POULTRY PRODUCTION NEXUS-FEW: A STUDY ABOUT THE EFFECT OF PUBLIC AND PRIVATE INVESTMENTS ON THE EFFICIENT USE OF WATER

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ABSTRACT

Purpose: This paper aims to analyse how investments in innovation, research and development in poultry production affect the water's efficient use.

Theoretical framework: To understand water stress, the literature review addresses content related to the analysis of the balance between water and food production (Nexus Few), as well as those that support the analysis of the effects of investments in research and development in poultry production and improving the efficient use of water.

Method/design/approach: The data were collected from the FAOSTAT database, where were analysed the investments in research and development (government and private), poultry production, water stress and efficient water use (US$/m³). The period of analysis is from 2005 to 2019, and priority was given to countries with the highest production of poultry, based on available data (Brazil, India, Mexico, Myanmar and Russia).

Results and conclusion: the results reveal that there is interdependence between water and poultry production. On the one hand, factors that can lead to water stress (climate, competition for water, food production) can also affect poultry production, as the more water stress, the greater the risk for poultry production that depends on these resources. On the other hand, public and private investments in research and development (R&D) can be crucial to reduce water stress, improve water use efficiency and poultry production performance.

Research implications: The study shows to poultry farmers that water stress (demand greater than supply) interferes with poultry production, and that private or public investment in R&D is important for the efficient use of water. The paper revews to governments and companies what actions are necessary to encourage the sector to seek the Nexus Few (balance between water and food production).

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Originality/value: expands understanding of the sustainability of the poultry production chain and the goals of sustainable development, in order to encourage the efficient use of water. The study reveals too the importance of public and private investments to promote the balance between water use and poultry production.

Keywords: Nexus-Few, Water Stress, Poultry Production, Investments.

NEXUS-FEW DA PRODUÇÃO DE AVES: ESTUDO SOBRE O EFEITO DE INVESTIMENTOS PÚBLICOS E PRIVADOS PARA O USO EFICIENTE DA ÁGUA

RESUMO

Objetivo: analisar como os investimentos em inovação, pesquisa e desenvolvimento na produção de aves de corte afetam no uso eficiente da água.

Referencial teórico: o referencial teórico corresponde conteúdos relacionados à análise do equilíbrio entre água e produção de alimentos (Nexus-Few) para compreender o estresse hídrico, bem como aqueles que subsidiam a análise dos efeitos de investimentos em pesquisa e desenvolvimento na produção de aves, na melhoria do uso eficiente da água.

Método: foram analisados estatisticamente dados disponíveis na plataforma FAOSTAT da Food and Agriculture Organization of the United Nations (FAO) a respeito dos investimentos em pesquisa e desenvolvimento (governamental e privado), produção de aves (mais precisamente aqueles realizados pelo setor governamental e os desembolsados pelo setor privado), estresse hídrico e uso eficiente da água (US$/m³). O período de análise é de 2005 a 2019, e para compor a amostra foram priorizados os países com maior produção de aves de corte e que possuíam os dados disponíveis (Brasil, Índia, México, Myanmar e Rússia).

Resultados e conclusão: os resultados revelam que há interdependência entre água e produção de aves. De um lado fatores que podem levar ao estresse da água (clima, competição pela água, produção de alimentos) também podem afetar a produção de aves, pois quanto mais estresse de água maior é o risco para a produção avícola que depende destes recursos. Por outro lado, investimentos públicos e privados em pesquisa e desenvolvimento (P&D) podem ser determinantes para reduzir estresse hídrico, melhorar a eficiência no uso da água e o desempenho da produção de aves.

Implicações da pesquisa: o estudo mostra aos avicultores que o estresse da água (demanda maior que a oferta) interfere na produção das aves. E que o investimento privado ou público em P&D é importante para o uso eficiente da água. E, mostra aos governos e empresas que ações são necessárias para incentivar o setor pela busca do Nexus Few (equilíbrio entre água e produção de alimentos).

Originalidade/valor: amplia a compreensão sobre a sustentabilidade da cadeia produtiva de aves e os objetivos de desenvolvimento sustentável, de forma a fomentar o uso eficiente de água e revela a importância dos investimentos públicos e privados para promover o equilíbrio entre o uso da água e a produção de aves.

Palavras-chave: Nexus-Few, Estresse Hídrico, Produção de Aves, Investimentos.

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1 INTRODUCTION

The rational use of water resources has been the subject of the United Nations (UN) Global Agenda 2030, in the face of the challenge of water availability for the survival of the inhabitants of the Earth (Vanham et al., 2013). At the same time, water stress (relationship between water demand and availability) is identified as one of the main bottlenecks for sustainable economic growth (Moro et al., 2018; Grejo & Lunkes, 2022). The sixth UN Sustainable Development Goal (SDG-6) suggests as a global goal to substantially increase
water use efficiency in all sectors and ensure sustainable withdrawals and fresh water supply for all (UN, 2015). This goal requires countries and production systems to commit to the efficient use of water, to do so, one must change processes and products to consume this resource efficiently.

The relevance of achieving the SDG-6 targets is justified by the urgency of the environmental problems experienced today. Empirical evidence reveals that the consequences of unbalanced development have led the world to suffer from physical factors such as extreme weather and natural risks, both in the supply of water and energy, and in food production (Challinor et al., 2010; Bandara & Cai, 2014; Famiglietti, 2014; Schmitt et al., 2020).

Specifically, the poultry production chain is water-intensive, from breeding to processing (SASB, 2021). In addition, companies in the sector generate wastewater, or effluents, and may face higher operating costs or loss of revenue due to water scarcity, increased per capita consumption, poor water management, climate change, and changes in regulations (Govoni et al., 2021).

What is known is that inefficient water consumption and the discharge of effluents into rivers and streams have led to diminished supply of surface water (rivers) and groundwater (groundwater table) in various parts of the world (Rahmani et al., 2023). In this sense, the relationship between food production, climate effects and the management of social and economic systems affect the availability of water and hinder economic development (Govoni et al., 2021; Brito, 2018; Lathuillière et al., 2018). On the other hand, investments in innovation, research and development (R&D) have contributed to the improvement of sustainable water resource management, as they make processes and products more efficient (Lunkes et al., 2020; Rosa et al., 2020; Rahmani et al., 2023). Thus, investments in R&D are needed to reduce pressure on water resources, either in reducing demand or increasing water supply (Michetti et al., 2019).

However, there is an emerging literature on Nexus-Few (nexus between food, energy, and water) understood as a systems-based approach that explicitly recognizes food, energy, and water subsystems as interconnected and interdependent (Bazilian et al., 2011, Wolfe et al., 2016, Foran, 2015; Hoekstra, 2017; Cai et al., 2018; Rosa et al., 2021). The difficulty pointed out in the literature lies precisely in the fact that food production depends on water throughout the value chain, while at the same time it generates tensions for natural resources, either by the amount of clean water needed for production or by the load of effluents that this activity releases into the natural environment (Lawford et al., 2013; Liu et al., 2016; Cai et al., 2018; Rosa et al., 2021), which generates water stress, and puts into question the capacity of the natural environment to provide clean water and regenerate. As well as, the capacity of the productive system to provide food in the quantity desired for human consumption (Hoekstra, 2017; Cai et al., 2018; Rosa et al., 2021), which makes water stress understandable (Govoni et al., 2021; Brito, 2018; Lathuillière et al., 2018) and the ability to intervene to reduce this tension (Rahmani et al., 2023), which is crucial for sustainable development. From this context emerges the research question: How do investments in innovation, research and development (R&D) in the production of broiler birds affect the efficient use of water?

To identify the extent to which investments have boosted water stress management and reduction, this research aims to analyze how investments in innovation, research and development (R&D) in poultry breeding affect water efficiency.

This study makes a practical contribution by pointing out to the managers the impact of water stress on the performance of poultry production, as well as seeking to identify how public and private investments in innovation - research and development (R&D) boost the efficient use of water in productive systems. It is hoped, therefore, to better understand the limits and possibilities between the natural and productive system, and to support managers in the
decisions on investments that lead to a reduction in water stress and contribute to sustainable development.

The result of this study allows the government to draw up public policies to promote innovation through investment in R&D in the poultry sector, considering that these investments can improve water efficiency, that is, they can be determinant for improving the relationship between the capacity of the natural environment to make water available and the demand from the productive sector in the use of water. Furthermore, private investments in R&D can contribute to the efficient use of water. Thus, investing in new technologies that promote the rational use of water (e.g. drinking fountains, reuse of water for cleaning, use of remote sensing and information technology) allows for the improvement of water management practices and processes.

2 THEORETICAL BENCHMARK AND DEVELOPMENT OF HYPOTHESES

2.1 Production of Cutting Birds

The production of poultry plays an important role in the global economy, being the main source of protein for poor and emerging countries. Its derivatives are consumed in various cultures, promoting food and nutrition security to the world population (Mottet & Tempio, 2017).

According to data from FAOSTAT (2016), there are a total of 21 billion birds on the planet, this number represents approximately 3 birds per capita. Currently, the largest producers are the United States of America with 20 million tons per year, followed by China, the European Union and Brazil, with 18, 13 and 13 million tons per year respectively. The sector has been growing at an average rate of 5% per year for the last 50 years, making it the culture with the highest growth in the last decades. The per capita consumption of broiler birds reflects this figure, rising from 2.88 kg in 1961 to 14.13 kg in 2010. Figure 1 shows the growth of production by region, in the period of 50 years.

![Figure 1. Growth of poultry production in millions of tons](image)

Source: Mottet & Tempio (2017)

The main cause for the increase in productivity was the technological changes of the last decades, which transformed the production of bred animals loose for confinement in aviaries, where the control of feed, temperature and diseases caused the increase of the poultry population (Narrod & Tiongco, 2012).
Much of the world's production of poultry comes from specialized producers (92%), which make intensive use of technology, infrastructure and equipment. Only 8% of the production is carried out in the domestic mode, where there is the predominance of subsistence culture and local trade (FAOSTAT, 2016).

Most of the funding in this sector is made up of private investments. However, there is a growing public interest about the impacts on the environment and collective health. Poultry production requires large amounts of water, land and food and contributes to climate change by emitting greenhouse gases, either directly (through poultry and dung production) or indirectly (through feed production, deforestation, soil recovery) (Mekonnen & Hoekstra, 2014; Mottet & Tempio, 2017). The production of feed for the use of the poultry industry still causes the expansion of arable land, causing a loss of biodiversity.

The use of natural resources in conjunction with pollution caused by pesticide use, soil nutrient losses and climate change are challenges for the poultry sector requiring the creation of public policies and regulations.

2.2 Nexus-FEW

Economic and population growth in modern economies is confronted with environmental constraints. Demand for water, food and energy is estimated to increase by 40%, 35% and 50% respectively by the year 2030, causing serious supply problems and fostering the use of more efficient technologies for food production (National Intelligence Council, 2012; Shariff et al., 2022).

The Nexus-FEW (NF) has been debated by the academic community since the 1970 Oil Crisis. This concept represents the interaction between food, energy and water as finite and interdependent resources, as Figure 1 (Zhang et al., 2019). Water resources are needed for the production of almost all types of energy. Energy resources are essential for the transportation and treatment of water and both (energy and water) are indispensable for food production (Sukhwani et al., 2019).

![Figure 2. Model Nexus-FEW](source: Adapted from Yu et al. (2021))

In 1986, with the organization of the second international conference of the United Nations on Ecosystems and Food-Energy Nexus, the debate on the topic was intensified, introducing economic, political and social aspects in the context of the NF. However, studies
of this era considered the dual aspect of nexus, analyzing the relationship between water and energy or water and food (Zhang et al., 2019).

Only in the last decade has the discussion on the interrelationship between water, food and energy taken on international proportions, with the conference entitled "Security Nexus FEW - Solutions for a Green Economy", encouraging more than three hundred initiatives around the world, during the period 2011 to 2015 (Bonn, 2011). More recently, research on NF focuses on food, energy and water security through emerging technologies and policy tools (Zhang et al., 2019).

2.3 Water Stress and Performance in Poultry Production

The interdependence of food production with water has aroused the interest of the scientific community and government regulators as critical themes for global sustainable development. Some literature has treated this topic as Nexus-Few (Hoekstra, 2017; Zhang et al., 2018).

At the World Economic Forum (2008), the systemic view of Nexus gained popularity, where global challenges related to economic development were recognized from the perspective of the water-energy-food Nexus (Nexus-Few). This system is understood as the interactions between different subsystems (Sanders & Webber, 2012) that interact and compete at the same time, as they are coupled in their supply, processing, distribution and use of the natural resource for food production (Lawford et al., 2013; Liu et al., 2016; Cai et al., 2018; Rosa et al., 2021). Among the different concerns presented in the previous studies on NF are those that discuss how water stress affects and is affected by food production (Hoekstra, 2017; Cai et al., 2018; Rosa et al., 2021). And these studies recognize that one of the concerns arising from the understanding of this interdependence between water and food lies in the understanding of how water stress occurs and can be minimized (Rahmani et al., 2023).

Water stress is known as the intensity of water withdrawal, identified by the ratio of the total freshwater withdrawn by the main economic sectors to the total renewable resources of fresh water available (SDG-6, UN, 2022), when demand is greater than water supply can increase the risk related to the availability of drinking water. The imbalance between water withdrawal and availability, turns water stress into one of the most serious environmental problems of the present time (Van Beck et al., 2011).

Agricultural displacement and climate change in recent decades have led to increased water stress, specifically with reduced rainfall patterns and amounts, water quality, river flows, and water retention (Govoni et al., 2021). The production of poultry can also contribute to water stress, due to water consumption and emissions of liquid effluents (Brito, 2018; Lathuillière et al., 2018), that is, poultry production affects and is affected by water supply (Mekonnen & Hoekstra, 2014).

With this interdependence, it is fundamental to recognize the water challenges faced by the sector, since water stress (lack of natural recharge of aquifers and surface waters) can negatively affect the performance of poultry production (Rahmani et al., 2023). This is because the reduction in the supply of water for poultry production leads to increased bird mortality, reduced bird size and increased costs for water treatment etc. (Govoni et al., 2021; Xu et al., 2021). Given the understanding that water stress affects poultry production, the first hypothesis of the research emerges:

**H1**: Water stress negatively influences performance in poultry production.
2.4 Public and Private Investments and Efficient Water Use

Recognizing that the availability of water resources and food production interact and compete, there is a concern for how to manage this relationship and ensure better resource efficiency (Bazilian et al., 2011, Wolfe et al., 2016, Foran, 2015; Hoekstra, 2017; Cai et al., 2018; Rosa et al., 2021). What is known is that the practices and technologies that drive water resource efficiency and the resulting productivity gains are commonly due to investments in research and development (R&D), supported by appropriate strategies and implementation practices that meet the interests and priorities of the food sector (Yunusa et al., 2018).

This is because public investments make it possible to carry out actions that are considered important for the prosperity of society, with the objective of detecting, evaluating and mitigating environmental and biological risks, contesting technical barriers, and subsidizing the formulation of public policies (Baa & Chattoraj, 2022; Bassi et al., 2013), such as, for example, the expansion of water reserves, the increase of checks on irregular discharges of effluent or the unauthorized use of water, the expansion of fiscal and financial incentives. Private investments (e.g. improvement of processes to reduce the generation of effluents, development of new products to reduce water consumption), in innovation or R&D, make it possible to predict risks, reduce waste, reduce water demand or increase water supply (Bassi et al., 2013; Hoekstra, 2017; Zhang et al., 2018; Michetti et al., 2019). Given the understanding that public and private investments contribute to the efficient use of water, we have the following research hypotheses:

- **H2a**: Public investments have a positive effect on water efficiency
- **H2b**: Private investments have a positive effect on water efficiency

3 METHOD

To test the three hypotheses of this study, multiple linear regression models A, B and C were developed. The data were obtained from the database of the Food and Agriculture Organization of the United Nations, from the period 2005 to 2019. The sample considered the countries with the highest production of broiler birds and which had the data available in the FAOSTAT database (Brazil, India, Mexico, Myanmar and Russia). In all, 29 observations were obtained related to investments in governmental research and development, being used for models A and B, and 12 observations containing data of investments in research and development carried out by the private sector, used to test the hypothesis of model C.

On the FAOSTAT platform, agricultural and food production indicators were compiled from 5 different data sources. The variables used, data sources and descriptive statistics are available in Table 1.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Source: FAOSTAT (2022)</th>
</tr>
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<tr>
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<tr>
<td></td>
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<td>Dev Pad: 66 267.70</td>
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<td>Max Value: 236 442 00</td>
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<td>Medium: 344 024.11</td>
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<td>Min Value: 14 225.00</td>
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<td>Max Value: 664 921.07</td>
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<tr>
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<td>Medium: 8.64e+14</td>
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<td>Dev Pad: 4.03e+14</td>
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<tr>
<td></td>
<td>Medium: 8.66e+09</td>
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</table>
Looking at the minimum, maximum, average and standard deviations we can see a large variability of the data, indicating different behavior between the countries that make up the sample. Data analysis was performed by multiple linear regression with support from the Jupyter Notebook and with the Python programming language.

The production variable of brood birds was characterized as dependent on model A and was therefore used to test the H1 hypothesis. The Water Efficiency Index (IEUA) was used as a dependent variable of the B and C models, and was used to test the H2a and H2b hypotheses, respectively.

The independent variables included water stress (models A, B and C), the production of poultry (Models B and C) and investments in government research and development (Models A and B) and private (Model C). Finally, the area of the country (Area) was used as the control variable. In the treatment the data underwent logarithmic transformation, aiming to reduce the influence of outliers. Figure 1 presents the equations of regression models:

![Figure 3. Regression model equations](source)

**Source:** Prepared by the authors (2022)

### 4 RESULTS AND DISCUSSIONS

#### 4.1 Results of Template A

The first model sought to test whether water stress negatively influences performance in the production of poultry. In the analysis of the results, model A was found to comply with the assumptions of multiple linear regression (no heterocedasticity, no autocorrelation and normal residues). A high coefficient of determination was also observed ($R^2=0.927$). Table 2 presents the results of the statistical analysis.

| Variable                | Coefficient | Standard Error | T     | P>|t| |
|-------------------------|-------------|----------------|-------|-----|
| Intercept               | 29.3682     | 0.369          | 79.5  | 0.000 |
| np.log(wstress_total)   | -0.1137     | 0.024          | -4.6  | 0.000 |
| (PHP 3, PHP 4)          | 0.2412      | 0.021          | 11.7  | 0.000 |
| np.log(area)            | 0.0219      | 0.038          | 0.5   | 0.572 |

$R^2=0.927$, multiple linear regression analysis, number of observations 29.


Corroborating with H1, it could be observed that the variable hydric stress negatively affects the production of poultry in the countries that make up the sample. It was also possible to verify the positive impact of government investment in the production of poultry for cutting.
The following figure presents the equation with the angular coefficients made available by multiple linear regression:

\[
\ln(\text{avescorte}_t) = 29.36 - 0.11 \ln(\text{wstress}_t) + 0.24 \ln(\text{agri}_{research3})_t + 0.02 \ln(\text{area})_t + \epsilon_t
\]

**Figure 4.** Equation of regression model A  
**Source:** Prepared by the authors (2022)

The coefficients of Model A allow us to conclude that a 1% increase in the level of water\(^8\) stress, brings about a 0.11% decrease in the production of poultry for cutting. An increase of 1% in public\(^9\) R&D investments, on the other hand, results in an increase of 0.24% in poultry production levels.

The results show that a high level of water stress, poultry production can be directly affected, but with government intervention the problem can be minimized. That is, when in the poultry production region there is a greater demand than the supply of water can raise the level of risk in the availability of drinking water for all (SDG-6, UN, 2022), and this can lead to a reduction in the supply of water for poultry production, with consequences in increasing mortality of birds, in reducing the size of birds or in increasing the costs for water treatment etc. (Govoni et al., 2021; Xu et al., 2021). Thus, water and food production are two interrelated factors as suggested in the literature of Nexus Few (Sanders & Webber, 2012; Lawford et al., 2013; Liu et al., 2016; Hoekstra, 2017; Cai et al., 2018; Rosa et al., 2021). The government’s understanding and management of this factor can be decisive, especially when this understanding leads to specific investments to reduce this water stress (Yunusa et al., 2018).

### 4.2 Results of Template B

In the analysis of Model B results, high coefficient of determination (0.957) was observed, data without heterocedasticity, without autocorrelation and normal residues. Table 3 presents the results of the statistical analysis, considering data on investment in government research and development.

| Variable | Coefficient | Standard Error | T      | P>|t| |
|----------|-------------|----------------|--------|-----|
| Interceot | -78,4223 | 21,780 | -3,601 | 0,002 |
| np.log(wstress_total) | 3,3836 | 1,715 | 1,973 | 0,061 |
| np.log(avessection) | 2,4296 | 0,645 | 3,765 | 0,001 |
| np.log(wstress_total):np.log(avessection) | -0,0976 | 0,050 | -1,954 | 0,063 |
| (PHP 3, PHP 4) | 0,0881 | 0,041 | 2,174 | 0,040 |
| np.log(area) | -0,6540 | 0,040 | -16,458 | 0,000 |

\(R^2=0.957, \text{ multiple linear regression analysis, number of observations 29.}


From the FAO data it was observed that the variables: water stress, poultry production and government innovation (spending on research and development in agriculture, livestock and forest recovery) positively affect the efficient use of water. The equation with the angular coefficients made available by multiple linear regression is rewritten below:

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\(^8\) P-value of the variable water stress is significant at 1%

\(^9\) P-value of public R&D investments is significant at 1%
\[ \ln(IEUA_t) = -78,42 + 3,38 \times \ln(Wstress_t) + 2,42 \times \ln(Avescorte_t) - 0,09 \times \ln(Wstress_t) \]
\[ \times \ln(Avescorte_t) + 0,08 \times \ln(Agriresearch_3_t) - 0,65 \times \ln(Area_t) + \varepsilon_t \]

**Figure 5.** Equation of regression model B

**Source:** Prepared by the authors (2022)

The coefficients of multiple linear regression allow us to conclude that a 1% increase in the level of water stress leads to a 3.38% increase in the water use efficiency index (IEUA). A 1% increase in poultry production results in a 2.43% increase in the USA and, finally, a 1% increase in R&D resources leads to a 0.08% increase in the USA index, at the 95%, 99% and 95% confidence level, respectively.

However, when there is an interaction between the production variables of poultry and water stress, a negative coefficient (-0.0976) is noted, probably because of the difficult management of water resources under these two conditions. This result may indicate that an increase in the two variables may also modify the angular coefficient of the regression line, decreasing the positive effect on the level of efficiency of water resources. It can be inferred that the presence of public investments may improve water efficiency, or that is to say, the investments or incentives of the government in R&D may be determinant for improving the relationship between the capacity of the natural environment in making water available and the demand from the productive sector in the use of water.

### 4.3 Results of Template C

Table 4 presents the results of the linear regression model, considering data on investment in research and development by the private sector. The effect of investments in R&D by the private sector on the efficiency of water use is even more significant, in which a 1% increase in R&D resources leads to a 3.53% increase in the IUSA index.

**Table 4 - Model C Results**

| Variable                  | Coefficient | Standard Error | T     | P>|t| |
|---------------------------|-------------|----------------|-------|-----|
| Intercept                 | 3,196 0861  | 1,199,847      | 2,664 | 0,037 |
| np.log(wstress_total)     | -254 2093   | 93,390         | -2,722| 0,035 |
| np.log(avessection)       | -94 4707    | 35,546         | -2,658| 0,038 |
| np.log(wstress_total):np.log(avessection) | 7,3080 | 2,685 | -2,722 | 0,035 |
| (PHP 3, PHP 4)            | 3,5394      | 1,215          | 2,912 | 0,027 |
| np.log(area)              | 0,6955      | 0,738          | 0,942 | 0,383 |

R²=0,936, multiple linear regression analysis, number of observations 12.


Considering the angular coefficients derived from multiple linear regression with investments in R&D by the Private sector, equation 3 is rewritten:

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10 The p-value of the hydric stress variable is significant at the level of 10% significance;
11 The p-value of the bird production variable shows that it is significant at levels 1%, 5% and 10% of significance;
12 The variable that represents R&D resources is significant at the levels of 5% and 10% significance;
13 The p-value of the interaction between the production variables of poultry and water stress shows that the coefficient of this interaction is significant at the level of 10% significance.
14 The coefficient that represents the effect of investments in R&D by the private sector on the efficiency of water use is significant at the levels of 5% and 10% of significance.
\[ \ln(\text{IEUA}_t) = 3196,08 - 254,20 \times \ln(\text{Wstress}_t) - 94,47 \times \ln(\text{Avescorte}_t) + 7,30 \times \ln(\text{Wstress}_t) \times \ln(\text{Avescorte}_t) + 3,53 \times \ln(\text{Agriresearch}_2) + 0,69 \times \ln(\text{Area}_t) + \varepsilon_t \]

**Figure 6.** C regression model equation

**Source:** Prepared by the authors (2022)

Therefore, with the FAO data, one can diagnose the positive impact of investments in research and development (R&D) on the efficient use of water (US$/m³), in countries with a large production of poultry (Brazil, India, Mexico, Myanmar and Russia).

Private investments were larger ($\beta=3,53$) compared to public investments ($\beta=0,08$). This result may indicate a characteristic of the sector of agriculture, cattle raising and forest recovery, with the participation of large private companies, which make intensive use of technology.

Thus, the use of private investments can lead to the efficient use of water, with the adoption of new technologies that promote the rational use of water (e.g. drinking fountains, water reuse for cleaning, remote sensing and information technology use), which allow to improve practices and processes used in water management (Bassi et al., 2013; Hoekstra, 2017; Zhang et al., 2018; Michetti et al., 2019).

**5 FINAL CONSIDERATIONS**

This study aims to analyze how investments in innovation, research and development in the production of broiler birds affect the efficient use of water. To this end, data from Brazil, India, Mexico, Myanmar and Russia were analyzed in the period from 2005 to 2019. The data was collected from the FAOSTAT platform on investments in research and development (government and private), poultry production (more precisely those carried out by the government sector and those disbursed by the private sector) and water stress.

The results reveal that there is an interdependence between water and poultry production, and the stress of water (greater demand than supply) can affect poultry production. And that public and private investments in research and development (R&D) can be determinant for reducing water stress, improving efficiency in the use of water, and improving performance in poultry production.

This study may be important for poultry farmers to take into consideration the need to better understand the need to care about the natural resource "water", as this is finite, and when water stress occurs the production of poultry may be affected. Furthermore, it can serve as a warning to companies in the sector and to the government, which constantly needs to innovate in poultry breeding equipment, processes and methods for producing, so that water stress is reduced and at the same time to guarantee the production of poultry. This calls for a constant look at the balance between water and food production.

This study presents limitations that provide opportunities for future research. FAOSTATA data has more general information and is based on estimates for each country. Furthermore, among the various elements considered in the Nexus-Few literature, research is limited to those linked to water and food production, but issues related to the use of energy for food production and marketing can also affect resource efficiency and food productivity. In addition, data on the total value of investments can be better explored, broadening the look to also analyze the quality and objectives of these investments.

For future studies, it is suggested to explore what innovations are carried out and environmental practices adopted by integrated industries, poultry farmers and abattoirs, since from the understanding on the influence of all the links of the productive chain on the efficient use of water it is possible to advance towards sustainability.
REFERENCES


