
Caxias	-0,1097	0,084	stable	---
Barra do Corda	-0,0293	<0,001	descending	-6,54%
Chapadinha	0,0574	0,041	growing	14,13%
Itapecuru-mirim	0,0941	0,077	stable	---
Pinheiro	0,0260	0,002	growing	6,18%
Rosário	0,2798	0,001	growing	9,47%
Viana	0,0741	0,004	growing	18,61%
São João dos Patos	0,1295	<0,001	growing	4,76%
Zé Doca	0,0191	0,673	stable	---
Maranhão	0,0424	<0,001	growing	10,27%

*Significantly different from zero (p<0.05).**Trends were classified as increasing (p ≤ 0.05 and positive regression coefficient); decreasing (p ≤ 0.05 and negative regression coefficient); and stable (p > 0.05).

Table 2. Prais-Winsten regression model of schistosomiasis prevalence by Health Regions in the state of Maranhão, 2007-2016

Socioeconomic determinants related to the prevalence of schistosomiasis in Maranhão

After correlation analysis, it was found that the indicators water supply, inadequate sanitation and garbage collection showed a weak correlation with the positivity rate of schistosomiasis. The other indicators did not show a significant correlation with the positivity of the disease (Table 3).

The indicator inadequate water supply and sanitation showed a positive correlation with the positivity rate of schistosomiasis in the Regions ($r = 0.3941$; $p < 0.01$). The indicator garbage collection showed a negative correlation with positivity ($r = -0.3092$; $p < 0.05$).

Indicators	r	p-valor
Inadequate water supply and sanitation	0.3941	0.0081
Garbage collection	-0.3092	0.0411

*Indicators that showed a significant correlation.

Tabela 3. Spearman correlation coefficient between the positivity rate and socioeconomic indicators* in Maranhão

DISCUSSION

In a study similar to this, Mendes et al (2022)[14], analyzing the spatial distribution in the state of Maranhão in the same period, reported that the average positivity of schistosomiasis for the state of Maranhão (3.87) remained below the Brazilian average (4.77), only matching this in the years 2010 and 2015. The temporal analysis also showed that although there was a tendency to reduce positivity in Maranhão, this is not significant, concluding that there is a stable trend in the schistosomiasis rate in the state.In fact, another study that analyzed the temporal trends and spatial and spatiotemporal distribution of schistosomiasis mansoni in northeast Brazil between 2005 and 2016 found out that the tendency of the disease in Maranhão was descending, although with a significant difference, indicating that the reduction was real[15].

Between the years of 1947 and 1952, Pellon and Teixeira carried out the first inquiry on schistosomiasis, which comprised nine states of Northeast Region, besides the states of Espírito Santo and Minas Gerais and revealed a prevalence of 10%. Two other inquiries followed this one. The second one (1975-1979), carried out in the context of the implementation of the Special Program for the Control of Schistosomiasis - PECE, examined 447,786 students, from which 30,068 tested positive, reaching a prevalence of 6,7%. The most current Schistosomiasis and Geohelminth Prevalence Survey, which covered all states of the Federation, has surveyed 197,564 schoolchildren aged 7 to 17 years old. The results showed that Northeastern and Southeastern regions of the country had the highest rates of positivity, 1.27% and 2.35%, respectively. The data brought by these surveys reveal that there is a trend of reduction in the rate of positivity of the disease in the country. However, the Northeastern and Southeastern regions still remain important areas for the spread of the endemic disease[16].

When we analyze the international context of the disease, the prevalence of schistosomiasis has also decreased over the years, mainly in South American and Asian

countries. Morocco and some countries in the Caribbean islands have made significant progress in controlling and managing the disease. Brazil, China and Egypt are taking measures to eliminate the endemic disease, such as implementing their own surveillance and control programs, chemotherapy treatment and water distribution through the general network (plumbing). Most sub-Saharan countries, however, still agonize under the weight of the disease[17].

Schistosomiasis is the second most common neglected tropical disease in sub-Saharan Africa. This region is home to 93% (192 million) of the world's 207 million cases of schistosomiasis. The highest prevalence of this infection is seen in Nigeria (29 million), closely followed by the United Republic of Tanzania (19 million), Ghana and the Democratic Republic of Congo (15 million), which make up the top five countries in Africa that record infection. by *S. mansoni*. The main factors responsible for the persistence of schistosomiasis transmission in the region include climate change and global warming, proximity to water bodies, irrigation and dam construction, as well as socioeconomic factors, such as occupational activities and poverty[17].

This scenario with its biotic, social and economic factors is similar to some regions of Brazil, such as the Northeast region, and consequently, the state of Maranhão. The Maranhão Epidemiological Situation Report for 2011 showed that schistosomiasis was considered endemic in 20 municipalities and focal in 29 of the 217 existing municipalities. The North Coast and Baixada Maranhense regions, according to the report, concentrated the oldest epidemics and the highest prevalence rates when compared to others.

Mendes et al (2022)[14] brings similar results, showing that schistosomiasis has two main endemic nuclei in Maranhão, highlighting the epidemiological importance of the Baixada Maranhense, an area considered endemic and comprising the Pinheiro, Viana, and Ze Doca Regions (partially), with positivity rates of 7.69, 3.07, and 3.18 respectively. With more than 500 thousand inhabitants, Baixada Maranhense is a geographic micro-region located on the banks of the GolfãoMaranhense and has a predominantly rural population. The region's economy is largely made up of agriculture, especially family and subsistence agriculture, such as babassu vegetable extraction, artisanal fishing and small family farming. Rice cultivation, for example, has great socioeconomic importance for the region, as families take advantage of the flooded region to grow this crop[18].

The environmental characteristics of the area, added to the economic activities performed there, create a favorable scenario for the spread of several diseases. For example, schistosomiasis was recorded in the area because of the presence of snails *B. glabrata* and *B. straminea*, which are epidemiologically important species of the disease. The presence of floodplains for long periods of the year contributes to the reproduction of those molluscs, which later transmit the disease to humans. Ramos et al. (1970)[19] concluded that floods can promote the spread of schistosomiasis, creating conditions for new outbreaks.

In Maranhão, studies show that the species *B. glabrata* and *B. straminea* cohabit different regions of the state. Cantanhede et al. (2014)[20], in a study on freshwater gastropods in the endemic area of Baixada Maranhense, found the presence of *B. glabrata* specimens in five municipalities, and *B. straminea* in nine. These species were observed in synanthropy in two biotopes in Pinheiro and four biotopes in São Bento. On the east coast of Maranhão, in the municipality of Tutóia, snails of the species *B. glabrata* were found, of which 8.3% were infected by *S. mansoni*[21]. In the city of São Luís, studies identified the two species of gastropods in two neighborhoods on the outskirts of the capital, however, only *B. glabrata* snails were infected[22-24]. Em um estudo sobre a análise epidemiológica da esquistossomose em áreas de risco em São Luís, Nascimento (2011)[25] encontrou que os bairros que apresentaram prevalência mais alta para a doença reuniam as mesmas condições ambientais de cidades do interior do estado.

In addition to environmental factors, socioeconomic characteristics of the municipalities that belong to these Regions also help to explain the maintenance of schistosomiasis in the state. According to Cantanhede et al. (2011)[26] "low socioeconomic development and the absence of health education and sanitation actions are important characteristics in the context of factors that act as determinants for the transmission and establishment of this parasitic disease".

In China, the morbidity and prevalence of helminthiasis has decreased significantly in the last 50 years, being considered one of the most successful countries in controlling these diseases, especially schistosomiasis, which is already in the pre-elimination stage. In addition to routine activities such as chemotherapy, molluscicide treatment in snail habitats and health education, other important interventions including mechanization of livestock farming, prohibition of pastures along rivers, improvement of sanitary conditions through the provision of drinking water, construction of toilets and latrines, construction of gas tanks and the provision of fecal matter containers for fishing boats were integrated into the control of schistosomiasis[27].

The years included in this study correspond to the stage subsequent to the decentralization of the PCE, in which municipalities took over schistosomiasis control actions, starting in 1999. It can be noted that the PCE-MA underwent a broad reduction in its activities throughout the analyzed period. There was a significant reduction in the total number of people worked, exams carried out and the number of people treated.

As measures to prevent and control schistosomiasis, the Control Programs have two main combat fronts: the identification of *S. mansoni* carriers, through biannual coproscopic surveys and the demand for health services and the treatment of carriers to reduce the parasitic load and prevent emergence of severe forms of the disease. In addition to this, other measures must be taken, such as environmental sanitation, which is also listed as one of the main measures in preventing schistosomiasis, as it creates conditions that reduce the proliferation and contamination of intermediate hosts, with a consequent reduction in human contact with transmitting agents (infected snails)[28].

Some special programs have been developed to tackle neglected diseases, as a complement to regular control programs. In the state of Pernambuco, the Sanar Program, established in 2013, aims to reduce or eliminate some neglected communicable diseases as a public health problem. The Program selected 40 municipalities located in endemic areas of Pernambuco, in which actions to control schistosomiasis and geohelminthiasis were intensified. These cities were selected because they had an annual average positivity rate greater than 10%, between 2006 and 2010. A logical model was then used to control the disease, developed within five main components: management, epidemiological surveillance, laboratory support, patient care and health education and communication. The great differential attribute of the program was that, in addition to providing assistance to municipalities, it was also the executor of actions with the development of interventionist activities[29].

In Maranhão, in 2015 the "Mais IDH" Program was launched, which is the current government's main program to combat extreme poverty and social inequalities in the 30 municipalities with the lowest HDI in Maranhão. In the area of health, in addition to other actions, the program proposes to carry out health stations and active search for patients at risk and/or symptomatic for neglected endemic diseases[30].

Based on all these perspectives, investing in the quality of the Schistosomiasis Control Program is essential if managers aim to control the disease in their municipality, district, region or state, following the example of other countries that have already achieved success by applying the necessary efforts to such.

CONCLUSION

It is possible to conclude that the Maranhão State presented a tendency towards stability in the positivity rate of schistosomiasis between 2007 to 2016**.** The Health Regions including the municipalities of Baixada Maranhense presented the highest positivity rates. This fact can be explained by the presence of biotic factors associated with precarious environmental conditions and low socioeconomic indicators of the population living in this region. An integrated approach may be necessary for the effective control of the disease in the state, which can include preventive actions such as sanitation and information, suitable treatment of infected people and strengthening health programs.

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DECLARATIONS OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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CHAPTER 2

SCHISTOSOMIASIS MANSONI IN THE STATE OF MARANHÃO, BRAZIL: AN INTEGRATIVE MINI-REVIEW

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ABSTRACT: Schistosomiasis is a chronic parasitic disease characterized by its significant prevalence, the severity of its clinical forms, and its progression, making it a major public health issue in the country.

The etiological agent is *Schistosoma mansoni*, with snails of the genus *Biomphalaria* serving as intermediate hosts. The endemic disease affects nearly 240 million people worldwide; however, 700 million people live in endemic areas. Currently, schistosomiasis is reported in Brazil across 19 federative units, distributed throughout all regions of the country, making it the largest endemic area in the Americas. In the state of Maranhão, schistosomiasis has been known since 1920. According to a 2011 epidemiological situation report, the disease was considered endemic in 20 municipalities and focal in 29 of the 217 existing municipalities. The species *S. mansoni* is the only one described in Brazil. The lack of sufficient financial investment and trained human resources severely limits the effectiveness of programs in addressing the population's demands for a long-term solution. Consequently, what we see are shallow achievements, never leading to a definitive result. As a disease linked to underdevelopment, to achieve the elimination of schistosomiasis and other infectious and parasitic diseases, governments will need to promote significant improvements in the socioeconomic conditions of the population, along with a safe water supply and sanitation improvements in urban centers and rural areas.
KEYWORDS: Schistosomiasis, Public Health Endemic Disease

GENERAL ASPECTS OF THE PARASITIC DISEASE

Schistosomiasis is a chronic parasitic disease whose magnitude of prevalence, severity of clinical forms, and evolution characterize it as a significant public health problem in the country. Commonly referred to as Bilharzia, Snail fever, and Katayama fever, this parasitosis is part of an important group known as Neglected Tropical Diseases (BRAZIL, 2017; WHO, 2018).

Initially, schistosomiasis is a predominantly rural disease, but it has become urbanized with the extensive migration from rural areas to cities. This process often occurs in an unorganized manner, leading to the formation of peripheral urban conglomerates with no planning. In these areas, the state of basic sanitation, coupled with low levels of education and economic status of the population, creates favorable environmental conditions for the establishment of infectious-parasitic diseases, including schistosomiasis. Thus, it is considered a disease associated with poverty and underdevelopment. People become infected when they come into contact with water infested with the parasite's larval forms. These occurrences are generally linked to labor or leisure activities in rural areas, such as washing clothes, bathing, and fishing, as well as contact with water contaminated by domestic sewage in peripheral urban areas (COLLEY et al., 2014).

Transmission of schistosomiasis occurs through the complex life cycle of the worm, which requires two hosts (an intermediate and a definitive host) as well as specific environmental conditions for infection to occur.

As a strategy for controlling its transmission, various prophylactic measures and treatment methods are required, such as mollusk control, treatment of infected individuals with medication, provision of potable water, adequate sanitation, and health education for exposed populations (WHO, 2018).

EPIDEMIOLOGY OF SCHISTOSOMIASIS

Schistosomiasis is a tropical disease. Endemicity affects nearly 240 million people worldwide, yet 700 million live in endemic areas. Its transmission has been recorded in 78 countries, primarily in Africa and the Eastern Mediterranean, affecting regions such as the Nile Delta and countries like Egypt and Sudan. Estimates show that at least 219.9 million people required preventive treatment for schistosomiasis in 2016, of which 89 million were reported as having been treated. In 2017, 98.7 million people received preventive treatment in 52 countries, where moderate to high transmission is reported (WHO, 2018-A; WHO, 2018-B).

The first recorded case of schistosomiasis in Brazil dates back to 1908, as documented by Pirajá da Silva (BRAZIL, 2014; NEVES, 2016). Currently, schistosomiasis is reported in 19 Federative Units distributed across all regions of the country, making it the largest endemic area in the Americas. However, almost all cases are concentrated in the Northeast and Southeast regions (Figure 2). The occurrence is directly related to the presence of transmitting mollusks. In 2015, the country recorded 459 deaths due to schistosomiasis, with the Northeast and Southeast regions accounting for the majority, with 300 and 147 deaths, respectively.

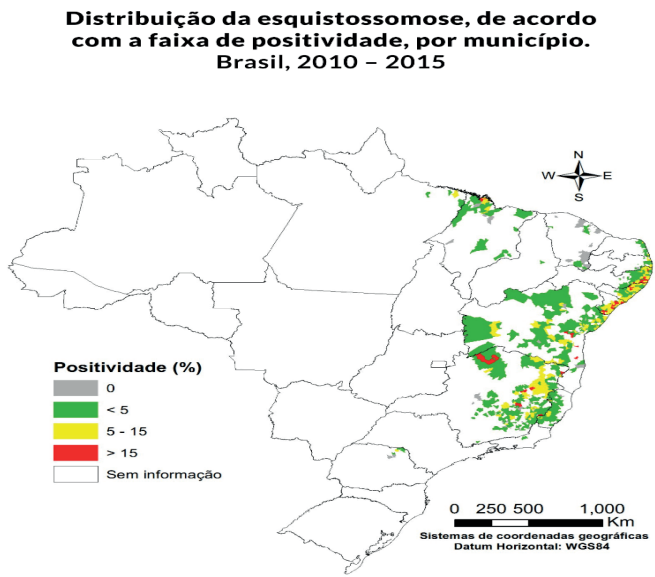

Figure 1 – Geographic distribution of schistosomiasis, according to the range of positivity, by municipality. Brazil, 2010-2015

Source: Secretaria de Vigilância em Saúde/MS

In the state of Maranhão, schistosomiasis has been known since 1920 (ALVIM, 1980, apud LIRA, 2017). According to the 2011 epidemiological situation report, the disease was considered endemic in 20 municipalities and focal in 29 of the 217 existing municipalities. The oldest and highest prevalence foci are found in the North Coast Zones and Baixada Maranhense. In 2010, the state's prevalence was 5.27% among 69,005 examined individuals. Between 2005 and 2010, there was an average of six hospitalizations and eight deaths per year, with a reduction in the mortality rate per 100,000 inhabitants from 0.20 in 2005 to 0.02 in 2010 (BRAZIL, 2011).

In 2007, 5,363 cases of schistosomiasis were reported in the endemic area of the state, a number that gradually decreased to 920 cases by 2016. For the non-endemic area, three cases were recorded in 2007, rising to 79 cases in 2010, and gradually decreasing to nine cases in 2016 (BRAZIL, 2018).

ETIOLOGICAL AGENT OF MANSONIC SCHISTOSOMIASIS

The causative agents of schistosomiasis are macroscopically visible schistosomes, with a cylindrical, whitish-gray body approximately 1 cm (male) to 1.5 cm (female) in length. Taxonomically, they belong to the phylum Platyhelminthes and the class Trematoda (GRYSEELS, 2012). The genus *Schistosoma* (schisto = fissure; soma = body) comprises dioecious individuals (separate sexes) with different developmental stages (adult worms, eggs, miracidia, sporocysts, cercariae, and schistosomules). In the adult stage, the male (which is smaller) houses the female in a kind of fissure in his body, known as the gynecophoral canal (SOUZA et al., 2011; BRAZIL, 2017). This groove is actually formed by the lateral edges of the male, which fold ventrally.

There are about 16 species within the genus, but only five of them can infect humans, divided into two major groups: parasites causing hepatic and intestinal diseases (*S. mansoni, S. japonicum, S. mekongi, S. intercalatum*) and parasites causing renal and bladder diseases (*S. haematobium*) (JAKA et al., 2014).

The species *S. mansoni* is the only one described in Brazil. The initial designation was given by Sambon in 1907, although Pirajá da Silva was also observing the species around the same time independently. This author confirmed that the *Schistosoma* producing eggs with lateral spines lived in the mesenteric veins and was a species distinct from those previously described. However, the species name was actually attributed to the first author (NEVES, 2016).

It is believed that this species was brought to the American continent through the slave trade from Africa, where it found favorable conditions for its development, including vertebrate (definitive) and invertebrate (intermediate) hosts, as well as a suitable environment (SOUZA et al., 2011).

S. mansoni lives in the bloodstream of vertebrate hosts, with an average lifespan of three to five years, but can reach up to 30 years. This is a notable evolutionary milestone achieved through an intrinsic mechanism of evasion of all forms of innate and acquired immunity (GRYSEELS, 2012). The helminth has two suckers: oral and ventral (acetabulum), located at the anterior region of the body and feeds on blood, ingesting about 300,000 erythrocytes per hour. It lacks a circulatory system. Its tegument is composed of a syncytial layer of anucleate cells, covered by a thick heptalamellar membrane, which is constantly renewed (PRATA, 2007, apud SOUZA et al., 2011). The male has tiny projections (tubercles) that give it a rough appearance, while the female has a smooth tegument (NEVES, 2016) (Figure 2).

Figure 2 – Photomicrographs of the adult form (male and female) and egg of *S. mansoni*

Source: Science Photo Library and CDC

The eggs of *S. mansoni* measure approximately 50 µm in length by 60 µm in width. They are oval-shaped, with a spine at their widest part, which is a specific characteristic of the species. Inside the egg is the miracidium, a larva with cilia that allows movement in aquatic environments. The cercaria, which originates from the miracidium after it penetrates the intermediate host, is a larval form consisting of two parts: a cercarial body measuring 190 by 70 µm and a bifurcated tail measuring 230 by 50 µm. It has an oral sucker and a ventral sucker, with the latter being the main structure the larva uses to attach to the host's skin during the penetration process (NEVES, 2016)

LIFE CYCLE

For the disease transmission to occur, the presence of humans as definitive hosts and aquatic snails of the genus *Biomphalaria* as intermediate hosts is essential. An infected human eliminates viable *S. mansoni* eggs through feces. When these eggs come into contact with water, they rupture, allowing the release of the ciliated larval form known as the miracidium. The miracidia penetrate the snail, where they multiply over a period of four to six weeks. After this period, the snails release cercariae, which are the infective larvae of *S. mansoni*. These cercariae penetrate humans through the skin and/or mucous membranes, more frequently through the feet and legs, as these are areas of the body that come into more contact with contaminated water (BRAZIL, 2008).

HOSTS INVOLVED IN THE PARASITE'S LIFE CYCLE

Intermediate Hosts

The biological cycle of *S. mansoni* depends on the presence of the intermediate host in the environment. The intermediate hosts are aquatic gastropod snails belonging to the family Planorbidae and the genus *Biomphalaria*. In these snails, the asexual reproduction of the helminth occurs (BRAZIL, 2017).

Biomphalaria snails have a planispiral shell, with a diameter varying between 7 mm and 40 mm in adult individuals, and a natural yellowish color. However, depending on the substances the snail contacts in its habitat, the shell color can vary from brown to black. They have two long, filamentous tentacles with eyes located at their base, a mouth surrounded by a T-shaped jaw when viewed from the front, an oblong foot, and a cephalic portion of the visceral mass. The mantle folds to form the pulmonary cavity, which is an important characteristic for the specific identification of the species *B. glabrata*, as it contains the renal crest (BRAZIL, 2008).

Biomphalaria snails have predominantly pulmonary respiration but can also respire in aquatic environments through the pseudobranch (main respiratory organ) and the skin in contact with the liquid medium. They are hermaphroditic, with cross-fertilization predominating over self-fertilization (BRAZIL, 2008).

Among the 11 species of *Biomphalaria* present in Brazil, only three are involved in the transmission of schistosomiasis: *Biomphalaria* glabrata Say, 1818, *Biomphalaria* straminea Dunker, 1848, and *Biomphalaria tenagophila* Orbigny, 1835. These are considered natural hosts of *S. mansoni*. Other species of the genus *Biomphalaria* are potential hosts, such as *Biomphalaria* amazonica Paraense, 1966, and *Biomphalaria* peregrina Orbigny, 1835. Of the three species of greatest epidemiological importance, at least one (*B. straminea*) has been reported in 24 of the 26 Brazilian states, in addition to the Federal District, according to data from the Ministry of Health (BRAZIL, 2008).

In a study on the geographic distribution of intermediate hosts of Schistosoma mansoni in Brazil, Carvalho et al. (2018) found that out of 429 municipalities selected for the study, *Biomphalaria* snails were found in 300 (70.2%) of them, distributed across states in the Northeast, Southeast, and South regions. The species *B. glabrata*, the most important in epidemiological terms, was reported in 16 Brazilian states, as well as in the Federal District, and in 806 municipalities, primarily concentrated in the Northeast and Southeast regions, with its distribution almost always associated with the distribution of schistosomiasis (Figure 3).

Figure 3 – Distribution of *B. glabrata* snail foci

Source: Carvalho et al. (2009)

The species *B. straminea* is found in almost the entire Brazilian territory, with the exception of the states of Amapá and Rondônia (Figure 4). These mollusks inhabit both permanent and temporary water bodies and are better adapted to the dry climate of the Northeast.

The species *B. tenagophila* has been reported in 603 municipalities across 10 Brazilian states, as well as in the Federal District. It has a more limited geographic distribution, being mostly restricted to the states in the Southeast and South regions, while also reaching southern Bahia (Figure 5) (BRAZIL, 2008; CARVALHO et al., 2009).

Figure 4 – Distribution of *B. straminea* snail foci

Source: Carvalho et al. (2009)

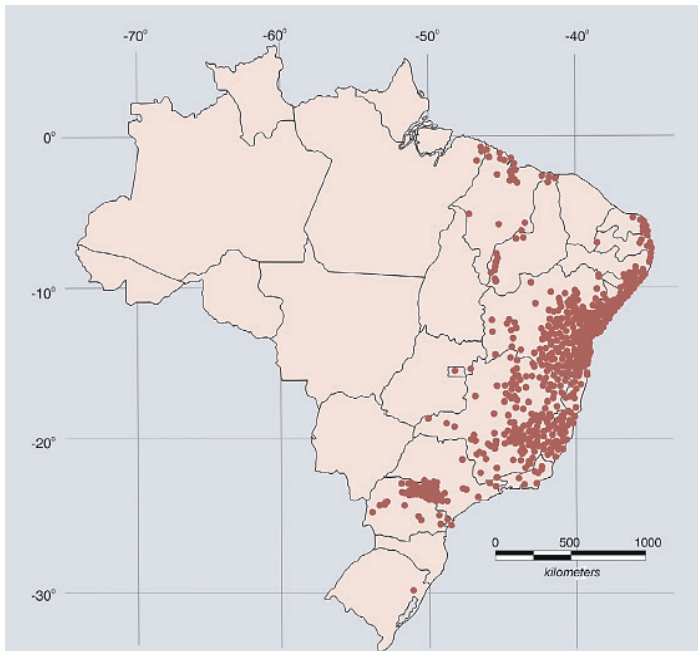

Figure 5 – Distribution of *B. tenagophila* snail foci

Source: Carvalho et al. (2009)

In the state of Maranhão, the species *B. glabrata* and *B. straminea* are predominantly found, mainly in the flooded fields of the Baixada Ocidental and the Northern Coast of the state. According to malacological surveys conducted by PCE-MA from 1997 to 2016, 67.40% of the captured mollusks were identified as *B. glabrata*, 28.36% as *B. straminea*, and 0.10% as *B. tenagophila*, the latter being restricted to the municipality of São Luís (BRAZIL, 2019).

The mollusks can colonize a wide variety of habitats, ranging from small puddles to streams and ponds. When located in urban areas, the transmission sites generally have similar ecological characteristics, being located near houses, in artificial water collections such as ditches, gutters, and drains (temporary breeding grounds) (GOMES et al., 2012). These communities, whether urban or rural, lack piped water, proper sanitation, and rainwater drainage, and are deprived of street cleaning services and garbage collection. The presence of vegetation along the margins of streams is essential both for the snails' food supply and for their shelter and egg-laying. These organisms are highly adaptable to various environmental changes, using several mechanisms to survive stressful situations such as anhydrobiosis, burial, diapause, and quiescence, in which snails reduce their biological activity until favorable conditions are available again (BRAZIL, 2008).

Definitive Hosts

On the other side of the schistosomiasis cycle, mammals act as the definitive hosts of the parasite. Primates, marsupials (opossums), ruminants, rodents, and lagomorphs (hares and rabbits) are considered permissive hosts or reservoirs; however, the role of these animals in the transmission and epidemiology of the disease is unclear, despite their ability to excrete eggs in their feces (BRAZIL, 2010).

In the Baixada Maranhense region, Bastos (1982) identified another definitive host in the transmission cycle besides humans: the wild rodent of the genus *Holochilus*. With rapid reproduction, this animal lives in constant contact with water bodies and is highly adapted to the region's environmental conditions, acting as a natural reservoir for the parasite. Schistosomiasis transmission is then enhanced by the presence of both definitive hosts in the same environment, establishing two parasite strains: the wild strain (carried by the rodent) and the human strain (LIRA et al., 2016).

Humans are considered the primary host due to their epidemiological importance. In them, the worm will complete its body development and sexual maturity. The reproduction of *S. mansoni* in the human body causes various symptoms characteristic of schistosomiasis mansoni, which vary depending on the stage of the disease (SOUZA, 2011).

In the acute phase, abdominal pain, nausea, diarrhea, and blood in the stool may occur. In more advanced stages of the disease, liver enlargement (due to the immune response caused by egg deposition), fluid accumulation in the peritoneal cavity, and hypertension of the mesenteric veins may occur, leading to the characteristic chronic condition of the parasitosis, known as "water belly" (NEVES, 2016).

DISEASE CONTROL

The first control program for schistosomiasis began in 1913 in Egypt, where both the local population and stationed soldiers were heavily infected. At that time, the approach used was the control of transmitting mollusks. In the 1930s, sanitation was incorporated into the program, such as the construction of latrines and piped water supply, but the results were still insufficient. With the progressive elucidation of the evolutionary cycle of Schistosoma spp., mollusk control and mass treatment became the model for strategy (USEH, 2012).

The WHO Expert Committee on Schistosomiasis Epidemiology and Control adopted a holistic approach to disease control and noted that "a comprehensive understanding of environmental, demographic, social, behavioral, and economic factors" in schistosomiasis is essential for the planning of successful long-term programs (USEH, 2012).

The first large-scale coproparasitological survey in Brazil was conducted only in 1950, when the existence of the disease was evidenced in 612 of the 877 localities surveyed in the Northeast region and the state of Minas Gerais (PELLON & TEIXEIRA, 1950), allowing knowledge of its national distribution (CARMO & BARRETO, 1994). In this survey, schoolchildren aged 7 to 14 years were examined, with priority given to localities with populations over 1,500 inhabitants.

In 1975, a specific control program for the disease was created in Brazil, the Special Schistosomiasis Control Program (PECE), under the then Superintendency of Public Health Campaigns (SUCAM). This was later replaced by the Schistosomiasis Control Program (PCE) in the 1980s. In the state of Maranhão, disease surveillance and control activities have existed since 1977 (CUTRIM, 1987).

In 1999, the Program was decentralized, with municipalities taking responsibility for epidemiological surveillance activities, vector control, and patient treatment (BRAZIL, 1999).

Currently, the World Health Organization suggests, as a control strategy, what is called an integrated approach, which includes the following efforts: mass chemotherapy; snail control, which involves the use of chemical and natural molluscicides; proper sewage treatment; adequate environmental engineering designs for the development of irrigation and hydroelectric systems that limit the viability of breeding sites for host snails; safe drinking water supply; and extensive health education and population mobilization to raise awareness about the control program (KING, 2009).

Therefore, the enormous morbidity associated with schistosomiasis, which is significantly close to malaria in terms of significance and public health impact, requires coordinated and sustainable means for disease control, involving the agreement of different sectors of the public power, research institutions, and society (USEH, 2012).

FACTORS RELATED TO THE OCCURRENCE OF SCHISTOSOMIASIS

As it is a waterborne disease, for the biological cycle of *S. mansoni* to be completed and the transmission of parasitosis to be established in a particular area, three conditions must necessarily be met: a) the existence of parasitized people; b) the existence of water bodies contaminated by feces and colonized by *Biomphalaria* snails; c) human contact with these water bodies.

The areas where these conditions are most commonly observed are rural regions and peri-urban areas of municipalities. The lack of basic sanitation, inadequate water supply, and lack of information are the factors that contribute most to this situation (BARBOSA et al., 2008; SAUCHA et al., 2015; FREEMAN et al., 2017).

Although in 2008 only 33 municipalities in Brazil did not have a water supply service, 2,495 municipalities (44.8% of Brazilian municipalities) remained without sewage collection coverage. This serious situation persists in much of the states of the Northeast and North regions of the country, with Bahia, Maranhão, Piauí, and Pará standing out (IBGE, 2011).

According to the 2008 National Basic Sanitation Survey, only 6.5% of municipalities in Maranhão had a sewage collection network (considering that at least one district, even if only part of it, had sewage treatment).

The natural conditions of such environments themselves favor the transmission of the disease. In a study on the importance of floods in the spread of schistosomiasis mansoni, Ramos (1970) pointed out that floods can contribute to the expansion of schistosomiasis by providing conditions for the establishment of new foci, favoring the increase in the proliferation of *Biomphalaria tenagophila*.

In Maranhão, the micro-region of Baixada Maranhense constitutes a peculiar environment for the transmission of schistosomiasis, as it combines both natural and socioeconomic conditions. This region is located in the transition area between the Amazon and the Northeast, in a low latitude zone, and is characterized by high rainfall rates. The Baixada is located in a region of low, flat, and floodable lands, characterized by fields, gallery forests, mangroves, and lacustrine basins. Its population is predominantly rural (FARIAS FILHO, 2013). The extensive engagement in activities related to this environment, such as fishing, washing clothes, or leisure, constitutes a high risk factor for the spread of the disease in this and other regions with similar characteristics, such as the rural and peri-urban areas of São Luís (Figure 6).

Figure 6 – Environmental characteristics of Baixada Maranhense

Source: Google Images

CONCLUSION

Schistosomiasis is the second most prevalent disease worldwide, second only to malaria. It belongs to a special group of diseases known as Neglected Tropical Diseases. This parasitic disease is of high relevance in the global health scenario, predominantly affecting poorer populations living in rural or vulnerable urban areas. Such environments gather conditions that contribute to the successful establishment of schistosomiasis, such as the absence or inadequacy of basic sanitation, the abundance of water collections, and the lack of information about the disease or how to prevent it.

In Brazil, the so-called Schistosomiasis Control Programs (PCE) have been striving and have, to some extent, managed to reduce prevalence rates in the states. However, the fact that this is already a neglected disease in itself means that these programs face difficulties in effectively carrying out their prevention and control actions in a satisfactory manner. Being a disease linked to underdevelopment, there is no doubt that to achieve the elimination of schistosomiasis and other infectious and parasitic diseases, governments will need to promote significant improvements in the socio-economic conditions of the population, coupled with a secure water supply and sanitary improvements in urban centers and rural areas.

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CHAPTER 3

USE OF INSECTS AND BY-PRODUCTS IN QUAIL FEEDING

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ABSTRACT: Protein is essential for the growth and development of poultry and plays a crucial role in tissue maintenance and repair. However, the use of animal-derived protein meals faces significant challenges, such as high costs and risks of disease transmission. In this context, the search for safer and more accessible alternatives is essential. Insects have emerged as a promising solution due to their high nutritional value, low environmental impact and ability to transform waste into rich food. In addition, insect production does not compete with food resources and has an amino acid profile comparable to or superior to that of soybean meal. This study explores the inclusion of insects in quail diets, highlighting their nutritional benefits and their potential to promote sustainable and ecologically responsible feeding practices.
KEYWORDS: Quails, Insects, Animal nutrition, Alternative protein, Sustainability.

USO DE INSETOS E SEUS SUBPRODUTOS NA ALIMENTAÇÃO DE CODORNAS

RESUMO: A proteína é fundamental para o crescimento e desenvolvimento das aves, desempenhando um papel crucial na manutenção e reparação dos tecidos. No entanto, o uso de farinhas proteicas de origem animal enfrenta desafios significativos, como altos custos e riscos de transmissão de doenças. Nesse contexto, a busca por alternativas mais seguras e acessíveis é essencial. Insetos surgem como uma solução promissora, devido ao seu alto valor nutricional, baixo impacto ambiental e capacidade de transformar resíduos em alimentos

ricos. Além disso, a produção de insetos não compete com recursos alimentares e apresenta um perfil aminoacídico comparável ou superior ao de farelo de soja. Este estudo visa explorar a inclusão de insetos na dieta de codornas, destacando seus benefícios nutricionais e seu potencial para promover práticas alimentares sustentáveis e ecologicamente responsáveis.
PALAVRAS-CHAVE: Codornas, Insetos, Nutrição animal, Proteína alternativa, Sustentabilidade.

INTRODUCTION

Protein is an essential nutrient in poultry diets and plays a crucial role in tissue maintenance and repair, which is essential for proper growth and development (Hatab et al., 2020). However, the high cost of animal protein meals and their potential to transmit diseases have imposed new restrictions on global poultry production (Womeni et al., 2012; Hatab et al., 2020). Therefore, it is vital to find safe, accessible and low-cost feed sources to replace traditional proteins.

Insects have emerged as a viable alternative due to their high nutritional value (rich in energy, proteins, amino acids and fatty acids) and low environmental impact (Bovera et al., 2016; Hatab et al., 2020; Cufadar et al., 2021).

Large-scale insect production for animal feed is advantageous because it does not compete with food resources and land use. In addition, insects can transform industrial by-products and polluting waste into food with high nutritional content, promoting nutrient recycling (Prates et al., 2023). They act as immunomodulators and have beneficial effects on the microbiota of the digestive system. Protein production per hectare is higher than grain production, with an amino acid profile similar or superior to soybean meal and animal meal, which can reduce the final cost of the feed (Oliveira et al., 2020; Prates et al., 2023).

In this context, the aim of this study was to explore the feasibility and potential nutritional benefits of including insects and their co-products in quail diets. Emphasizing the essential role that this approach can play in promoting a healthy and ecologically responsible diet for quails, in line with the growing demands for sustainable food practices.

USE OF INSECTS IN ANIMAL FEEDING

The world's population is continually growing, which raises essential questions about our future capacity to produce and provide adequate and nutritious food. There is an estimate of a necessary 70% increase in global food production by 2050, compared to 2009 (FAO, 2009), to meet the additional need for food for human and animal populations, as real challenges have arisen for food production professionals, researchers and politicians will face (Henchion et al., 2017). The growing demand for animal proteins negatively impacts the environment because of rising greenhouse gas emissions and increased water, energy, and land use (Ishangulyyev et al., 2019). Fears about global food security have arisen from

the loss and waste of food throughout the supply chain, which accounts for around one-third of all food produced for human consumption (1.3 billion tons of food) and has significant negative economic and environmental impacts (Roma et al., 2020).

Within research focused on prospecting alternative sources of protein in human and animal nutrition, as well as in food waste, edible insects are increasingly presenting themselves as valid alternatives for proteins of animal origin (Borrello et al., 2016) and in the treatment of waste (Madau et al., 2020). Insects efficiently bio-convert food or by-products into proteins of high biological value (Van Zanten et al., 2015), and depending on the species or processing method, insects and their co-products can contain an average amount of protein (on a dry matter basis, %MS) ranging from 50% to 82%, as well as being rich in nutrients such as calcium, iron, and zinc (Rumpold & Schlüter, 2013). Insects are a source of food with a low environmental impact due, among other things, to the limited need for arable land and water compared to traditional livestock farming (Banjo et al., 2006) and the low ecological cost (low greenhouse gas and carbon dioxide emissions) (Fasakin et al., 2003).

Entomoculture has remained an almost unknown practice until recently. Insects are typically captured in wild conditions in Africa and Asia (Lorenzo et al., 2020). Land use for agriculture, desertification, and urbanization has progressively reduced the capture of wild insects (Lorenzo et al., 2020). At the same time, the rearing of edible insects has begun to emerge as a viable and sustainable alternative to wild capture (Raheem et al., 2019). In this way, insect farming is also attracting growing interest in countries that are not traditionally involved in entomophagy, such as Europe and the United States of America, where insect-based co-products are increasingly commercialized (Nadeau et al., 2015). Insect farming, also known as entomoculture, combines economic benefits with the production of food and feed ingredients that can beneficially affect the diet of the population in both developed and developing countries (Nadeau et al., 2015). It has been highlighted in scientific literature that insects have a nutrient composition suitable for inclusion in ruminant feed (although their use is still prohibited in Brazil for these animals) and in aquaculture production systems (rearing fish, crustaceans and other aquatic animals), pigs, poultry, dogs, and cats (Kerensa et al., 2021).

Consumption of poultry products is expected to increase in the coming years; therefore, there is a significant need for new feed ingredients that can sustainably facilitate intensive poultry production (Yuan and Moriguichi, 2006). Insects are high-quality protein sources rich in essential amino acids and lipids. The protein content of insect meal can vary significantly, ranging from almost 40% to 60% (Jabbour et al., 2019). Variation in nutrient content can also be influenced by factors such as feeding habits, including the types of food consumed in the ecological niche (preferably natural feeding patterns, and how these aspects affect the nutrient content and overall nutritional profiles of insects), developmental stage, and prevailing environmental conditions, leading to very different nutritional profiles, even among phylogenetically related insect taxa (Gallaud and Laperche, 2016).

The protein composition of insect dry matter varies significantly between different insect species, ranging from 35% in termites to 61% in crickets and grasshoppers, with some species exhibiting even higher protein contents of up to 77% (Rumpold and Schlüter, 2013). Most edible insect species exhibit adequate levels of essential amino acids, including tyrosine, tryptophan, phenylalanine, lysine, and threonine, in line with recommended dietary requirements. Edible insect species possess sufficient levels of these important amino acids, which may be beneficial for commercial poultry nutrition (El-Sabrout et al., 2023). Insects mainly store carbohydrates in two forms: chitin and glycogen. Chitin, the main component of their exoskeleton, is a polymer of N-acetyl-D-glucosamine. In contrast, insect muscle cells store glycogen as an energy source (Ojha et al., 2021). Edible insects contain varying amounts of carbohydrates (Tenebrio mealworm larvae: 14-18%; crickets: 10-20%; grasshoppers: 11-21%; silkworm pupae: 10-20%; ants: 2-15%). However, specific carbohydrate content may depend on factors such as insect species, diet and stage of development (Mlček et al., 2014).

he literature shows that insects contain variables ranging from 2% to 62%, with large amounts of unsaturated FAs constituting up to 75% of the total fatty acid content. Although the vitamin content of insects is not particularly high, they do contain notable amounts of vitamins A, C, D, and E (Zamudio-Flores et al., 2019). Insects such as crickets and termites have varied mineral contents, with some being rich in magnesium, zinc, and copper, while others such as grasshoppers and mealworms have higher levels of copper, magnesium, manganese and zinc than beef. However, insects are generally low in sodium, calcium and potassium (Mwangi et al., 2018). The substantial amounts of amino acids, mineral substances and vitamins make insect meal a potential competitor to conventional protein sources such as fishmeal and soy.

As insects are a source of food for many species of birds, their introduction into poultry farming is being intensively studied by researchers around the world. These studies covered different types of diets, species and stages of insect development. Furthermore, these studies focused on both broilers and laying hens. Recently, tests with broilers have been carried out using diets of different insect species, such as BSF (*H. illucens*), houseflies, silkworms (*Bombyx mori)* and giant tenebrio (*Zophobas morio*), testing isoprotein and isoenergetic diets (Murawska et al., 2021).

Murawska et al. (2021) studied the inclusion of BSF in broiler diets, tested high levels of dietary inclusion (starter: 20-30 and 40%; grower: 20-25 and 35%; finisher: 10-20 and 30%) and reported lower growth performance (CP, feed consumption and daily weight gain (DWG)) in the insect treatments than in the control, except for the DWG of the 10% group during the finisher phase. Regarding FC, no differences were observed between the control and the two diets with the lowest inclusion levels, while the dietary treatment with the highest insect content produced the lowest value (Murawska et al., 2021).

SPECIES USED IN ANIMAL FEED

The use of insects in animal feed is a sustainable and efficient alternative to meet the growing demands of the farming industry. This practice, known as entomophagy, involves including insects in the diet of farmed animals such as poultry, fish, and pigs, providing both environmental and nutritional benefits (Gałęcki et al., 2021).

Edible insects are known to have significant levels of protein, fat, vitamins, fiber, and minerals, although these levels can vary between different species (Kouřimská and Adámková, 2016). Considering the concern for sustainability, exploring alternative food sources, such as insects, could help reduce dependence on ingredients such as fishmeal/oil and soy, which are considered less sustainable for feed production. However, it is essential to carry out a detailed analysis of the nutritional composition of each insect species, taking into account factors such as life stage, rearing conditions and specific diet, to ensure that they meet the nutritional requirements of the species of interest. Only in this way can it be possible to formulate balanced rations that promote the best performance and health of the animals, regardless of their species (Nascimento et al., 2020).

It is important to note that certain types of insects not only represent an excellent source of nutrients but also have antimicrobial compounds (Li et al., 2023). These nutrients play a crucial role in enhancing the animals' immune response, and even help to prolong the shelf life of feed incorporating insect meal.

The use of edible insects in the feeding of farm animals is a scientific area that is still in its infancy compared with research dedicated to the production of these animals (Gomes et al., 2023). The significant number of studies in this field has provided promising results. Despite this, the current production of edible insects does not yet fully meet the growing demand for animal protein on the market. However, it is already feasible to reap the benefits of edible insects by integrating them as supplements at specific stages of the production process. It is crucial for researchers and producers pay due attention to the particularities of each location, situation and production sector in order to optimize this practice (Nascimento et al., 2020).

Among the categories of edible insects, 80% are associated with the orders Coleoptera (beetles), Hymenoptera (ants, bees), Orthoptera (grasshoppers and crickets), and Lepidoptera (caterpillars). The remaining 20% covers orders such as Hemiptera (cicadas, aphids), Isoptera (termites), Diptera (flies) and others (Lavalette, 2013). However, comprehensive research into these orders is limited due to the peculiar characteristics of certain species, which make them more promising than others for the current application of entomoculture in animal feed. Although thousands of species of food insects are cataloged globally, only a few are commercially produced in captivity for animal feed, including crickets, beetles, cockroaches and flies (Nascimento et al., 2020).

Coleoptera, Diptera, and Lepidoptera are predominantly consumed during the larval stage, while the other species are generally eaten in the adult stage (Yi et al., 2013). In terms of consumption, the adult stage is initially more convenient although the larval stage may have a higher nutritional profile. In addition to the larval and adult stages, some species go through additional stages, such as pre-pupa and pupa. For example, during the pre-pupal stage, the black soldier fly demonstrates two notable advantages: reduced risk of pathogenicity due to the emptying of the digestive tract and a migration behavior adapted to facilitate self-collection in industrial-scale systems (Danieli et al., 2019).

Tenebrio molitor

Tenebrio molitor, popularly known as the "flour maggot", is a member of the *Tenebrionidae* family, also known as the "dark beetles", which is the fifth largest family in the Coleoptera order, with more than 14,000 species distributed globally. Like many other members of this family, *T. molitor* is a nocturnal species that prefers dark and humid environments, such as grain elevators, bird cages, chicken nests, grain silos, feed sacks and food storage facilities (Gkinali et al., 2022). The specimens varied in size, with females reaching between 10 and 18 mm, while males usually measure between 10 and 15 mm (Figure 1).

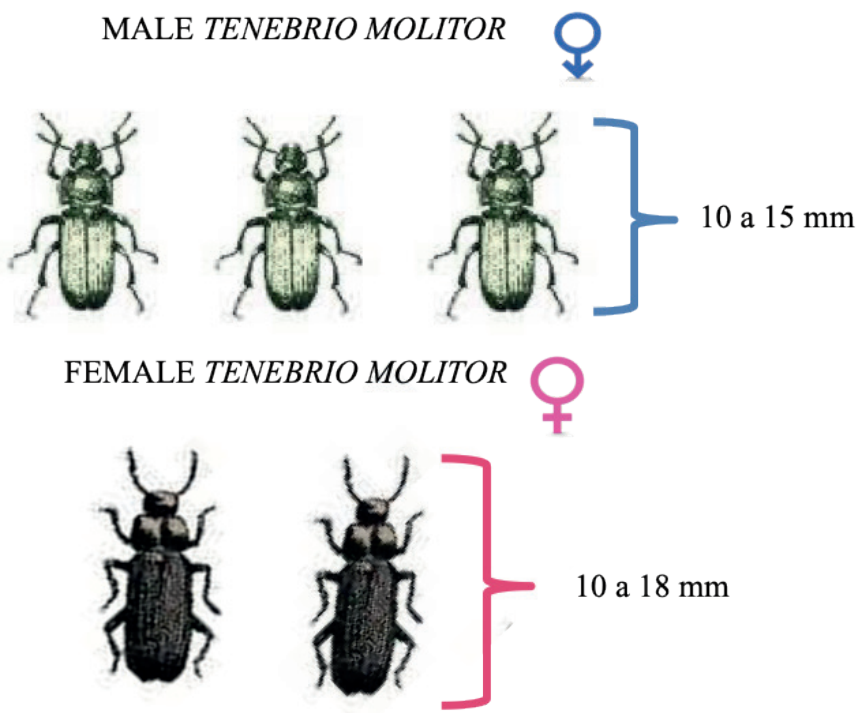

Figure 1: Male and Female *Tenebrio molitor*

The life cycle of the tenebrio is complete and variable, lasting from 280 to 630 days and consisting of four distinct metamorphic stages (Figure 2): egg, larva, pupa and adult (Finke, 2002; Yu et al., 2021). Each female had the capacity to lay approximately 500 eggs, which are ovoid and elongated in shape, coated with a sticky substance that adheres the eggs to the substrate. The larvae hatch in a period of 10–12 days, measuring around 3 mm in length and displaying a whitish color. In a few days, the larvae produce a chitinous exoskeleton with a yellowish hue. The complete larval stage is 2–3.5 cm long and weighs between 130 and 160 mg, lasting 3 to 4 months. The pupal stage lasts approximately 7–9 days, is creamy white in color and measures 1.2 to 1.8 cm in length. The adult resulting from the larval stage of flour lives for around 3 to 4 months (Siemianowska et al. 2013; Makkar et al. 2014; Alves et al., 2016).

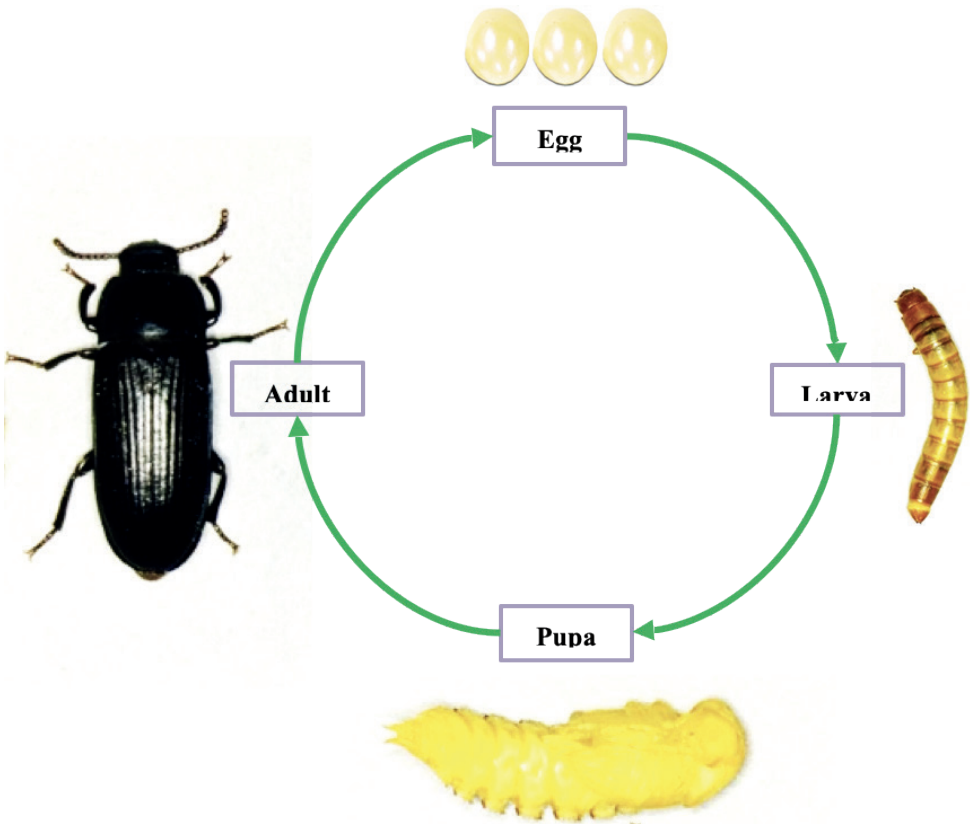

Figure 2. Life cycle of *the Tenebrio molitor*

Tenebrio molitor (*T. molitor*) larvae are considered good sources of protein for non-ruminant animals. High protein content and amino acid profile in quantity and quality. The crude protein (CP) content of *T. molitor* larvae averaged 52.4% and ranges from 47.0% to 60.2%, which is higher than that found in soybean meal (49.4%) and lower than that found in fishmeal (67.5%). *T. molitor* larvae contain an average of 30.8% crude fat, which can vary depending on the processing method used to extract it. The crude fat content of *T. molitor* larvae were higher than those found in soybean meal (1.4%) and fishmeal (10.4%). However, the average crude ash content (4.2%) of *T. molitor* larvae is lower than that of soybean meal (7.2%) and fishmeal (17.2%) (Hong et al., 2020).

The fiber content of *T. molitor* larvae originates from their cuticles. The crude fiber content of *T. molitor* larvae was 7.43% and ranges from 4.19% to 22.35%. The average crude fiber content of *T. molitor* larvae was similar to that found in soybean meal (7.43%) and higher than that found in fish meal (0.26%) (Hong et al., 2020).

The amino acid profile of *T. molitor* larvae revealed that leucine, valine, and lysine were the most prevalent essential amino acids, while Histidine, Methionine and Tryptophan are the least abundant. Lysine's proportion varies from 1.58% to 5.76%, and that of Methionine varies from 0.52% to 2.20% in the larvae. Additionally, Threonine levels vary from 1.57% to 4.29%, and Tryptophan levels vary from 0.02% to 1.86%. *T. molitor* larvae exhibit higher levels of lysine, methionine, threonine, tryptophan, valine, and isoleucine than soybean meal. Although the levels of lysine, methionine, and threonine are lower than those of fishmeal, the contents of Tryptophan, Valine and Isoleucine exceed those of fishmeal (Hong et al., 2020). Table 1 presents the nutritional composition of *Tenebrio molitor* larvae with potential for use in animal feed.

Items	Values
	Tenebrio molitor larvae
Crude protein, g/kg	490,2
Ether extract, g/kg	335,4
Gross energy, kcal/kg	7188,6
NDF, g/kg	71,8
FDA, g/kg	64,0
Ash, g/kg	36,8
Macrominerals (g/kg)	
Total phosphorus	8,56
Potassium	8,39
Sodium	1,39
Total calcium	0,44
Magnesium	2,30
Microminerals (mg/kg)	
Iron	48,4
Manganese	15,0
Zinc	189
Copper	18,0

Table 1. Proximal composition and mineral content of *Tenebrio molitor* larvae (based on dry matter).

Source: Adapted from Fialho et al. (2021)

In summary, studies have shown that *Tenebrio molitor* larvae represent a promising and sustainable alternative for feeding poultry, especially quails, due to their high protein content, suitable amino acid profile, and environmental benefits associated with their production (Prates et al., 2023). Morsy et al. (2022) evaluated the replacement of levels of 2.5, 5.0, 7.5 and 10.0% of a basal diet with *Tenebrio molitor* meal. The results indicated that 10% substitution maximized body weight and weight gain and improved the feed conversion ratio. In addition, we observed that the use of *Tenebrio molitor* meal can positively influence the immune status and biochemical parameters of quails. There were improvements in meat quality, carcass weight, and levels of crude protein, methionine, lysine, leucine, isoleucine, arginine, valine, glycine and saturated fatty acids present in the meat. In addition, there was a reduction in the levels of triglycerides and total cholesterol.

The inclusion of mealworm meal along with other alternative ingredients, such as meal derived from olive leaves (*Olea europaea* L.), can improve the body weight of Japanese quails. These benefits were observed when replacing 3% of the standard diet with mealworm meal and 2% with olive meal, without causing negative impacts on carcass yield, edible organs, and biochemical levels such as lipids, serum proteins, creatinine and urea (Ait-Kaki et al., 2021).

When incorporated into the diet at levels of up to 30 g/kg of feed, replacing soybean meal and fishmeal, beneficial effects were observed on body weight, weight gain, feed conversion, breast yield, carcass yield, meat quality, and jejunal morphology (Zadeh et al., 2019). On the other hand, replacing fishmeal exclusively with the same amount (up to 30 g/kg) resulted in an increase in weight gain and a reduction in cholesterol levels and did not interfere with hematological and biochemical indices or the expression of the interferon ɣ (IFN-ɣ) gene, which is associated with infectious and inflammatory processes. This suggests that the state of health was not affected (Zadeh et al., 2020).

In summary, the inclusion of tenébrio meal in the diet of quail is a promising strategy to promote intestinal health, improve feed efficiency and contribute to the overall performance of these birds. However, it is important to consider factors such as meal quality, diet balance, and the specific needs of quails at different life stages in order to optimize the benefits provided by the meal.

Zoophobas morio

Zophobas morio is a member of the extensive family of Tenebrionidae beetles, which includes several species of insects associated with stored products, such as *Tenebrio molitor* and *Alphitobius diaperinus*. Other notable members of this family include the confused flour beetle, *Tribolium confusum* Jacquelin du Val (Coleoptera: Tenebrionidae), and the red flour beetle, Tribolium castaneum (Herbst) (Coleoptera: Tenebrionidae) (Rumbos & Athanassiou, 2021).

Although *Z. morio* is classified as a storage insect, it has been identified associated exclusively with wheat flour (Hagstrum and Subramanyam, 2009), suggesting its insignificant relevance as a secondary pest of storage insects. In nature, reports indicate its presence in association with fruit bat guano (feces) and organic waste (Tschinkel and Willson, 1971). Originally from the tropical regions of Central and South America (Marcuzzi, 1984; Tschinkel, 1984; Hagstrum and Subramanyam, 2009), the beetle has also been introduced to various regions of Europe and Asia (Yuan et al., 2012; Fursov and Cherney, 2018; Rumbos & Athanassiou, 2021).

Zophobas morio: Identification, Main Characteristics and Biology

Similar to *Tenebrio molitor*, *Zoophobas morio*'s life cycle is complete and variable, consisting of four distinct metamorphic stages (Figure 3): egg, larva, pupa, and adult stages.

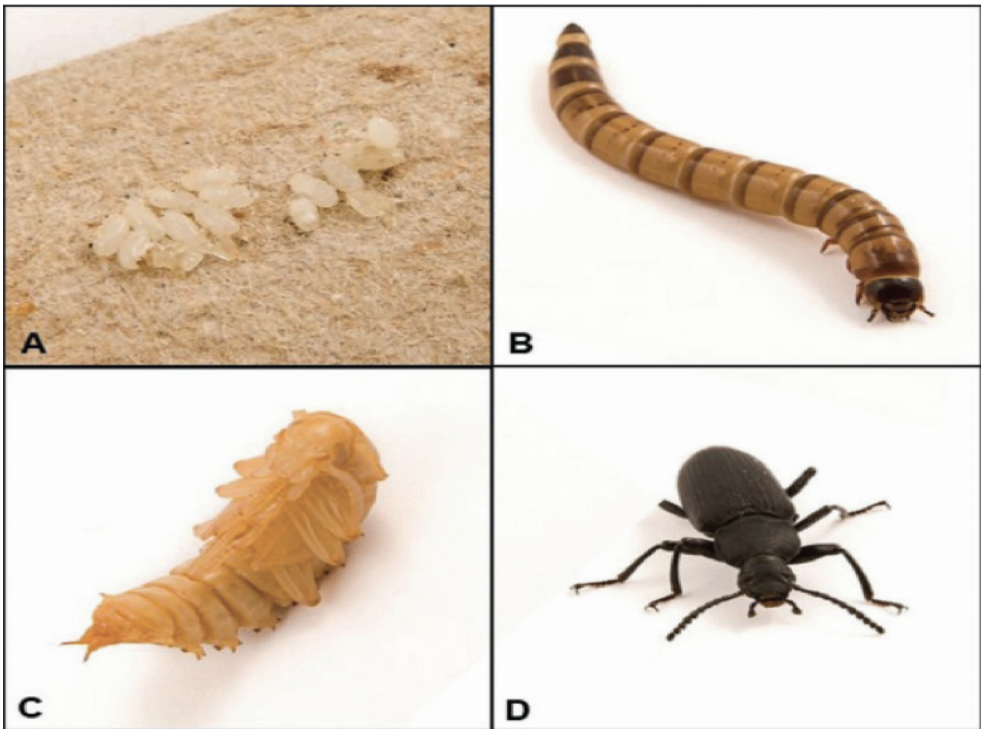

Figure 3: Life stages of *Zophobas morio*: (A) eggs, (B) late-stage larva, (C) pupa (D) adult.

Source: Adapted from Rumbos & Athanassiou, 2021

The eggs of the *Z. morio* species are oval in shape with rounded edges and white in color. They are approximately 1.7 mm long and 0.7 mm wide (Figure 3A) (Fursov and Cherney 2018). Each female has the capacity to lay a significant number of eggs, which can reach up to 2,200 during her lifetime. This number of eggs is inversely related to the maternal age of the female and directly related to the population density of adults (Rumbos & Athanassiou, 2021).

In the larval stage, they are yellow in color with dark brown anterior and posterior extremities (Figure 3B; Fursov and Cherney 2018). Their exoskeleton is cylindrical, highly sclerotized, and narrowed conically from the seventh to the ninth abdominal segment. The maximum length they could reach was 55 mm (Friederich and Volland 2004). Hatching occurs after approximately 8 days at a temperature of 25°C (Kim et al. 2015). One of the most notable peculiarities of this species is that its larvae cannot proceed to the pupal stage under conditions of overpopulation, despite the continuity of the larval moulting process until death (Rumbos & Athanassiou, 2021).

The pupae (Figure 3C) predominantly remain quiescent. However, when tactilely stimulated, they can perform circular movements with their abdominal segments (Ichikawa and Kurauchi 2009, Ichikawa et al. 2012b) or exhibit other physical responses (Ichikawa et

al. 2012a, Ichikawa and Sakamoto 2013). These reactions are considered effective defense mechanisms for pupa against predators and cannibalistic behavior by other larvae.

The pupal period lasts 13–15 days at 25°C, varying according to pupal weight (adults emerge more quickly from small pupae) and temperature (adult hatching occurs more quickly at 29°C) (Quennedey et al. 1995). Similar to other tenebrionid species, such as *T. molitor* (Bhattacharya et al. 1970) and *A. diaperinus* (Esquivel et al. 2012), it is possible to easily distinguish the sex of individuals during this life stage. This can be done by observing the presence of two distinct projected pygopodes on the ninth abdominal segment of female pupae, close to the urogomphus, which are absent in male pupae (Fursov and Cherney 2018).

During their adult phase, *Z. morios* reach large proportions, with bodies ranging in length from 38 to 57 mm in length, having an elongated shape and filiform antennae (Figure 3D). The surface of the elytra was marked by nine rows of perforations, each with bristles. The life expectancy of adults can reach up to 6 months (Fursov and Cherney 2018).

Studies on the nutritional profile of *Zophobas morio* larvae have indicated their significant quality as sources of nutrients (Barroso et al., 2014; Bosch et al., 2014; Adámková et al., 2017; Araújo et al., 2019). The larvae were shown to be rich in nitrogen, with their total content varying between 6.2% and 8.6% (Table 2). Reports indicate that larvae have chitin contents of between 3.9% and 6% (Adámková et al., 2017; Shin et al., 2019; Benzertiha et al., 2020; Kulma et al., 2020). Regarding amino acid profile, *Z. morio* larvae have relatively high amounts of all essential amino acids, except methionine (Table 2). In terms of fat content, larvae have a high proportion of lipids, ranging from 35.0% to 43.6% (Table 2), considerably exceeding other insect species that are also considered sources of nutrients (Barroso et al., 2014). Fatty acid analysis revealed that *Z. morio* larvae have high levels of saturated (SFA) and monounsaturated (MUFA) fatty acids, with palmitic acid and oleic acid being the most abundant, respectively (Table 2). Among the polyunsaturated fatty acids (PUFA), omega-6 linoleic acid is abundant in *Z. morio* larvae (Table 2; Barroso et al., 2014). In addition, *Z. morio* larvae contain various minerals (Table 2) and vitamins (Finke, 2002, 2015), as well as high nitrogen and lipid contents.

Centesimal composition	**Larvae**
Dry matter (% as fed)	35,2-42,1
Total nitrogen (% DM)	6,2-8,6
Crude fat (% DM)	35,0-43,6
Ash (% DM)	2,4-8,2
Neutral detergent fiber (NDF) (% DM)	9,3-13,0
Acid detergent fiber (FDA) (% DM)	6,3-6,5
Energy (kcal/100 g DM)	559,2-575,5
Amino acid content (% DM)	
Arginine	2,2-3,5
Histidine	1,4-2,3
Leucine	3,4-4,5
Lysine	2,4-2,9
Isoleucine	2,2-2,4
Phenylalanine	1,6-2,2
Methionine	0,5-1,0
Threonine	1,9-2,0
Tryptophan	0,4-0,5
Valine	2,4-3,4
Alanine	3,4-4,0
Aspartic acid	3,8-4,7
Glycine	2,3-3,0
Serina	2,2-2,7
Proline	2,6-3,7
Cystine	0,4-0,5
Glutamic acid	5,7-6,6
Tyrosine	3,3-3,9
Mineral composition (mg/100g DM)	
Calcium	31,9-70,8
Phosphorus	562,9-564,9
Magnesium	39,2-118,3
Sodium	104,1-112,8
Potassium	750,6-773,0
Chloride	361,1-440,5
Iron	2,3-5,4
Zinc	2,5-8,2
Copper	0,5-1,0
Manganese	0,5-1,0
Fatty acid composition (% of total fatty acids)	
Palmitic (C16:0)	29,1-32,4
Palmitoleic (C16:1)	1,0-3,2

Stearic (C18:0)	6,4-8,8
Oleic (C18:1)	31,1-38,0
Linoleic (C18:2)	15,6-23,4
Saturated (SFA)	38,8-44,6
Monounsaturated (MUFA)	32,1-42,4
Polyunsaturated (PUFA)	15,7-24,0
Omega-6	16,5-24,0

Table 2. Composition of *Zophobas morio* larvae

Source: Adapted from Rumbos & Athanassiou, 2021

Diets containing *Zophobas morio* larvae meal has recently aroused considerable interest among researchers, especially in poultry feed. Benzertiha et al. (2020) evaluated the effects of including small proportions (0.3%) of whole *Z. morio* larvae meal in broiler diets, either added directly to a complete diet or incorporated into calculated diets. The study examined the resulting effects on performance, as well as on characteristics of the birds' immune system. The researchers observed significant improvements in body weight gain and feed consumption. In addition, they identified positive effects on plasma immunoglobulin levels, namely IgY and IgM.

In a similar study, Benzertiha et al. (2019) investigated the effects of adding minimal amounts (0.2% and 0.3%) of *Z. morio* meal to broiler diets. The study assessed apparent ileal digestibility coefficients, pancreatic enzyme activity, short-chain fatty acid concentrations, bacterial enzymes and the composition of the microbiota in the caecal digesta. The results revealed no adverse effects on ileal nutrient digestibility coefficients or pancreatic enzyme activity. The inclusion of whole *Z. morio* flour in the diet improved bird health by reducing concentrations of pathogenic bacteria such as *Bacteroides-Prevotella* and *Clostridium perfringens*. In addition, supplementation with small amounts of *Z. morio* flour (0.2% and 0.3%) stimulated the microbiota of the gastrointestinal tract to produce glycolytic enzymes. This addition showed a prebiotic effect, increasing the relative abundance of probiotic and commensal bacteria, such as Actinobacteria, in the cecal microbiome. These microorganisms protect against infection by pathogenic bacteria (Józefiak et al., 2020; Rumbos & Athanassiou, 2021).

In the same way that adding *Zoophobas morio* (Tenebrio gigante) meal to broiler chicken feed has proved to be a promising strategy, the same principle can be applied to quails, with the aim of promoting the birds' intestinal health. This practice can stimulate the microbiota of the gastrointestinal tract to produce predominantly glycolytic enzymes, resulting in improved feed efficiency and contributing to the productive performance of these animals.

Hermetia illucens (Black soldier fly)

The black soldier fly (*Hermetia illucens*) (Figure 4), also known as the Black Soldier Fly (BSF), inhabits tropical and subtropical regions (Antunes, 2022; Ewusie et al., 2019). Since the 1990s, its breeding has been suggested as an efficient way to manage organic waste, turning it into biomass rich in proteins and fats (Makkar et al., 2014).

The black soldier fly goes through five main stages of its life cycle: egg, larva, pre-pupa, pupa and adults (Figure 4) (Li et al., 2011; Silva & Hesselberg, 2019). The larval and pupal stages were the longest, while the egg and adult stages are shorter. Females lay between 500 and 900 eggs (Julita et al., 2020), which hatch in around four days, although this can vary depending on the season, region, and temperature. During the six larval stages, the larvae vary in size from 1.8 to 20 mm, with mature larvae reaching 20 mm.

Upon emerging, the larvae immediately begin to feed on various types of organic matter, such as animal manure, decaying fruit and vegetables, and food waste, with the rate of consumption increasing significantly after the third instar (Liu et al., 2019). In the 6th instar, the larvae undergo melanization, darkening the cuticle, and turning into prepupae. At this stage, the insect empties its digestive tract and stops feeding, migrating to dry areas to metamorphose into pupae over a period of 7–10 days.

During the pupal stage, which lasts at least 8 days, the larvae do not move or feed, culminating in the emergence of the adult (Silva & Hesselberg, 2019). Adult flies feed only on water, using the fat reserves accumulated during the larval stage. It does not damage crops, pollute the environment, spread disease, or invade homes or restaurants, preferring shaded areas (Liu et al., 2019) for maturing and mating. The reproductive cycle of the adult fly lasts for 5–8 days, after which the female dies shortly after oviposition (Silva & Hesselberg, 2019).

Figure 4: Life cycle of the black soldier fly. Adapted from an Insect School in 2023

The larvae have the ability to rapidly consume between 25 and 500 mg of fresh matter/larva/day, covering a wide variety of decomposing materials, such as decaying fruit and vegetables, coffee pulp, distillery grains, fish remains, and especially animal manure and human excrement (Huis et al., 2013).

Contrary to what was previously thought about the black soldier fly, in which adult insects sustained themselves exclusively from the fat reserves accumulated in the larval stage, recent studies investigating the midgut of adult BSF have reported that these flies can ingest and digest food. The quality and quantity of the ingested food affects the longevity of the flies. These findings suggest that adult BSF does not exclusively rely on nutrient and energy reserves accumulated during the larval stage (Bruno et al., 2019)

The nutritional composition of black soldier fly larvae meal varies depending on the chemical composition of the feeding substrate (Spranghers et al., 2017; Meneguz et al., 2018) and the weight and developmental stage of the larvae (Lalander et al., 2019). In general, they are rich in protein (350 to 610 g/kg crude protein) and lipids (70 to 420 g/kg ether extract) (Barragan-Fonseca et al., 2017). In addition, BSF contains 0.8–9 g/kg methionine, 3.4 to 33 g/kg lysine and 2.2 to 22.6 g/kg threonine (Elahi et al., 2022). Another important component of the composition of BSF larvae is chitin, present in the insect's exoskeleton (Xiong et al., 2023). This non-starch polysaccharide can be found in black soldier fly meals at levels of up to 87 g/kg and can reduce the digestibility of nutrients in the diet (Kroeckel et al., 2012). On the other hand, lower levels of chitin can increase the activity of the innate immune system and exert antibacterial effects (Xu et al., 2013).

According to Makkar et al. (2014), the larvae of the black soldier fly are a food source rich in fats, with a lipid content that varies from 7% to 39% in dry matter, depending on the substrates used to cultivate the larvae (Barragan-Fonseca et al., 2017). The lipids in BSF larvae can replace soybean oil in animal feed. Studies have shown that there were no adverse effects on the development and growth of chickens and Jian carp (Cyprinus carpio var. Jian) when 100% soybean oil was replaced with fat from *Hermetia illucens* larvae in the animals' diets (Schiavone et al., 2018).

Zotte et al. (2019) evaluated the black soldier fly (Hermetia illucens) as a food source for laying quails, analyzed live performance, the physicochemical quality of the eggs, the sensory profile and storage stability. They concluded that, based on the results of the experiment, black soldier fly larvae meal can be considered an alternative ingredient to soybean meal in diets for laying quails, up to an inclusion level of 15%. No negative effects were observed on the productive performance of the birds, and the eggs generally had satisfactory physicochemical characteristics and sensory profile in general.

Silva et al. (2024), when evaluating the effects of larvae meal from the black soldier fly (*Hermetia illucens*) on quail performance, concluded that the inclusion of 100 g/kg larvae meal improves the feed conversion ratio for growing quails, highlighting the potential of using insects in quail feed.

CONCLUSION

Incorporating insects and their co-products into quail feed is proving to be a solution that is not only viable, but also highly sustainable and innovative. The nutritional benefits associated with these ingredients, with their rich protein, amino acids and fatty acids, position them as a promising alternative for meeting the specific needs of quail. In addition, the sustainability inherent in insect production offers a responsible approach, which is in line with growing environmental concerns and the search for greener feeding practices in poultry farming.

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CHAPTER 4

EXPLORANDO OS ECOSSISTEMAS AQUÁTICOS: AQUICULTURA, FITOPLÂNCTON E QUALIDADE DA ÁGUA EM PESQUE-PAGUES BRASILEIROS

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RESUMO:. A aquicultura, prática ancestral de cultivo controlado em ambientes aquáticos, desempenha um papel crucial na produção alimentar global, abrangendo uma variedade de organismos aquáticos, como peixes, crustáceos, algas e moluscos. Nesse contexto, a comunidade de

microalgas planctônicas desempenha um papel vital na cadeia alimentar e na qualidade da água, influenciando diretamente a dinâmica dos viveiros de cultivo. A qualidade da água emerge como um elemento crucial para o sucesso da aquicultura, sendo impactada por diversos fatores, incluindo práticas de fertilização e manejo. Além disso, os pesque-pagues, empreendimentos voltados para a pesca esportiva, surgem como uma fonte adicional de renda dentro do setor aquicultura. No entanto, eles demandam um monitoramento rigoroso da qualidade da água devido aos potenciais impactos que podem ocorrer, necessitando de manejo adequado e medidas preventivas para garantir a sustentabilidade desses empreendimentos.
PALAVRAS-CHAVE: Aquicultura, pesque-pague, qualidade da água, comunidade fitoplanctônica,

EXPLORING AQUATIC ECOSYSTEMS: AQUACULTURE, PHYTOPLANKTON AND WATER QUALITY IN BRAZILIAN FISHING FARMS

ABSTRACT: Aquaculture, an ancient practice of controlled cultivation in aquatic environments, plays a crucial role in global food production, covering a variety of aquatic organisms, such as fish, crustaceans, algae and molluscs. In this context, the planktonic microalgae community plays a vital role in the food chain and water quality, directly influencing the dynamics of cultivation ponds. Water quality emerges as a crucial element for the success of aquaculture, being impacted by several factors, including fertilization and management practices. Furthermore, fishing services, enterprises focused on sport fishing, emerge as an additional source of income within the aquaculture sector. However, they require rigorous monitoring of water quality due to the potential impacts that may occur, requiring appropriate management and preventive measures to ensure the sustainability of these projects.
KEYWORDS: Aquaculture, fishing, water quality, phytoplankton community,

INTRODUÇÃO

A aquicultura é uma prática antiga e tradicional, encontrada em diversas culturas pelo mundo. Pode ser definida como o cultivo de animais ou vegetais em um espaço delimitado e controlado, que precisam de ambientes aquáticos para o desenvolvimento de parte ou da totalidade do seu ciclo vital, assim essa atividade engloba o cultivo de vários grupos aquáticos, dos quais os principais são: peixes, crustáceos, algas e moluscos. (OLIVEIRA, 2009, BRAGA; PORTO; TUCCI, 2006).

A comunidade de microalgas planctônicas ou fitoplâncton é constituída de organismos microscópicos e clorofilados que flutuam livremente na massa d'água e engloba algas e cianobactérias. Esses organismos, portanto, são fundamentais na manutenção dos ambientes aquáticos, pois além de serem produtores primários constituindo a base da cadeia alimentar, influenciam diretamente na qualidade da água, uma vez que, através da fotossíntese e da respiração inferem na dinâmica e produtividade de gases nos viveiros (SANT'ANNA; GENTIL; SILVA, 2006, MERCANTE et al., 2011).

A comunidade biótica dos viveiros de peixes é formada por vários organismos imensamente dependentes da qualidade da água e do equilíbrio entre organismos planctônicos e o meio ambiente, sendo que essa qualidade da água pode ser alterada por diversos fatores, particularmente pela fertilização (orgânica ou inorgânica) e pelo arraçoamento portanto, o monitoramento dos parâmetros limnológicos é imprescindível, para manter a estabilidade dinâmica entre todas as variáveis físicas, químicas e biológicas, tornando assim a produção de peixes e o sucesso econômico da piscicultura possíveis (ELER et al., 2001; ARANA, 2004; MATSUZAKI, MUCCI, ROCHA, 2004; LACHI, SIPAÚBA-TAVARES, 2008).

Pesque-Pague pode ser definido como um empreendimento comercial de pesca esportiva, realizada em um lago de água artificial ou natural e particular, povoado por peixes vindos da aquicultura (VENTURIERI, 2002). Esses sistemas além dos tanques para pesca, possuem uma estrutura capaz de atender aos visitantes, como restaurantes e atrativos para o turismo, produzindo uma ótima renda complementar. A conciliação destes serviços, com a aquicultura podem resultar em impactos positivos para o desenvolvimento sustentável das comunidades locais, bem como acarretar em prejuízos ambientais (EMBRAPA, 2003).

Muitas das interferências do homem em ambientes naturais acontecem sem nenhum planejamento, ocasionando frequentemente em mau uso dos recursos, principalmente dos hídricos, e esses danos mesmo com altos investimentos são difíceis de ser reparados, o que torna indispensável o manejo pertinente para empreendimentos que usem recursos naturais (PRESOTTO; CABIANCA, 2006).

Nesses empreendimentos, assim como em toda prática aquícola, a preocupação com a qualidade da água é de essencial importância para o ambiente (SIPAÚBA-TAVARES; GUARIGLIA; BRAGA, 2007), pois influencia diretamente na composição e dinâmica da comunidade fitoplanctônica (SILVA 2005).

REVISÃO DE LITERATURA

Estudos da qualidade da água em pesque-pagues no Brasil

O conhecimento acerca da pesca esportiva no Brasil ainda é pouco (GÓES, 2015), são raros os estudos relacionados a qualidade da água em pesque-pagues (MERCANTE et al., 2005), sendo que a maior parte, concentra-se no Estado de São Paulo na Região Sudeste, seguido do Estado do Ceará na Região Nordeste com três trabalhos, do Estado de Goiás na Região Centro-Oeste e do Estado do Paraná na Região Sul, ambos com apenas um trabalho.

Na Região Centro-Oeste no Município de Inhumas/GO, Blanco et al. (2013) realizaram uma avaliação qualitativa de comunidades fitoplanctônicas em viveiros de pesque-pague e sua relação com a saúde pública. Os resultados dos parâmetros físico-químicos não

apresentaram qualquer tipo de associação com os dados biológicos, apesar de em alguns casos não estar de acordo com as características químicas da água, adequadas para o cultivo de peixes. O pH avaliado nos ambientes estudados variou entre 7 e 8, a temperatura variou entre 34 e 36 ºC, podendo causar interferências na dinâmica do pH, já o oxigênio dissolvido não apresentou anormalidades, apesar dos ambientes serem eutrofizados. No entanto, os autores recomendam que as variáveis físico-químicas devem ser avaliadas com cautela, uma vez que esses parâmetros não constituíram o objetivo principal desse trabalho.

Fernandes, Gomes e Agostinho (2003) na Região Sul, realizaram uma pesquisa em três pesque-pagues nas imediações do Município de Maringá/PR, identificaram a presença de espécies exóticas nos cursos d'água adjacentes aos pesque-pague e os problemas característicos dos mesmos. Dessa forma, dos 757 peixes analisados, das 11 espécies identificadas, duas eram exóticas. Segundo os autores os proprietários apresentaram pouco preparo para desempenho da atividade, tornando quase impossivel evitar o escape de espécies.

Na Região Nordeste no Município de Crato/CE, Alencar et al. (2011) analisaram os parâmetros ambientais e de qualidade da água no pesque-pague do Clube Recreativo Grangeiro. De acordo com os autores não foi diagnosticado nenhum impacto significativo na área, e não houve registro de contaminação ou poluição por produtos químicos, a análise ambiental foi positiva. Os parâmetros físico-químicos foram condizentes com os valores considerados normais segundo a legislação, afora a análise do teor de amônia que se mostrou em nível acima do ideal, podendo comprometer a sobrevivência dos peixes.

Góes (2015) avaliou a influência das variáveis físico-químicas sobre estrutura da comunidade fitoplanctônica em diferentes períodos (seco e chuvoso), em dois lagos de pesqueiros no semiáridos Cearense no Município de Crato. Os valores dos parâmetros: Temperatura, transparência, pH, condutividade elétrica e oxigênio dissolvido mostraram-se variados tanto entre os períodos quanto entre os lagos. Os valores do pH apresentaram-se dentro dos padrões da resolução do CONAMA, exceto no mês de março. Já o oxigênio dissolvido (OD) apresentou-se abaixo (<5), podendo ocasionar a mortandade dos peixes e desequilíbrio nos processos biológicos do ecossistema aquático.

Ainda nesse mesmo ambiente Alves, Silva e Melo Junior (2016) avaliaram através de parâmetros limnológicos a qualidade da água de um dos lagos do Pesque-Pague Quinta dos Lobos entre duas sazonalidades. Comparando os resultados da pesquisa com a resolução do CONAMA, os autores detectaram que os parâmetros estiveram adequados à prática da piscicultura, menos os sólidos totais dissolvidos na estação seca, pois todos os valores apresentaram-se acima dos limites legais. Verificou-se também uma alteração expressiva entre o período seco e chuvoso para os parâmetros: transparência, condutividade, sólidos totais dissolvidos e potencial hidrogeniônico, já os outros parâmetros foram praticamente similares.

Na Região Sudeste Mercante et al. (2004), avaliaram o processo de eutrofização nos períodos seco (inverno) e chuvoso (verão) em 30 pesque-pagues da Região Metropolitana de São Paulo, para conseguirem respostas sobre a qualidade da água, utilizaram como instrumento o índice de estado trófico, sendo encontrados elevados valores de nitrogênio e fósforo, e, consequentemente, grande eutrofização desses corpos d'água. O estudo sugeriu que as estratégias de manejo exercem maior influência sobre a dinâmica dos sistemas do que propriamente as variações sazonais, pois as análises de variância não apresentaram diferenças significativas entre as duas épocas do ano.

Nestes mesmos sistemas, Mercante et al. (2005) através de variáveis abióticas realizaram uma análise comparativa da influência dos períodos seco e chuvoso na qualidade da água. Os altos valores de condutividade elétrica e de saturação do oxigênio indicaram excesso de matéria orgânica, resultando em uma degradação da qualidade da água. Não foram encontradas grandes diferenças entre as variáveis e os diferentes períodos, indicando o manejo como maior influência na dinâmica dos sistemas do que as variações climáticas.

Prosseguindo os estudos nos mesmos pesqueiros, Cabianca (2005), descreveu a composição, a estrutura e a dinâmica da comunidade zooplanctônica e suas relações com as variáveis bióticas e abióticas. Os resultados encontrados revelaram que a comunidade destes ambientes foi semelhante tanto em estrutura quanto em composição à de lagos eutróficos, e que se o manejo for inadequado pode produzir efeitos graves do ponto de vista ecológico e sanitário.

Próximo à cidade de Campinas/SP, Queiroz et al. (2006) avaliaram a qualidade da água de nove pesque-pagues. Fizeram a análise físico-química da água e utilizaram questionários em relação ao manejo dos lagos, estoque de peixe, taxa de alimentação, características do entorno dos lagos e determinaram que de forma geral os pesque-pagues estudados tiveram um desempenho ambiental positivo, mas com desenvolvimento pobre relacionado a ações de manejo.

Castro et al. (2006) realizaram uma pesquisa sócio-econômica e ambiental englobando 24 pesque-pagues na Bacia do Rio Tietê, Estado de São Paulo. Foram entrevistados os proprietários e os pescadores esportivos e feita uma análise tipológica dos pesqueiros, caracterizando-se em quatro tipos: serviço básico, básico mais opcionais e proprietários com ou sem capacitação. Concluíram que os pesque-pagues apareceram como uma atividade alternativa de renda e lazer, embora atualmente não seja mais lucrativa como na época da sua implantação. Com relação à qualidade da água, os valores das concentrações de nitrogênio e fósforo apontaram a presença de grande carga orgânica, que favoreceu para a deterioração dos corpos d'água do entorno, demonstrando ainda a carência de um manejo adequado dos lagos dos pesqueiros e da implantação de estação de tratamento da água.

Esteves e Sant'Anna (2006) ainda relacionado a pesque-pague desta mesma bacia, fizeram uma análise em 30 pesqueiros sob uma visão integrada de meio ambiente, saúde pública e manejo.

Avaliando a dinâmica de movimentação de peixes em um lago de pesque-solte no Estado de São Paulo, ainda nesse mesmo ano, Sanches e Graça-Lopes (2006), descobriram que a dinâmica de peixes praticada leva à imobilização de capital, põe em risco a segurança sanitária do ambiente e torna a propriedade uma exportadora de poluição via água de despejo. Segundo os autores a rentabilidade positiva do empreendimento depende dos critérios para a escolha das espécies e as técnicas de manejo adequadas.

No Município de Dracena / SP, Sandre et al. (2008), realizaram uma pesquisa objetivando conhecer aspectos estruturais em três pesque-pagues e sua influência na qualidade da água, onde fizeram uma análise físico-química da água e revelaram que todos os pesqueiros estudados estavam habilitados para a criação de peixes tropicais, uma vez que os valores ficaram dentro da faixa tolerável para a sobrevivência dos animais.

Prosseguindo os estudos, nesses mesmos pesqueiros, Sandre et al. (2009), analisaram a influência dos fatores climáticos durante as estações de verão e inverno nos parâmetros de qualidade da água. Apesar das variáveis: temperatura da água, oxigênio dissolvido, pH, transparência, alcalinidade e amônia total terem exibido alterações durante as estações analisadas, dependendo das características estruturais de cada propriedade, os sistemas de pesque-pague mostraram condições adequadas para desempenho e sobrevivência dos peixes.

Em um estudo Sanches e Lopes (2009) buscaram avaliar a dinâmica de cultivo e comercialização de peixes (aquisição, estocagem e venda) em um empreendimento de pesca esportiva do tipo "pesque e solte" no Estado de São Paulo, efetuaram o levantamento dos dados através das "comandas de venda" e das notas fiscais de compra de peixes. A pesquisa mostrou que a dinâmica de movimentação de peixes praticada leva à imobilização de capital, põe em risco a segurança sanitária do viveiro e torna a propriedade fonte de poluição via água de despejo. Portanto a inserção de novas espécies deve obedecer ao ritmo de saída (pesca/venda) dos peixes, evitando-se ultrapassar a capacidade de suporte do viveiro.

Nunes (2009) analisou as condições da qualidade da água nos períodos de seca e de chuva, as características e o manejo ambiental de cinco pesque-pagues da região nordeste do Estado de São Paulo. Nesse estudo foram observadas diferentes formas de manejos praticados e a falta de conhecimento técnico por parte dos proprietários e funcionários. A autora sugeriu que a qualidade da água deveria ser monitorada.

Ainda nesse mesmo ano, em Jaboticabal/SP, Millan (2009) estudou a dinâmica da qualidade da água em tanques de peixes de sistema pesque-pague entre dois períodos (seco e chuvoso), através das variáveis físicas e químicas da água: temperatura, pH, oxigênio dissolvido, dureza total, alcalinidade total, amônia, nitrato, nitrito, fósforo total,

ortofosfato, clorofila-a, DBO5. O autor observou que as duas estações, assim como o manejo aplicado ao sistema, interferiram diretamente na dinâmica da qualidade da água e que o fluxo contínuo de abastecimento de água, acumulou nutrientes ao longo dos pontos, principalmente no último tanque. Entretanto, o canal efluente contendo macrófitas e rochas, com aproximadamente 400m de extensão, propiciou melhoria na qualidade da água que é lançada no ambiente.

Estudando a qualidade da água de efluentes de pesqueiros situados na bacia hidrográfica do Alto Tietê, Mercante et al. (2011), avaliaram as concentrações e cargas de emissão dos efluentes de acordo com os padrões e recomendações da resolução CONAMA 357/2005, empregando também o Índice de Estado Trófico (IET) para descrever a qualidade da água lançada no corpo receptor. Os resultados mostraram valores fora dos padrões recomendados gerando um processo de degradação da qualidade da água.

Bonazzi (2013) realizou um estudo onde associou o manejo das atividades em quatro viveiros de engorda e quatro de pesque-pagues no município de Corumbataí/SP com características limnológicas, bem como descreveu o impacto provocado na água utilizada nestas atividades e fez uma avaliação nictemeral. A autora observou que o local que recebia os efluentes dos viveiros apresentou maiores concentrações de nutrientes e concluiu que das variações limnológicas que ocorreram ao longo do dia (temperatura e oxigênio dissolvido) foram mais acentuados e também que os diferentes manejos empregados aos viveiros tornaram, os de engorda, ambientes mais eutrofizados especialmente no verão.

Siqueira (2015) avaliou a influência da variação sazonal, representada pela época da seca e época das chuvas, sobre a qualidade da água e do pescado (tilápia do Nilo – *Oreochromis niloticus*) oriundos de cinco diferentes pesque-pagues localizados no Estado de São Paulo. Foram realizadas análises físicas e químicas (temperatura, oxigênio dissolvido e pH) e microbiológica da água de cultivo. O autor observou que houve diferença significativa ($p<0,05$) entre os períodos analisados para a temperatura, o oxigênio dissolvido e o pH da água de cultivo dos pesque-pagues e concluiu que o período das chuvas interferiu de forma negativa na qualidade da água e do pescado, mas, independentemente do período, são necessárias medidas higiênico-sanitárias preventivas.

Estudos da comunidade de microalgas planctônicas em pesque-pagues no Brasil

No Brasil o estudo do fitoplâncton em pesqueiros possui grande importância para a piscicultura, porém os estudos nessa área ainda são bastante escassos, com poucos trabalhos, sendo que a maioria se concentra na região Sudeste, especialmente no Estado de São Paulo, seguido da Região Nordeste com quatro trabalhos no Estado do Ceará e da Região Centro-Oeste com apenas dois trabalhos no Estado de Goiás.

No Município de Descalvado/SP na Região Sudeste Eler et al. (2001) realizaram exames clínicos em peixes moribundos de um pesque-pague, após analisarem, associaram a mortandade dos peixes a uma floração de cianobactérias, já que os peixes apresentavam sinais claros da intoxicação como massas de algas na pele e nas brânquias, hemorragia nas brânquias e na pele. O fitoplâncton apresentou dominância (>60%) das espécies *Anabaena spiroides* e *microcystis aeruginosa* (Kützing) Kützing, espécies altamente tóxicas.

Na zona Sul da Cidade de São Paulo, Matsuzaki, Mucci e Rocha (2004) realizaram uma análise qualitativa da comunidade fitoplanctônica de um pesque–pague e identificaram 91 táxons distribuídos em oito classes: Chlorophyceae (52%), Cyanophyceae (16%), Euglenophyceae (12%), Zygnemaphyceae (10%), Bacillariophyceae (5%), Xanthophyceae (3%), Dinophyceae (1%) e Chrysophyceae (1%). Dentre as espécies de cianofíceas identificadas, destacaram-se *Microcystis panniformis* Komárek, *Cylindrospermopsis raciborskii* (Woloszynska) Seenayya & Subba Raju, *Anabaena* cf *danica* e *Anabaena* sp., que apresentaram maior importância do ponto de vista sanitário devido à produção de toxinas.

Na Região Metropolitana de São Paulo, Silva (2005), tendo em vista que o gênero *Microcystis* (Cyanobactéria) é bastante encontrado em ambientes eutrofizados, que as microcistinas acumulam-se na musculatura dos peixes e que o estudo destes organismos em pesque-pague é muito escasso, analisou a ocorrência das espécies de *Microcystis* bem como a relação com os fatores ambientais de 20 pesqueiros da região metropolitana de São Paulo. A autora registrou a presença de quatro espécies: *M. aeruginosa, M. protocystis* W. B. Crow, *M. wesenbergii* **(**Komárek) Komárek ex Komárek *e M. panniformis,* porém outras cianobactérias apresentaram-se com elevadas densidades, as espécies *Aphanocapsa Holsatica, A. elachista, Merismopedia tenuissima e Synechococcus* sp. No período chuvoso as espécies de *Microcystis* apresentaram maiores biomassa, frequência e densidade e distribuição. Os parâmetros abióticos pouco variaram nas duas sazonalidades, e a ação antrópica influenciou diretamente na dinâmica desses sistemas.

Também em pesqueiros da Região Metropolitana de São Paulo, Honda et al. (2006), fizeram um levantamento das condições sanitárias da água em relação à presença de Cianobactérias, utilizando o meio de isolamento de cultura. Com a análise de cultura os autores afirmaram que no período seco há a presença de espécies tóxicas de cianobactérias, principalmente do gênero *Microcystis*, além de microcistinas (cianotoxinas) que ocorreram em 46,7% nos pesqueiros no período chuvoso. Com base nos resultados os autores alertaram a comunidade sobre uma possível via de intoxicação alimentar pelo consumo de peixes contaminados por cianotoxinas.

Ainda na Região Metropolitana de São Paulo, Sant'Anna, Gentil e Silva (2006), analisaram a comunidade fitoplanctônica de 30 pesqueiros e observaram que as algas verdes (Chlorophyceae) seguidas pelas algas azuis (Cyanobateria), representaram a maior riqueza de espécies durante o período seco e chuvoso. Dentre os gêneros de

clorofíceas mais amplamente distribuídos nos pesqueiros destacaram-se: *Coelastrum, Dictyosphaerium, Scenedesmus, Monoraphidium e Pediastrum* e dentre os gêneros de cianobactérias, segundo grupo mais representativo destacaram-se *Aphanocapsa, Merismopedia, Microcystis e Pseudoanabena.* Foi determinada a dominância apenas da classe Cyanobacteria e observado que um único pesqueiro foi exceção à dominância das cianobactérias coloniais, o qual apresentou densa floração e dominância de *Cylindrospermopsis raciborskii*, espécie filamentosa.

Gentil (2007), ainda nesses mesmos ambientes aquáticos buscou conhecer a estrutura da comunidade fitoplanctônica e suas relações com as variáveis ambientais, buscando contribuir com dados para subsidiar o manejo adequado desses corpos d'água tanto do ponto de vista ecológico como sanitário. O estudo foi feito na primavera e verão. Foram encontrados 708 táxons, distribuídos em nove classes (Bacillariophyceae, Chlorophycae, Cyanobacteria, Chrysophyceae, Cryptophyceae, Dinophyceae, Euglenophyceae, Xanthophyceae e Zygnemaphyceae) e as mais representativas quanto a riqueza e densidade foram as Cyanobacterias. Os resultados qualitativos e quantitativos da comunidade fitoplanctônica dos corpos de águas estudados, demonstraram que esses sistemas são classificados como eutróficos e hipereutrófico, o que a autora afirma que esses resultados podem ser utilizados como uma boa ferramenta para a avaliação do grau de trofia do ecossistema.

No município de Jaboticabal na Região Metropolitana de Ribeirão Preto (SP) Lachi e Sipaúba-Tavares (2008) realizaram uma análise da qualidade da água com base em variáveis limnológicas e a comunidade fitoplanctônica, o estudo foi feito em viveiros de piscicultura utilizado para fins de pesca esportiva e irrigação. Observou-se que no viveiro as variáveis ambientais apresentaram cargas nutricionais, condutividade, sólidos totais solúveis e dureza total elevados influenciando, assim nas varáveis biológicas como fitoplâncton e clorofila *a*. Dentre as classes encontradas a Zygnematophyceae foi a de maior riqueza em número de indivíduos, com 34% dos indivíduos, a classe Chlorophyceae foi a mais representativa com relação ao número de gênero com 33% sobre o total de indivíduos registrados. As autoras expressaram preocupação com a necessidade de ser reavaliada a utilização deste viveiro para fins de irrigação em razão das condições eutróficas da água, presença de cianobactérias potencialmente tóxicas e do manejo empregado.

Continuando os estudos em Jaboticabal (SP), Millan (2009) analisou as variações da comunidade fitoplanctônica em um pesqueiro durante os períodos de seca e chuva. No fitoplâncton foram identificadas 52 espécies, distribuídas em: Cyanobacteria (8 spp.), Chlorophyceae (16 spp.), Oedogoniophyceae (1sp.), Zygnematophyceae (9 spp.), Dinophyceae (1sp.), Euglenophyceae (2 spp.), Bacillariophyceae (14 spp.) e Chrysophyceae (1sp.). Chlorophyceae foi a classe mais representativa com relação a riqueza de espécies principalmente nos tanques, durante os dois períodos, O autor concluiu que o ecossistema estudado sofreu influência tanto de manejo quanto da variação sazonal.

Em um estudo do levantamento da biodiversidade fitoplanctônica em 10 pesqueiros da Região Metropolitana de São Paulo, Rosini (2010) identificou 145 táxons, distribuídos em nove classes, 20 ordens, 35 famílias, 73 gêneros, 144 espécies, 16 variedades e três formas taxonômicas. A classe Chlorophyceae com 64 táxons (44%) teve a maior riqueza específica, seguida por Bacillariophyceae com 24 táxons (17%), Cyanobacteria com 23 táxons (16%), Zygnematophyceae com 13 táxons (9%), Euglenophyceae com 11 táxons (8%), Coscinodiscophyceae com quatro táxons (3%), Xanthophyceae três táxons (2%), Fragilariophyceae com dois táxons (1,5%) e Dinophyceae com um táxon (0,5%). Dos gêneros de cianobactérias tóxicas *Microcystis, Radiocystis, Planktothrix, Anabaena* e *Cylindrospermopsis*, todos foram registrados em pelo menos um dos pesqueiros avaliados.

Nesses dez pesqueiros na Região Metropolitana de São Paulo, Rosini, Sant'Anna e Tucci (2012) identificaram 38 táxons, distribuídos em oito famílias, 19 gêneros e quatro variedades não típicas das espécies, num levantamento das Chlorococcales, Chlorophyceae. Dos táxons identificados, 19 apresentaram frequência de ocorrência entre 30-55%, indicando melhor distribuição dessas espécies entre os pesqueiros estudados e corroborando com as informações da literatura, que discutem que várias espécies de Chlorococcales, Chlorophyceae são bem distribuídas entre os diferentes sistemas aquáticos brasileiros.

Continuando os estudos Rosini, Sant'Anna e Tucci (2013a) avaliaram nesses mesmos sistemas aquáticos a biodiversidade das Cianobactérias, que foram representadas por 23 espécies pertencentes a cinco ordens, sete famílias e 15 gêneros. Synechococcales foi a ordem com maior riqueza de espécies (8), seguida por Chroococcales (6), Pseudanabaenales (5), Oscillatoriales (2) e Nostocales (2). Os gêneros mais representativos foram *Aphanocapsa* Nägeli e *Microcystis* Kützing ex Lemmermann, com cinco e quatro táxons respectivamente. Dos 23 táxons identificados, 22% foram considerados frequentes, 35% pouco frequentes e 43% raros. Sendo que a espécie *Aphanocapsa annulata* foi a primeira citação para o Estado de São Paulo.

Rosini, Sant'Anna e Tucci (2013b) realizaram ainda nesses mesmo dez pesqueiros o levantamento das Scenedesmaceae. Foram identificadas 26 espécies distribuídas em 10 gêneros, 23 espécies, duas variedades e uma forma taxonômica. Os gêneros *Scenedesmus* e *Desmodesmus* foram os mais bem representados com nove e oito espécies, respectivamente. Os táxons *Desmodesmus lefevrei* (Deflandre) An, Friedl e Hegewald, *Dicloster acuatus* Jao, Wei e Hu e *Scenedesmus baculiformis* Chodat apareceram citados pela primeira vez para o Estado de São Paulo.

Em Minas Gerais Pandolpho et al. (2013) fizeram um estudo da avaliação da qualidade das águas de tanques de pesque-pagues por meio do monitoramento das cianobactérias em seis municípios da região dos Inconfidentes. Foram identificados além das populações de Chlorophyta, cinco gêneros de cianobactérias: *Phormidium* sp., *Geitlerinema* sp., *Anabaena* sp., *Nostoc* sp. e *Microcystis aeruginosa*, e todos os cinco

gêneros tem alto potencial para produção de cianotoxinas. Os autores realizaram ensaios de toxicidade administrando por via oral extratos brutos de *Microcystis* e *Phormidium* em camundongos, os resultados mostraram que as *Microcystis* obtidas nos pesque-pagues produziam cianotoxinas enquanto o gênero *Phormidium* não produziu ou a dose utilizada no ensaio foi insuficiente para obtenção da resposta toxicológica.

Costa et al. (2014) no Estado do Rio de Janeiro, analisaram a qualidade da água em 30 sistemas de piscicultura (utilizados para criação, engorda e pesca recreativa). Nenhum dos sistemas apresentou todas as variáveis de qualidade da água dentro dos limites aceitas para sistemas destinados a cultivo de peixes, de acordo com a legislação Brasileira (CONAMA), onde os mesmo variaram de eutrófico a hipereutrófico com alta biomassa de cianobactérias sendo as espécies mais abundantes: *Aphanocapsa delicatissima, A. incerta, A. elachista, Chrococcus* cf. *dispersus, C. minimus, Geitlerinema amphibium, Merismopedia tenuissima, Microcystis aeruginosa, Pannus mycrocystiformis, Planktolyngbya circumcreta* e *Pseudanabaena* cf. *acicularis.*

Na Região Nordeste, Góes et al. (2011) foram os pioneiros nos estudos sobre fitoplâncton em pesqueiros no Ceará, onde determinaram a ocorrência de clorofíceas em um lago de pesque-pague, localizado no Clube Recreativo Grangeiro na cidade de Crato. Foram identificados 10 táxons da divisão Chlorophyta, sendo a família Desmidiaceae com maior contribuição e melhor representada pelo gênero *Staurastrum,* e as espécies *Coelastrum* sp. e *Kirchneriella* sp. destacadas como muito frequentes. Relataram que o lago estudado apresentou condições favoráveis para crescimento de algas, principalmente de clorofíceas.

Prosseguindo os estudos no Ceará, Góes et al. (2013) buscaram conhecer a diversidade de algas planctônicas e sua relação com a qualidade da água em um pesqueiro no Município do Crato (CE). Identificaram 98 táxons distribuídos em cinco divisões: Chlorophyta que contribuiu com 62% do total de táxons ocorrentes, seguida de Euglenophyta (17%), Cyanobacteria (10%), Bacillariophyta (8%) e Dinophyta (3%). A comunidade apresentou índices de baixa diversidade (45%) e média (33%). Informações levantadas pelos autores demonstraram que a característica mais marcante do pesqueiro foi a estabilidade das águas nos níveis de meso a eutróficas, o que não impossibilitou a riqueza de espécies.

Também no Município de Crato/CE, Góes (2015) realizou uma pesquisa objetivando determinar a composição e estrutura da comunidade fitoplanctônica em dois lagos do Pesque-Pague Quinta dos Lobos em diferentes períodos sazonais. Foram identificadas 113 espécies, distribuídas em oito classes taxonômicas: Cyanophyceae (16 spp.), Chlorophyceae (59 spp.), Bacillariophyceae (6 spp.), Cryptophyceae (2 spp.), Euglenophyceae (17 spp.) Dinophyceae (2 spp.), Xanthophyceae (4 spp.) e Zygnemaphyceae (7 spp.), sendo que destas, a que apresentou maior riqueza foi Chlorophyceae, correspondendo a 52% das espécies. Com relação a frequência de ocorrência, oito táxons foram considerados

frequentes: *Synechocystis aquatilis*, *Chlorella minutissima*, *Chlorococccum infusionum*, *Crucigenia tetrapedia*, *Mucidosphaerium pulchellum*, *Monoraphidium contortum*, *Tetraedron minimum e Euastrum rectangulare*. A comunidade fitoplanctônica apresentou ampla distribuição e alta diversidade, especialmente no L1 (89%) e em L2 apenas 45%.

Ainda no Estado do Ceará Góes et al. (2016) realizaram um estudo com o objetivo de conhecer a composição fitoplanctônica ocorrente em dois pesqueiros no Município do Crato. Foram identificados 100 táxons distribuídos em cinco divisões: Chlorophyta (56%), seguida de Euglenophyta (18%), Cyanobacteria (16%), Bacillariophyta (7%) e Dinophyta (3%). Das famílias identificadas a Scenedesmaceae foi a mais representativa com 26 táxons, sendo os gêneros *Desmodesmus* e *Scenedesmus* com mais diversidade de espécies. Dentre as espécies registradas, *Desmodesmus comunis* (Hegewald) Hegewald, *Desmodesmus opoliensis* (P. Hichter) Hegewald (Chlorophyta) e *Aphanocapsa* sp. (Cyanobacteria) foram classificados como dominantes, enquanto *Desmodesmus armatus* (R. Chodat) E. Hegewald e *Scenedesmus producto-capitatus* Schumula, outras duas espécies de Chlorophyta foram classificadas como abundantes. Com relação a frequência de ocorrência 10% foram classificadas como muito frequentes, 14% frequentes e as demais pouco frequentes. Cerca de 75% da comunidade apresentou média diversidade e distribuição equitativa dos táxons. Ainda foi possível caracterizar os ecossistemas com nível trófico de meso a eutrófico com as informações levantadas em relação à comunidade fitoplanctônica.

Na Região Cento-Oeste, Nogueira, Gama Júnior e Alessandro (2011) fizeram uma listagem das espécies de cianobactérias planctônicas ocorrentes em um pesqueiro na área Municipal de Goiânia (Goiás). Identificaram 31 táxons de cianobactérias pertencentes aos gêneros *Dolichospermum* (cinco spp.), *Aphanocapsa* (quatro spp.), *Microcystis* (três spp.), *Pseudanabaena* (três spp.), *Radiocystis* (duas spp.), *Oscillatoria* (duas spp.), *Bacularia*, *Coelosphaerium*, *Cylindrospermopsis*, *Geitlerinema*, *Glaucospira*, *Limnothrix*, *Pannus*, *Phormidium*, *Planktolyngbya*, *Planktothrix*, *Sphaerocavum* e *Synechocystis*, todos esses últimos com uma espécie cada e 13 dessas aparecem na literatura como potencialmente tóxicas.

Blanco et al. (2013) realizaram uma avaliação qualitativa da comunidade fitoplanctônica em viveiros de pesque-pagues e sua relação com a saúde pública no Município de Inhumas/GO. Nas cinco áreas amostradas nas duas estações, foram identificadas 41 gêneros, 31 famílias,19 ordens, oito classes e cinco divisões. A maior representatividade de táxons identificados pertenceu à divisão Cyanobacteria e do total de gêneros encontrados, quase 50% foram exclusivos, isto é, encontrados em apenas uma das cinco áreas amostradas quando comparadas entre si e apesar de muitos destes gêneros se apresentarem em mais de um desses ambientes, nenhum deles foi comum a todos os pesque pagues. Visto que em todos os pesqueiros foram encontrados organismos produtores de toxinas nocivas a humanos e animais, próprios de ambientes ricamente eutrofizados, os autores concluíram que os ambientes estudados não possuem condições sanitárias e ambientais para cultivo e consumo de peixes.

CONCLUSÕES

Este estudo revela muitos desafios, como a presença de espécies exóticas e a falta de preparo por parte dos proprietários dos pegues-pagues. A presença de espécies exóticas pode desencadear desequilíbrios nos ecossistemas aquáticos locais, competindo com espécies nativas e causando danos ambientais significativos. além disso, a falta de preparo por parte dos proprietários dos pesque-pagues pode resultar em práticas inadequadas de manejo da água e dos estoques de peixes, levando a impactos negativos na qualidade da água e na saúde dos organismos aquáticos.

Diante disso, é crucial implementar medidas preventivas, como a realização de avaliações de risco antes da introdução de novas espécies nos pesque-pagues e a capacitação dos proprietários em boas práticas de manejo e conservação ambiental. além disso, o desenvolvimento de regulamentações claras e a fiscalização eficaz são essenciais para garantir o cumprimento das normas ambientais e a sustentabilidade a longo prazo desses empreendimentos.

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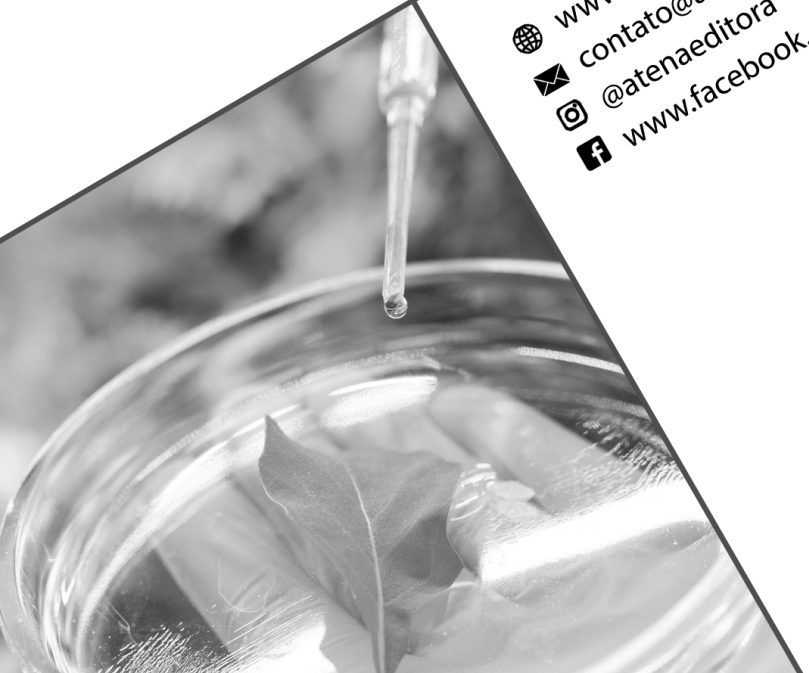

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