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PRESENTATION

Science is a field of knowledge in which different disciplines intertwine to form a greater whole. **Sustainable Fields: Advances in Agrarian and Life Sciences - 2 ed** is a work that expands this interconnection, bringing 11 articles on various topics, written by experts from different areas of knowledge.

Developed by **Seven Publications**, this book presents a broad overview of the challenges, discoveries and advances in fields such as degradation processes, dimensions of agricultural modernization, ESG in public administration and much more.

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PROCESOS DE DEGRADACIÓN EN LA REGIÓN SEMIÁRIDA: UN ANÁLISIS SOCIOAMBIENTAL



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Eleide Leite Maia¹, Adriana Ursulino Alves²

ABSTRACT

The depletion of natural resources, due to the increasing demand for agricultural and forestry products, combined with land use that disregards its potential and limitations, has led to the degradation of vegetation, soil, and water. The study of the vulnerability to which populations are exposed, as well as knowledge of land use capacity an important factor for proper soil management constitute essential elements for assessing the impacts on these areas. This study seeks information regarding socioeconomic, environmental, and drought-related vulnerabilities, as well as land use capacity in the northeastern semi-arid region. Furthermore, it highlights the need for planning and sustainable management guided by technical criteria and local realities, as indispensable strategies to mitigate degradation and promote the resilience of semi-arid populations. However, the adoption of appropriate land-use practices, combined with effective public policies, can contribute to the conservation of natural resources and to a more balanced and sustainable development of the region.

Keywords: Anthropogenic Impacts. Socioecological Resilience. Soil Conservation.

RESUMO

O esgotamento dos recursos naturais, devido à crescente demanda de produtos agrícolas e florestais, aliados à utilização das terras sem considerar suas potencialidades e limitações, tem levado à degradação da vegetação, do solo e da água. O estudo da vulnerabilidade a que as populações estão expostas, assim como conhecimento da capacidade de uso das terras, importante para o manejo adequado do solo, constituem elementos essenciais para a avaliação dos impactos sobre essas áreas. O estudo busca informações a respeito das vulnerabilidades socioeconômicas, ambientais e das secas, bem como capacidade de uso da terra no semiárido nordestino. Contudo, este estudo reforça a necessidade de planejamento e manejo sustentável, orientados por critérios técnicos e pela realidade local, como estratégias indispensáveis para mitigar a degradação e promover a resiliência das populações do semiárido. No entanto, a adoção de práticas adequadas de uso da terra,

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associada a políticas públicas eficazes, pode contribuir para a conservação dos recursos naturais e para o desenvolvimento mais equilibrado e sustentável da região.

Palavras-chave: Impactos Antrópicos. Resiliência Socioecológica. Conservação do Solo.

RESUMEN

El agotamiento de los recursos naturales, impulsado por la creciente demanda de productos agrícolas y forestales, junto con el uso de la tierra sin considerar sus potencialidades y limitaciones, ha llevado a la degradación de la vegetación, el suelo y el agua. El estudio de la vulnerabilidad a la que están expuestas las poblaciones, así como el conocimiento de la capacidad de uso de la tierra —importante para el manejo adecuado del suelo—, constituyen elementos esenciales para la evaluación de los impactos en estas áreas. Este estudio busca información sobre las vulnerabilidades socioeconómicas, ambientales y relacionadas con las sequías, así como la capacidad de uso de la tierra en el semiárido del nordeste. Asimismo, refuerza la necesidad de planificación y manejo sostenible, orientados por criterios técnicos y por la realidad local, como estrategias indispensables para mitigar la degradación y promover la resiliencia de las poblaciones del semiárido. La adopción de prácticas adecuadas de uso de la tierra, junto con políticas públicas eficaces, puede contribuir a la conservación de los recursos naturales y a un desarrollo regional más equilibrado y sostenible.

Palabras clave: Impactos Antrópicos. Resiliencia Socioecológica. Conservación del Suelo.

1 INTRODUCTION

In Brazil, environmental degradation began in the colonial period, with the exploitation of brazilwood, which marked the beginning of large-scale deforestation. This process has intensified over time and persists to the present day, being aggravated by the continuous expansion of industrialization and urbanization (Mesquita, 2026).

Environmental degradation, both worldwide and in the semi-arid region, has increased drastically due to the growing demand for agricultural, forestry and livestock products, combined with the inadequate use of natural resources, resulting in the degradation of vegetation, soil and water.

The main cause of degradation of natural resources is the predatory use by man, who acts in this environment, due to his low level of conservation awareness and lack of information about the use of natural resources in relation to their potentialities and limitations (Oliveira et al., 2007).

The beginning of environmental degradation begins with the removal of native tree vegetation and after the inadequate management of the natural resources of the area, leaving the soil without protection, it is subject to various types of erosion, negatively altering the attributes of the soil (Pereira, 2011).

Erosive processes are one of the main consequences of inadequate land use, which has been exploited and degraded intensively, causing a decrease in productivity and income of farmers. Soil conservation is undoubtedly one of the most important aspects today (Mota et al., 2008).

A soil conservation plan consists of the use of land related to its capacity and the application of conservation practices to allow its best use without suffering degradation (Giboshi et al., 2006).

The diagnosis of land use, which indicates the capacity to use it, is of great importance for territorial planning, in which it shows the way in which the use of the area is being used, with the classification of the capacity to use the land it is easy to identify the limiting factors and the potential of the soils in an area (Costa, 2009). However, inadequate land use planning causes impoverishment and low production, which results in a decrease in the socioeconomic and technological level of the rural population (Rampim et al., 2012).

In the semi-arid region of the Brazilian Northeast, the lack of planning for land use, together with prolonged droughts and the absence of adequate infrastructure to live with the semi-arid climate, has become one of the main sources of risks for the population of this region and, consequently, contributes to the increase in social, economic and environmental vulnerabilities.

It is verified that the concept of vulnerability refers to certain environmental issues, problems or impacts such as climate change, erosion, among others, in addition to being linked to other factors, such as exposure to pressures, sensitivity of the ecological system and adaptive capacity of society (Figueiredo et al., 2010).

Populations are constantly vulnerable, both economically and socially, and public policies are needed to minimize the needs and deprivations of families. These existing realities lead to the need for studies in these locations, which provide an assessment of the vulnerability index, informing the needs that reduce growth and development (Cruz et al., 2013).

Therefore, the land use capacity provides important information about the limitations and potentials of an area, while the vulnerability study indicates the carrying capacity of the area in relation to environmental aspects and its interactions with the population. These studies help to implement, according to the limitations or potentials of each region, adequate land use management and public policies for sustainable development.

2 SEMI-ARID REGION AND ENVIRONMENTAL DEGRADATION

In Brazil, environmental degradation is expressed in a differentiated way in different environments. In the Northeast region, especially due to the predominance of the semi-arid climate, which imposes limitations on the physical base, a strong relationship between human actions and environmental degradation processes is observed. This dynamic has its origins in the period of colonial occupation and persists to the present day, configuring a scenario marked by precarious working conditions and intense pressure on natural resources, resulting from livestock and family-based agriculture (Lemos, 2001).

In the semi-arid Northeast is the Caatinga biome, characterized by the semi-arid tropical climate, which forms an extensive area of land in the interior of the Northeast region, including the states of Piauí, Ceará, Rio Grande do Norte, Paraíba, Pernambuco, Alagoas, Sergipe, Bahia and the north of Minas Gerais (Brasileiro, 2009).

The semi-arid region has an area of 980,133 km², with approximately 22.5 million inhabitants. With rainfall of 800 mm on average, in the period from January to May, but distributed irregularly in time and space, making it a challenge for communities and the productive sector. These difficulties are accentuated by the occurrence of prolonged droughts that make life and production conditions in the semi-arid region even more difficult (Teixeira and Machado, 2015).

A determining aspect for the formation of semi-arid regions is drought, which is marked by a marked deficiency of rainfall, where the Caatinga biome is inserted with a

diversity of animal and plant species adapted to low water availability (Serafini Júnior, 2014). Originally, the Caatinga biome is formed by arboreal vegetation, being one of the richest in species among the regions with a dry climate in the world (Souza, 2011). The semi-aridity of the Northeast is a natural event that has been accentuated due to human activities and prolonged droughts, which cause a more accentuated use of natural resources by rural families with lower income and thus more vulnerable (Sousa et al., 2008).

The Brazilian semiarid region has a natural disposition for soil degradation due to irregular climate, prolonged droughts, high evapotranspiration, shallow soils, low water retention capacity and soil salinity, reflecting on productivity. In these environments, production systems have reduced or no sustainability, as a result of the use of technologies that degrade the soil, thus compromising its quality (Nunes et al., 2005).

In semi-arid areas, physical degradation is directly due to erosion, a consequence of the lack of vegetation cover that contributes to the surface runoff of water and the disaggregation of soil particles. Chemical degradation is related to the accumulation of salts in the soil profile, due to saline material, low rainfall, high evaporation of water on the soil surface, and the use of low quality water for irrigation. And biological degradation originates from the low content of organic matter in the soil, due to the characteristics of the vegetation and the accentuated deficit of moisture that contributes to reducing the activity and diversity of soil fauna (Melo Filho and Souza, 2006).

In these semi-arid regions, the vegetation is open, causing the soil to be uncovered and susceptible to erosion, but this was not always the case, the degree of cover has been suffering a process of degradation due to the removal of firewood, fires and deforestation for land use, agriculture and livestock, causing the extinction of several species and reducing the rich biodiversity of this ecosystem (Araújo, 2011).

The main anthropic impact caused in the caatinga is the formation of pastures, which begins with the removal of native vegetation for the production of firewood and charcoal, followed by the implementation of extensive pasture, which associated with the water deficit of the semi-arid region, causes the degradation of the soil and the local environment (Serafini Júnior, 2014). The change in the spatial configuration of the semi-arid region is linked to the impacts of land use by small, medium and large properties, but the most vulnerable populations, who practice family-based agriculture, are the most fragile to this whole process (Brasileiro, 2009).

Agricultural exploitation, with inadequate use of irrigation that contributes to soil salinization, extensive and semi-extensive cattle raising, and mining, expose the soil to erosion, and the lack of conservation practices, which have been causing changes in the

landscape of the semi-arid Northeast, aggravating the natural processes of degradation or desertification, in several regions, especially in the area of the drought polygon (Alves et al., 2009; Medeiros et al., 2012).

In this context, Travassos and Souza (2011), studying soils and desertification in the Paraíba hinterland, concluded that through the data it is possible to prove that frequent deforestation in caatinga soils, previously fertile, leads to a decline in their natural fertility, causing impacts on flora, and changes in chemical attributes and consequently in soil fertility. Showing that this management practice favors desertification.

The complexity and heterogeneity of the characteristics of the semi-arid region with regard to climate, soil and vegetation for agricultural activities become a challenge in the use and management of soil and water (Melo Filho and Souza, 2006). Research carried out by the Ministry of the Environment on the occurrence of desertification observed that 60.47% of the region of the Drought Polygon in the Northeast is in the process of desertification (Nóbrega et al., 2003).

3 SOCIOECONOMIC, ENVIRONMENTAL AND DROUGHT VULNERABILITY

The study of vulnerability has been highlighted with regard to the human being, in works of population groups, helping to understand human-environment interactions. It is used to assess and analyze the risk, danger, impacts and damages to which populations are exposed, in addition to the degree of susceptibility and adaptation to the disturbance to this exposure (Correia, 2010).

To know and identify the term vulnerability in different scientific areas, it is necessary to observe together with the concept of risk, in which in research on risk, vulnerability is initially found in the environmental dimension and only later in the socioeconomic dimension. Risk or vulnerability should not be treated in isolation, as risk comes from the danger-vulnerability relationship, in which each of them originates from various factors that involve sectors linked to the creation, coping and consequence of the phenomenon (Marandola Jr. and Hogan, 2005).

The terms danger and risk applied to the context of the semi-arid region, it can be said that Danger is represented by drought (natural danger) and desertification (environmental danger) driven by anthropic action. Risk is the probability of greater or lesser occurrence of hazards, such as droughts, atmospheric factors, desertification, human activities in the environment and the form of conservation management practices, etc. (Melo, 2010).

A given natural phenomenon only becomes a disaster if the area is vulnerable, socially, economically or environmentally, so it is of fundamental importance to understand the meaning of vulnerabilities (Melo et al., 2009).

In this scenario, according to Cardona (2001), vulnerabilities have their beginning in causes linked to economic, demographic and political processes, which can interfere in the distribution of power and thus in the destination and distribution of resources among the different population levels. Also according to the same author, the social processes developed in the communities are related to vulnerability, due to the difficulty of recovering from actions to which they are exposed. This vulnerability has increased in countries due to disorderly urban growth and environmental degradation, which has consequences for impacts on quality of life and natural resources.

Vulnerability is linked to the resilience of a certain area in relation to the impacts to which they are likely to occur, so understanding these factors that cause these environmental impacts helps to direct public investments to various regions (Figueirêdo et al., 2007).

At this juncture, Cruz et al. (2013) observed that the value of 80% of economic vulnerability (very high) is a consequence of the low working conditions of rural people conditioned by the lack of credit, technical assistance and the low level of education. Feitosa et al. (2010) found high social vulnerability in the municipalities of Mirandela, Portugal (37%), Serra Branca (42%) and Coxixola (42%), Brazil, reflecting the low level of education, housing and size of rural properties, which are small, causing families to lack sustainability.

The purpose of the Environmental Diagnosis is to know the direct impacts of the environment, through questionnaires with the population belonging to the Hydrographic Basin, to generate the curve of the line of environmental deterioration (Alves et al., 2011). The information obtained through these diagnoses is capable of identifying facts and techniques that favor the current level of the quality and use of water, soil and vegetation in these areas analyzed (Pereira and Barbosa, 2009).

The low capacity to resist droughts generates vulnerabilities that evolve with economic and social crises, caused by the form of population and productive occupation of the semi-arid region of Paraíba, which causes great impacts on the environment and natural resources that are already limited (Sousa et al., 2008). Socioeconomic and environmental diagnoses are considered to be of great relevance because they show the socioeconomic, technological and environmental situation of an area. These diagnoses seek answers to solve problems related to people's quality of life, while the environmental diagnosis is related to environmental impacts (Franco et al., 2005).

4 VULNERABILITIES AND THE SEMI-ARID

The vulnerabilities of families and the process of desertification of the lands are linked, impacting the environment and the quality of life of the population. This is due to the scarcity of natural resources in these desertified areas, which cause severe social, economic and environmental vulnerabilities, which are intensified with droughts and the lack of policies to coexist with them (Sousa et al., 2008).

Sensitivity to droughts directly affects social, technological, and economic vulnerabilities, making it the most impactful on the quality of life of the population of the semi-arid Northeast, such as the cariri of Paraíba. In these locations, public policies are needed to control the risks and their effects on the population (Feitosa et al., 2010).

Over five centuries of exploitation of the semi-arid region, there has been a risk of desertification, considering the form of colonization that sought only profitability without due care for the natural resources and the quality of life of this population, thus deconstructing the deterministic view of a punishing region and giving more emphasis to the understanding of the social action of vulnerabilities (Melo, 2010).

Considering this scenario, Alves and Alves (2012), studying some communities located in the Microregions of Cariri and Sertão of the State of Paraíba, observed that these communities are vulnerable to the adverse conditions of the semi-arid region because they have presented a high degree of socioeconomic deterioration.

In addition to the lack of water, the semi-arid region has soil limitations for agriculture and pest attacks. However, the climate is not the limiting factor according to farmers, but the lack of investment in production due to the scarcity of financial resources (Andrade et al., 2013). The high values of vulnerability obtained demonstrate the fragility of the population to social, economic, technological and environmental aspects, and the lack of public policies that reduce the impacts of droughts, which initiate the others (Alencar, 2008).

Vulnerability is understood as the decrease in the availability, access and management of assets that generate opportunities, leading to social inequalities such as marginality and exclusion. Reducing vulnerability provides increased sustainability, so teaching populations to respond to situations of social and environmental risks to which they are exposed, will produce their social inclusion and better quality of life (Marandola Jr. and Hogan, 2005).

In view of this, Andrade et al. (2013) mentions that the continuation of studies of the characteristics of the vulnerabilities of agriculture, related to communities, are important to seek solutions that contemplate the real needs and potentialities of these communities. Campos (2009) says that a deficiency was found in rural extension, with regard to the

absence of investments for the qualification of human resources, the number of technicians and infrastructure. In addition to technical training in agricultural schools and a technical assistance policy.

5 LAND CAPACITY AND USE

The use and occupation of land is the way in which the area is used by man, making it necessary to survey it, while the inadequate form of use leads to environmental degradation, allowing the identification of the current use of the area according to its suitability (Dortzbach et al., 2013).

In agri-environmental planning, information related to the physical diagnosis is sought, which involves aspects of soils, climate, relief, vegetation, water resources, among others. By means of methods to evaluate the areas, it is possible to indicate different forms of agricultural activities, providing soil production and conservation (Mendonça et al., 2006).

The land use capacity changes according to the characteristics of the soil (effective depth, internal drainage of the profile, slope and surface erosion) and environment, interfering with the classification at the group and class level. This classification makes it possible to indicate better practices in land use and management (Santos et al., 2012).

The survey of land use capacity is not the set according to economic use or its purchase cost. However, these classes indicate a decreasing ordering of the feasibility of more intense use of the land, without danger of soil degradation, providing the owner with better autonomy in the possibility of use (Niemann, 2012).

When carrying out agricultural or sustainable land use planning, it is necessary to follow a plan, despite having methods used in each phase, and it is necessary to evaluate, know and characterize. Starting with the diagnosis and environmental identification for the analyses and evaluations and thus being implemented according to the reality of the area (Alves et al., 2003).

The use of the Minimum Mandatory Formula to define classes of land use capacity brought together a set of knowledge of great importance regarding environmental physical-conservationist practices, for the planning and execution, by the component agencies, of a preservation zoning in the area of the Patativa do Assaré Settlement (Melo and Guerra, 2013).

The basis of agronomic planning is formed by the evaluation of the capacity to use the land together with the socioeconomic conditions. This assessment of land use capacity is related to various agricultural activities and not to specific crops. Grouping the plots into

hierarchically ordered categories or classes, based on the characteristics of the soil and the area (Alves et al., 2003).

The planning of the natural resources of a municipality requires the mapping of suitability for use, current use and permanent preservation areas, which makes it possible to define the areas with conflicts of use, making it possible with this data to improve the use of the areas in an economic and sustainable way (Pedron et al., 2006).

To obtain a conservationist purpose, it is necessary to raise awareness among rural producers, linked to technical assistance and financial resources. Understanding the dynamics of sustainability, the correct use of natural resources, including soil (Mota et al., 2008).

6 FINAL CONSIDERATIONS

The inadequate use of vegetation and soil in the semi-arid region has been causing environmental degradation, which leads to problems in agricultural activity, with a decrease in soil fertility and organic matter and, consequently, productivity, in addition to the reduction of flora and fauna, with social and economic impacts for the populations of the region.

The study of the vulnerabilities to which populations are susceptible is necessary for the implementation of public policies. Another important point is the conservation planning of the land, with identifications of its physical-environmental aspects, which demonstrate its capacity for use.

In the semi-arid Northeast, the conservationist use of natural resources is essential to reduce environmental degradation and ensure productive sustainability. Conservationist practices such as Environmental education and technical assistance, Proper management of the Caatinga, Crop-livestock integration, among others. These strategies contribute to the conservation of natural resources, increased productivity, and greater resilience of production systems in the face of recurrent droughts in the semi-arid region.

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PHYSICOCHEMICAL AND NUTRITIONAL CHARACTERISTICS OF DIFFERENT CASSAVA VARIETIES CULTIVATED IN NAMPULA PROVINCE

CARACTERÍSTICAS FÍSICO-QUÍMICAS E NUTRICIONAIS DE DIFERENTES VARIEDADES DE MANDIOCA CULTIVADAS NA PROVÍNCIA DE NAMPULA

PHYSICOCHEMICAL AND NUTRITIONAL CHARACTERISTICS OF DIFFERENT CASSAVA VARIETIES CULTIVATED IN NAMPULA PROVINCE



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ABSTRACT

Cassava (*Manihot esculenta* Crantz) is one of the main staple foods in Mozambique; however, variability among varieties may affect nutritional quality, food safety, and processing potential, representing a challenge for its proper utilization. This study aimed to evaluate the physicochemical and nutritional characteristics of five cassava varieties cultivated in Nampula Province (Badje, Mokhalana, Napirithe, Nziva, and Técnico). Mature roots were collected and laboratory analyses were performed for moisture, ash, pH, titratable acidity, cyanide, β -carotene, lycopene, and total solids, with statistical treatment by ANOVA. Moisture ranged from $51.91 \pm 1.54\%$ (Badje) to $58.35 \pm 0.96\%$ (Napirithe), while ash content varied between $1.06 \pm 0.08\%$ (Mokhalana) and $5.08 \pm 0.53\%$ (Napirithe). pH ranged from 6.64 ± 0.01 (Napirithe) to 7.79 ± 0.15 (Mokhalana), and titratable acidity ranged from $3.94 \pm 0.07\%$ (Napirithe) to $7.97 \pm 0.08\%$ (Técnico). β -carotene contents were highest in Nziva ($11.52 \pm 0.15 \mu\text{g/g}$) and Técnico ($20.81 \pm 0.27 \mu\text{g/g}$), while lycopene ranged from $6.99 \pm 0.09 \mu\text{g/g}$ (Mokhalana) to $11.18 \pm 0.45 \mu\text{g/g}$ (Técnico). Cyanide levels ranged from $3.70 \pm 0.48 \text{ mg/g}$ (Nziva) to $5.09 \pm 0.02 \text{ mg/g}$ (Técnico), remaining below critical limits for safe consumption after proper processing. It is concluded that varietal selection based on physicochemical and nutritional parameters is a relevant strategy to optimize food, industrial, and nutritional use of cassava in Nampula.

Keywords: Cassava. Physicochemical Properties. Carotenoids. Nutritional Quality. Food Safety.

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RESUMO

A mandioca (*Manihot esculenta* Crantz) constitui um dos principais alimentos básicos em Moçambique; contudo, a variabilidade entre variedades pode afectar a qualidade nutricional, a segurança alimentar e o potencial de processamento, configurando um desafio ao seu aproveitamento adequado. Objetivou-se avaliar as características físico-químicas e nutricionais de cinco variedades de mandioca cultivadas na província de Nampula (Badje, Mokhalana, Napirithe, Nziva e Técnico). Para tanto, procedeu-se à colecta de raízes maduras e à realização de análises laboratoriais de humidade, cinzas, pH, acidez titulável, cianeto, β -caroteno, licopeno e sólidos totais, com tratamento estatístico por ANOVA. Desse modo, observou-se que a humidade variou de $51,91 \pm 1,54\%$ (Badje) a $58,35 \pm 0,96\%$ (Napirithe), enquanto o teor de cinzas oscilou entre $1,06 \pm 0,08\%$ (Mokhalana) e $5,08 \pm 0,53\%$ (Napirithe). O pH apresentou valores de $6,64 \pm 0,01$ (Napirithe) a $7,79 \pm 0,15$ (Mokhalana), e a acidez titulável variou de $3,94 \pm 0,07\%$ (Napirithe) a $7,97 \pm 0,08\%$ (Técnico). Os teores de β -caroteno destacaram Nziva ($11,52 \pm 0,15 \mu\text{g/g}$) e Técnico ($20,81 \pm 0,27 \mu\text{g/g}$). O licopeno variou entre $6,99 \pm 0,09 \mu\text{g/g}$ (Mokhalana) e $11,18 \pm 0,45 \mu\text{g/g}$ (Técnico). Quanto ao cianeto, os valores oscilaram de $3,70 \pm 0,48 \text{ mg/g}$ (Nziva) a $5,09 \pm 0,02 \text{ mg/g}$ (Técnico), permanecendo abaixo dos limites críticos recomendados. Conclui-se que as variedades apresentam perfis físico-químicos e nutricionais distintos, sendo a selecção varietal uma estratégia relevante para otimizar o uso alimentar, industrial e nutricional da mandioca em Nampula.

Palavras-chave: Mandioca. Propriedades Físico-Químicas. Carotenoides. Qualidade Nutricional. Segurança Alimentar.

RESUMEN

La mandioca (*Manihot esculenta* Crantz) constituye uno de los principales alimentos básicos en Mozambique; sin embargo, la variabilidad entre variedades puede afectar la calidad nutricional, la seguridad alimentaria y el potencial de procesamiento, representando un desafío para su aprovechamiento adecuado. El objetivo de este estudio fue evaluar las características fisicoquímicas y nutricionales de cinco variedades de mandioca cultivadas en la provincia de Nampula (Badje, Mokhalana, Napirithe, Nziva y Técnico). Se recolectaron raíces maduras y se realizaron análisis de humedad, cenizas, pH, acidez titulable, cianuro, β -caroteno, licopeno y sólidos totales, con tratamiento estadístico mediante ANOVA. La humedad varió entre $51.91 \pm 1.54\%$ (Badje) y $58.35 \pm 0.96\%$ (Napirithe), mientras que el contenido de cenizas osciló entre $1.06 \pm 0.08\%$ (Mokhalana) y $5.08 \pm 0.53\%$ (Napirithe). El pH presentó valores de 6.64 ± 0.01 (Napirithe) a 7.79 ± 0.15 (Mokhalana), y la acidez titulable varió de $3.94 \pm 0.07\%$ (Napirithe) a $7.97 \pm 0.08\%$ (Técnico). El β -caroteno fue mayor en Nziva ($11.52 \pm 0.15 \mu\text{g/g}$) y Técnico ($20.81 \pm 0.27 \mu\text{g/g}$), mientras que el licopeno osciló entre $6.99 \pm 0.09 \mu\text{g/g}$ (Mokhalana) y $11.18 \pm 0.45 \mu\text{g/g}$ (Técnico). Los niveles de cianuro variaron de $3.70 \pm 0.48 \text{ mg/g}$ (Nziva) a $5.09 \pm 0.02 \text{ mg/g}$ (Técnico), permaneciendo por debajo de los límites críticos recomendados. Se concluye que las variedades evaluadas presentan perfiles fisicoquímicos y nutricionales distintos, y que la selección varietal basada en estos parámetros constituye una estrategia relevante para optimizar el uso alimentario, industrial y nutricional de la mandioca en Nampula.

Palabras clave: Mandioca. Propiedades Fisicoquímicas. Carotenoides. Calidad Nutricional. Seguridad Alimentaria.

1 INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is one of the most important food crops in tropical and subtropical regions, playing a central role in the food and nutrition security of millions of people, especially in African countries such as Mozambique. It is a root with a high starch content, low production cost and great capacity to adapt to different edaphoclimatic conditions, constituting an important source of energy and raw material for food and industrial uses (QUIRÓS, 2023). The nutritional relevance of foods rich in β -carotene is highlighted in regional crops, such as carrots in Ribáuè, recognized as a source of vitamin A essential for eye and immune health (ROSA, MIGUEL, DA CAMARA & EUGENIO 2026). Thus, the physicochemical characterization of cassava becomes fundamental to support food security and biofortification strategies.

Cassava is one of the pillars of food security in Mozambique, playing a central role in the diet of rural and urban populations, especially in the northern and central regions of the country. In provinces such as Nampula, Zambezia and Cabo Delgado, cassava is consumed daily in various forms fresh, dried, in flour or in traditional preparations, ensuring energy supply to millions of families. In addition to its food importance, the crop has high adaptability to low fertility soils and irregular rainfall regimes, common characteristics in several Mozambican agroecological zones, which makes cassava a strategic crop in the face of climate change and the instability of cereal production.

The physicochemical variability observed in agricultural products, such as carrots, demonstrates that edaphoclimatic factors and management practices influence the essential nutritional components (ROSA et al., 2026).

Parameters such as pH, titratable acidity, moisture, ash, total solids, carotenoids and content of cyanogenic compounds allow us to understand the conservation status, post-harvest stability, nutritional value and associated toxicological risks (PEREIRA, 2020, ROSA, et al., 2026). In particular, the content of β -carotene, a precursor of vitamin A, is of great relevance in contexts where deficiencies of this micronutrient persist, while cyanide levels require attention due to their potential adverse effect on health when cassava is not properly processed. As reported in nutritional studies of staple foods marketed in Nampula, foods of high nutritional value are essential for the food security of Mozambican populations (ROSA et al., 2025a). In Nampula province, cassava is widely cultivated and consumed, but there are still few comparative studies that systematically characterize the physicochemical and nutritional differences between local varieties (MACANE, 2024).

The realization of this study is justified by the need to generate scientific information that subsidizes the choice of more appropriate varieties from the point of view of nutrition,

food security and industrial use, contributing to the rational use of cassava and to the improvement of the diet of local populations.

In Nampula province, cassava is not only a food base, but also a raw material for emerging agro-industrial chains, such as the production of flour, starch and fermented beverages, including cassava beer, which reinforces its regional economic value. However, there are still few systematic studies that comparatively characterize the physicochemical and nutritional properties of locally cultivated varieties, limiting the definition of appropriate varietal selection strategies for human consumption and industrial use.

In this context, it is essential to generate scientific evidence that allows understanding the differences between cassava varieties grown in Nampula, contributing to the choice of safer, more nutritious and suitable materials for processing. Thus, the present study seeks to fill this gap by evaluating physicochemical and nutritional parameters of local varieties, with a view to strengthening food security, adding value to agricultural production and supporting sustainable rural development policies in Mozambique. Regional studies on plant resources emphasize that valuing traditional knowledge through scientific validation is fundamental, especially in contexts with limited access to technical and laboratory services (ROSA et al., 2025a). Such an approach has been successfully applied in phytochemical research of medicinal plants, which uses systematized methodologies for sample preparation and identification of bioactive compounds (ROSA et al., 2025b), and can also strengthen the understanding of the physicochemical and nutritional properties of strategic food crops such as cassava.

2 THEORETICAL FRAMEWORK

2.1 BOTANY, ORIGIN AND DISPERSION OF CASSAVA CULTURE

Cassava (*Manihot esculenta* Crantz) is a plant belonging to the Euphorbiaceae family, characterized as a perennial shrub, of variable size, with a woody stem, palmatilobed leaves, and starch-rich tuberous roots (SHILING, 2024; SILVA, 2019). The cassava can be divided into an aerial part composed of stems, petioles and leaves and an underground part, formed by tuberous roots. In mature plants, it is estimated that the biomass is distributed in approximately 50% tuberous roots, 40% stems and petioles, and 10% leaves (SILVA, 2020; ALVES & SETTER, 2004). This proportion, however, can vary according to the variety and edaphoclimatic conditions of the crop.

A fundamental aspect in the classification of varieties is the content of hydrocyanic acid (HCN), a toxic compound derived from the cyanogenic glucosides present in the plant. Cassava is traditionally classified as "tame" or "wild": the former have an HCN content of

less than 50 mg per kg of fresh root, and are safe for human consumption after minimal processing; the "bravas", also called bitter or poisonous, have a content higher than 100 mg/kg, requiring rigorous detoxification techniques before consumption and are often intended for industrial use, such as in the production of starch and bioethanol (DA SILVA MARTINS, 2018; SILVA, 2018).

The dispersion of the crop occurred mainly during the period of Portuguese and Spanish navigations, from the sixteenth century onwards, when cassava was introduced in Africa and Asia as a food alternative resistant to drought and poor soils (FERRÃO, 2013; DA COSTA NUNES, 2018). In Mozambique, the crop quickly adapted to local soil and climatic conditions, becoming the food base of many rural communities. Thus, the above leads us to argue that cassava is a paradigmatic example of how a crop originating in the Americas became central to food systems outside its original cradle.

2.2 CASSAVA VARIETIES GROWN IN NAMPULA PROVINCE

The province of Nampula has a high diversity of cassava varieties, as a result of the interaction between improved materials and local varieties (landraces). Among the widely cultivated varieties are: Nikwaha (interior of Nampula), Orrera (variety recently released by IIAM), Amwaali campiinxé, Badje, Mokhalana, Napirithe, Nziva and Técnico.

In addition to these, studies carried out by IIAM and agricultural development projects identify other local and improved varieties, such as Chinhembwe, Kakala, Muchele, Muali, Xitsekele, Kalima, TMS 60444, TMS 98/0581 and Sauti, mainly used in rural areas for fresh consumption, flour processing and rale production (IIAM, 2022).

This varietal diversity suggests that farmers select cassava based on criteria such as yield, drought resistance, starch content, taste, and ripening time. In view of the above, it is concluded that the genetic variability of cassava in Nampula is high and constitutes a strategic resource for food security. In this context, the present study specifically addresses the Badje, Mokhalana, Napirithe, Nziva and Técnico varieties, due to their productive representativeness and local consumption.

2.3 PHYSICOCHEMICAL COMPOSITION OF CASSAVA

Cassava's physicochemical composition is dominated by high water content (50-70%), starch (20-45%), low protein and lipid content, as well as minerals and bioactive compounds such as carotenoids (SOUZA, 2024; DE OLIVEIRA, 2007). The total solids and starch content is decisive for the industrial yield of cassava (SOUZA, 2024).

The main physicochemical parameters evaluated include pH, titratable acidity,

moisture, ash, total solids and cyanide content. pH and acidity indicate stability and susceptibility to spoilage; humidity influences texture and conservation; the ash reflects the mineral content; and cyanides determine safety for consumption (SILVA, 2009).

As for the nutritional composition, β -carotene stands out, an essential provitamin A in diets with a deficiency of this micronutrient. Studies conducted by BERNI, 2014 and FACUNDES, et al., 2021 observed that biofortified varieties may have significantly higher levels of β -carotene, contributing to the reduction of hypovitaminosis A.

2.4 INFLUENCE OF CULTIVATION CONDITIONS AND ENVIRONMENT ON PHYSICOCHEMICAL CHARACTERISTICS

The physicochemical and nutritional characteristics of cassava do not depend exclusively on the genetic material, but are strongly influenced by environmental and cultivation conditions, such as soil type, water regime, temperature, agronomic practices, harvest age and soil fertility. The cultivation environment has a direct influence on the dry matter, acidity and cyanogenic compounds content of cassava (SOUSA, 2024). As reported in nutritional studies of staple foods marketed in Nampula, foods of high nutritional value are essential for the food security of Mozambican populations (ROSA et al., 2025a).

2.5 CASSAVA QUALITY PARAMETERS

The quality of cassava is evaluated by a set of physical, chemical and nutritional parameters, which allow inferring its suitability for human consumption and industrial processing.

2.5.1 Titratable acidity and pH

Titrate acidity indicates the total amount of acids present in the root and is associated with fermentation, conservation and microbiological stability. High acidity values indicate greater metabolic activity and possible beginning of deterioration. The pH, in turn, complements the acidity, values between 6.0 and 7.5 are common in fresh cassava. Studies carried out by CHISTÉ & COHEN, 2011, affirm that cassava roots, before the fermentation stage, presented an acidity of $1.37 \text{ cmol NaOH.kg}^{-1}$ (0.0548%) and after 96 hours of fermentation the total acidity increased to $1.56 \text{ cmol NaOH.kg}^{-1}$ (0.0624%). The analyses of cassava titratable acidity carried out by DE LUNA, et al, 2013, found a content of 1.4 ± 0.57 .

2.5.2 Total moisture and solids

It refers to the amount of water in the fresh root, usually between 50% and 70%. High

humidity (>65%) is associated with shorter shelf life and a higher risk of rot, but can facilitate starch extraction. On the other hand, lower values (<55%) indicate higher dry matter content, favoring industrial yield. In the study carried out by CENI, et al., 2009, the moisture content found ranged from 64 to 70 g/100g. DE LUNA, et al, (2013), found in their research a content of $35.31 \pm 4.74\%$ in their cassava samples.

"The total solids indicate the dry fraction of the cassava (100%-moisture) and are directly related to the starch content. High total solids (>35% on a dry basis) indicate a high starch content, essential for industry. In the research carried out by CENI, et al., 2009, in five cultivars (BRS Rosada, Casca Roxa, BRS Dourada, BRS Gema de Ovo and Saracura) of cassava (*Manihot esculenta* Crantz) *in natura*, it varied from 30 to 36 g/100g.

2.5.3 Ashes

They represent the mineral residue after incineration (550 °C), indicating the content of minerals (calcium, potassium, magnesium, iron). Typical values range from 0.5% to 6.0%. Research conducted by DE LUNA, et al (2013), found ash content of 1.35 ± 0.29 .

2.5.4 Cyanide

"The cyanide content is one of the main indicators of food security. Measured as HCN (mg/kg), cyanides are toxic antinutritional compounds. Levels < 50 mg/kg classify the variety as "tame"; >100 mg/kg, as "brava". Thus, levels above the recommended limits represent a toxicological risk if cassava is not properly processed" (BARRONCAS, 2020). Research carried out by BORGES, FUKUDA & ROSSETTI (2002) found a content ranging from 22.33 to 90.00 mg/kg in ten samples analyzed by the titration method.

2.5.5 Carotenoids

Carotenoids, especially β -carotene, are fundamental because they are precursors of vitamin A. Studies have shown that varieties with higher levels of β -carotene contribute to reducing nutritional deficits in vulnerable populations. Lycopene, although less abundant, also has antioxidant properties (GAINO, 2012). Studies carried out by DE OLIVEIRA (2009), of the 28 hybrids evaluated showed β -carotene content between 7 and 10 $\mu\text{g/g}$ of fresh cassava.

In view of the above considerations, it is concluded that each physicochemical and nutritional parameter provides a specific dimension of cassava quality, and its interpretation must be contextualized as to the intended use, whether food, nutritional or industrial.

2.6 CASSAVA CULTIVATION IN AFRICA AND MOZAMBIQUE

The African continent is the world's largest producer of cassava, accounting for more than half of global production. According to FAO (2022), Nigeria and the Democratic Republic of Congo contribute about 50% of African production, while the remaining 37 producing countries account for the remaining volume (p. 23). This means that production is concentrated, but the culture is widely disseminated.

Although rice is the staple food of many African populations, cassava is cultivated as a complementary food and strategic reserve in times of scarcity. In Mozambique, "cassava is more widespread in the northern region, being consumed fresh or dried in the form of *makhaka*, as well as in the preparation of *xima* and traditional drinks".

Cassava is the main staple food in four provinces Nampula, Zambezia, Cabo Delgado and Inhambane and more than 1.2 million rural households depend on this crop, with about 43% concentrated in Nampula province. This province ranks first in national production, also standing out for the industrial use of cassava, as in the case of Impala beer (IIAM, 2022). Thus, the above leads us to argue that cassava is simultaneously a food, cultural and economic pillar in Mozambique.

3 METHODOLOGY

3.1 TYPE OF STUDY

This is an applied research, with a quantitative approach, with an experimental and descriptive design, as it seeks to characterize the physicochemical and nutritional properties of different varieties of cassava cultivated in the province of Nampula, Mozambique. The experimental part was adopted to allow the direct measurement of laboratory parameters, while the descriptive character allowed the interpretation of the variations observed among the varieties analyzed.

3.2 SAMPLE SELECTION

The study was conducted in the province of Nampula, Mozambique, a region of high productive relevance and consumption of cassava. Samples were taken from five local varieties: Badje, Mokhalana, Napirithé, Nziva and Técnico. The samples consisted of mature tuberous roots (10-12 months after planting), collected from agricultural plots of different producers in the districts of Nampula.

For each variety, 15 healthy and homogeneous roots were collected, totaling 75 samples. The selection followed criteria of physiological maturity, absence of physical damage and geographical representativeness, ensuring environmental diversity within the

province. After collection, the samples were packed in thermal boxes and transported to the laboratory for immediate analysis.

In the laboratory, the roots were washed under running water to remove impurities, peeled manually with stainless steel blades and crushed in an electric processor. The homogeneous pulp obtained was packed in airtight containers and used for the physicochemical analyses.

3.3 PARAMETERS ANALYZED

The physicochemical and nutritional analyses were conducted at the Laboratory of Agri-Food Analysis of Rovuma University, following internationally recognized methodologies:

Total moisture and solids: drying in an oven at 105 °C to constant mass (AOAC, 2002).

Ash: incineration in muffle furnace at 550 °C up to constant weight (AOAC, 2002).

pH: direct reading in calibrated digital pH-meter.

Titrateable acidity: acid-base titration with 0.1 N NaOH and phenolphthalein indicator

Total cyanide: argentometric titration after hydrolysis of cyanogenic glycosides

β-carotene and lycopene: acetone extraction and spectrophotometric reading at 450 nm and 472 nm, respectively.

All analyses were performed in triplicate, ensuring data reproducibility.

3.4 STATISTICAL TREATMENT AND ANALYSIS

The data obtained were organized in Excel and later submitted to statistical treatment using the Statgraphics statistical package (version 18). Then, analysis of variance (ANOVA-one-way) was applied to verify the existence of statistically significant differences between the means of the varieties studied. When significant differences were identified ($p < 0.05$), the LSD (Least Significant Difference) multiple means comparison test was performed at a 95% confidence level

3.5 ETHICAL CONSIDERATIONS

The collection of samples was carried out with the prior consent of the farmers, respecting the traditional knowledge associated with the local varieties. The study had an exclusively academic purpose, without commercial exploitation of the samples.

4 RESULTS AND DISCUSSIONS

4.1 PHYSICOCHEMICAL AND NUTRITIONAL CHARACTERIZATION OF CASSAVA

Table 1

Mean (and standard deviation), minimum and maximum moisture values, Ash, pH, Cyanide, β - Carotene, Total Solids, Lycopene and Titratable Acidity of the samples of five cassava varieties (Badje, Mokhalana, Napirithé, Nziva and Técnico) from Nampula, Mozambique. ANOVA results (F-ratio and significant differences) obtained for the "province" factor for each variable.

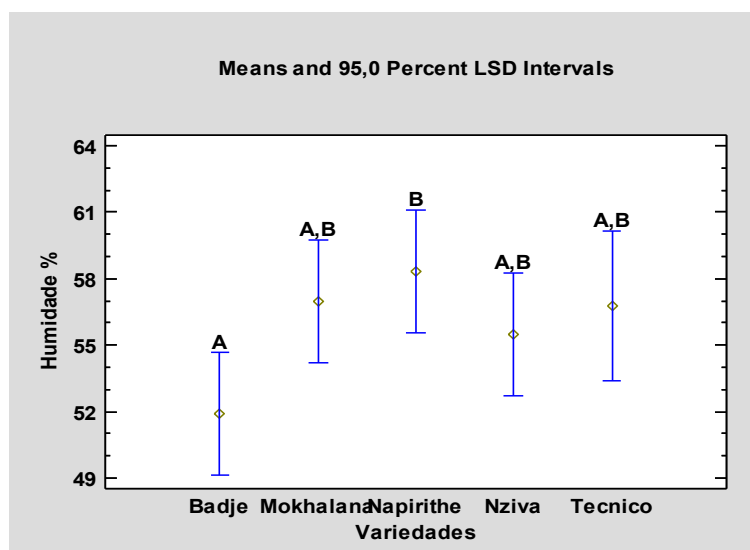
Parâmetros	Variedade de mandioca															Total
	Badje			Mokhalana			Napirithe			Nziva			Técnico			
	Média (Desp)	Min	Max	Média (Desp)	Min	Max	Média (Desp)	Min	Max	Média (Desp)	Min	Max	Média (Desp)	Min	Max	Razão F
Humidade (%)	51.91 (1.54) A	50.81	53.68	56.97 (6.04) AB	58,0	60,6	58.35 (0.96) B	57.78	59.46	55,48 (0,38) AB	55,04	55,7	56.78 (0,82) AB	56.20	57.36	1,99 ^{ns}
Cinzas %	4.91 (0.60) B	4,54	5,60	1.06 (0,08) A	0,97	1,13	5.08 (0,53) B	4,48	5,5	1.25 (0,13) A	1,17	1,4	4.36 (0,52) B	3,99	4,73	66,2****
pH	6.76 (0,01) A	6,75	6,77	7.79 (0,15) B	7,64	7,95	6.64 (0,01) A	6,63	6,64	7.78 (0,05) B	7,73	7,82	6.7 (0,0) A	6,7	6,7	174,8****
Cianeto (mg/kg)	4.65 (0,02) B	4,64	4,67	3.85 (0,12) A	3,72	3,92	4.86 (0,13) B	4,78	5,01	3.70 (0,48) A	3,19	4,15	5.09 (0,02) B	5,08	5,11	17,9****
β - Caroteno (µg/g)	8.88 (1.55) AB	7.90	10.67	7.69 (1.37) A	6.77	9.27	10.11 (0.64) AC	9.37	10.51	11.52 (0.15) C	11,35	11,64	20.81 (0,27) D	20.61	21,0	57,1****
Sólidos Totais	4.52 (0.04) A	4.47	4.55	4.53 (0.08) A	4.46	4.61	4.47 (0.01) A	4.45	4.48	4.55 (0.05) A	4.52	4.61	4.49 (0.02) A	4.48	4.51	1,15 ^{ns}
Licopeno (µg/g)	7.27 (0.51) AB	6.95	7.86	6.99 (0.09) A	6.89	7.07	10.69 (0.45) D	10.29	11.18	9.02 (0.12) C	8.89	9.12	7.90 (0.81) B	7.33	8.47	37,5****
Acidez titulável	4.15 (0.17) A	3,97	4,32	7.04 (0.09) C	6,99	7,15	3.94 (0.07) A	3,88	4,02	5.5 (0.25) B	5,23	5,72	7.97 (0.08) D	7,91	8,02	329,0****

*p < 0.05; **p < 0.01; p < 0.001. For each factor, there was no statistically significant difference and different letters on the lines indicated homogeneous groups (significant differences at the 95% confidence level obtained by the LSD test).

4.2 MOISTURE CONTENT

Regarding humidity, the values ranged between 51.91% (Badje) and 58.35% (Napirithé), with no statistically significant differences (ns), as shown in table 01 and graph 01. This range is compatible with the values reported for fresh cassava under different genotypes, growing conditions, where moisture is often remains close to 50-65 % and can fluctuate with ripeness, soil and management. This result suggests that Napirithé has greater water retention in the tissues, which may be associated with a less dense cell structure or a higher content of gelatinized starch, directly influencing the drying time and stability of the final product.

DE LUNA, et al. (2013) evaluated the composition of cassava and found a moisture content of 35.31±4.74%, a value much lower than that found in this research, while CENI et al. (2009) evaluated the centesimal composition of five varieties of cassava and observed moisture content from 64.0% to 70.0%, results different from those found in this study.

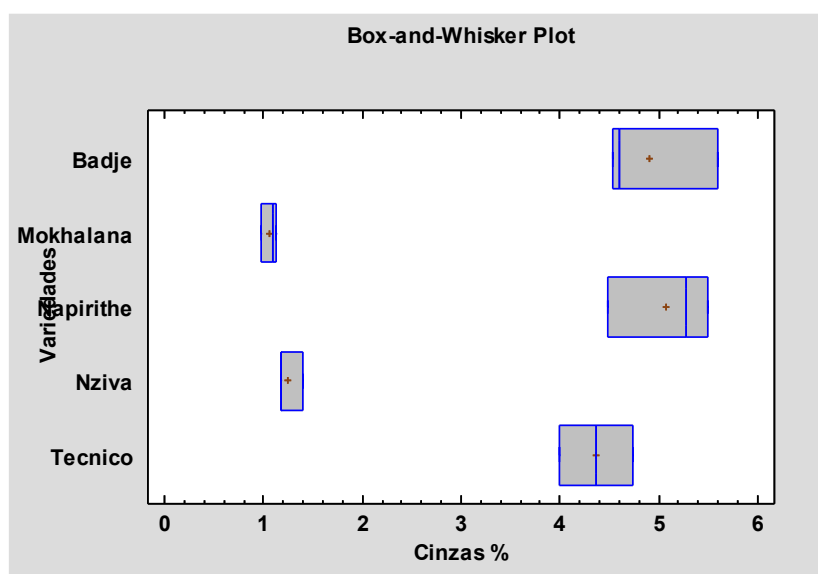
Figure 1*Moisture content in the cassava samples analyzed*

Source: Authors, 2025

4.3 ASH CONTENT

There were highly significant differences for ash ($p < 0.001$), where the Napirthe variety had the highest ash content (5.08%), followed by Badje (4.91%) and Técnico (4.36%) indicating the highest mineral concentration. On the other hand, Nziva (1.25 %) and Mokhalana (1.06%) showed low levels (graph 02), suggesting a lower density of micronutrients, possibly due to edaphoclimatic factors or different agricultural practices. The ash content values of Napirthe, Badje and Técnico are higher than those shown by DE OLIVEIRA (2007), studying fresh roots of table cassava varieties, cultivated in the organic system (1.67% to 1.27%) and close to those of Nziva and Mokhalana.

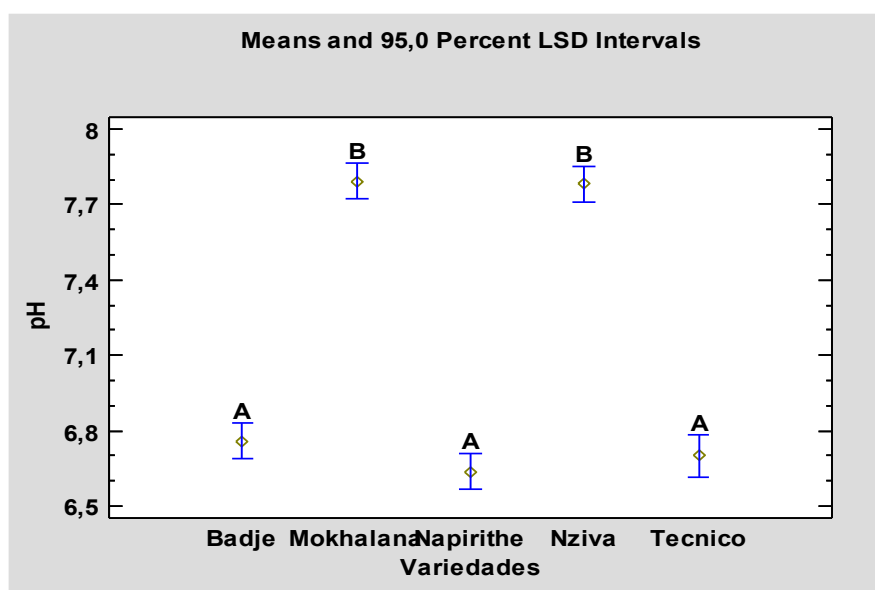
For DE LUNA et al. (2013), they reported ash levels of $1.35 \pm 0.29\%$ in sweet varieties of cassava acquired at two different points between street markets and markets in the city of Juazeiro do Norte. This value is very close to that found in Mokhalana (1.06 %) and N'Ziva (1.25 %), as illustrated in table 01, suggesting similarity in terms of mineral content.

Figure 1*Ash content per sample*

Source: Authors, 2025

4.4 PH

The pH ranged from 6.46 (Nziva) to 7.64 (Mokhalana), as shown in figure 03, revealing significant differences ($F=174.88$). The Mokhalana variety had the highest pH value, indicating a less acidic pulp, while Nziva had the lowest pH, denoting higher acidity. This variation may have technological implications, since the higher pH favors the stability of certain compounds, while the lower pH is related to better microbiological conservation. Similar results were found with LUNA et al. (2013), the pH of sweet cassava varieties in Brazil presented average values of 7.09 ± 0.25 . In fresh cassava, pH close to neutrality is common; in fermented products the pH tends to drop and acidity to rise due to the formation of organic acids. Therefore, pH differences between varieties may be related to tissue composition (available sugars, mineral buffer) and harvest/storage conditions, and also have implications for **microbiological stability** and behavior in fermentation processes.

Figure 2*pH levels in cassava samples*

Source: Authors, 2025

4.5 CYANIDES CONTENT

The cyanide content showed significant differences between the varieties ($p < 0.001$), as shown in table 01, indicating the influence of the genotypic factor on the concentration of cyanogenic compounds. It was observed that the Técnico variety had the highest content (5.09 mg/kg), followed by Napirithé (4.86 mg/kg) and Banje (4.65 mg/kg) while Badje had the lowest value (3.70 mg/kg) and Mokhalana (3.85 mg/kg), as shown in graph 04.

A study carried out by BORGES, FUKUDA & ROSSETTI (2002) found levels higher than those found in this research, values ranging from 22.33 to 90.00 mg/kg, in ten samples analyzed by the titrametric method.

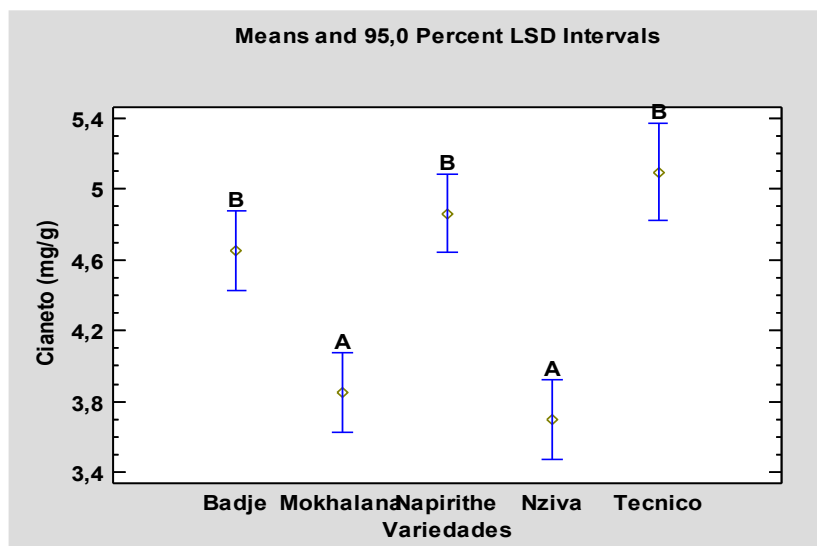
Additionally, research carried out by CHICOVELA, et al., (2025) when evaluating the cyanide content in dried and ground cassava leaves, observed that the Fernando Boa variety had the highest content (2.253 mg/kg), followed by A. Kampwiche (1.720 mg/kg) and Nassuruma (1.473 mg/kg). The cyanide content found in cassava leaf flour ranged from 1.473 to 2.253 mg/kg, values considerably below the maximum recommended limit for food safety.

In all cases, the samples in this study are within the standards required by the WHO (2021), the cyanide content in fresh cassava intended for human consumption should not exceed 10 mg/kg, since higher concentrations can cause acute cyanide poisoning, characterized by nausea, vomiting, and weakness, and, in chronic exposures, neurological disorders such as konzo. Thus, although the values found in the present study remain below the maximum recommended limit, the variability observed between varieties reinforces the

need to adopt appropriate processing practices (peeling, fermentation, drying and cooking) to ensure food safety.

Figure 3

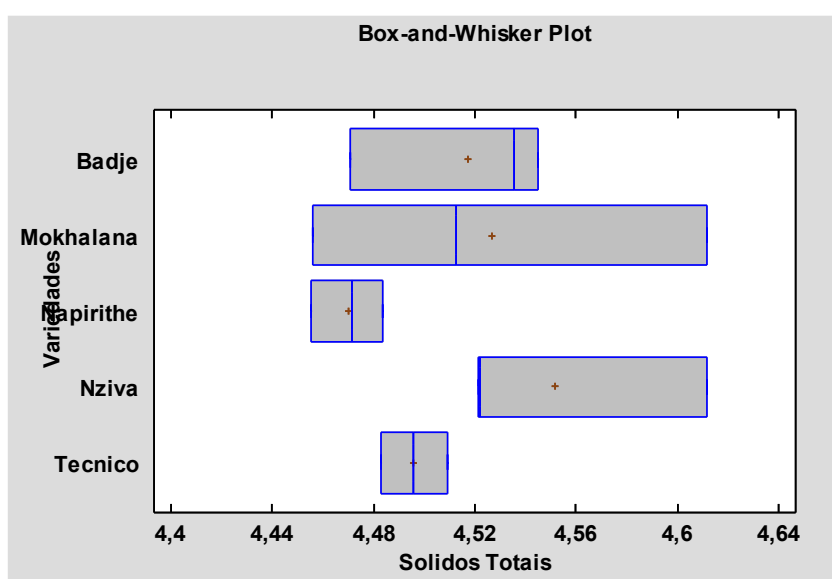
Cyanide levels found per sample



Source: Authors, 2025

4.6 TOTAL SOLIDS CONTENT

The total solids did not show significant difference (ns), indicating relative uniformity between varieties. Such homogeneity indicates that the solid content, composed mainly of starch and fibers, remained stable among the varieties, suggesting a similar structural composition. In food technology, total solids/dry matter are fundamental indicators for **flour and starch yield**, in addition to being associated with texture and culinary acceptance; recent literature widely discusses the importance of dry matter as a selection and quality criterion (BILATE DAEMO et al., 2024). The levels found in this study were lower than those found by CENI, et al., (2009), in five cultivars (BRS Rosada, Casca Roxa, BRS Dourada, BRS Gema de Ovo and Saracura) of cassava (*Manihot esculenta Crantz*) *in natura*, ranging from 30 to 36 g/100g

Figure 5*Average Findings for Total Solids*

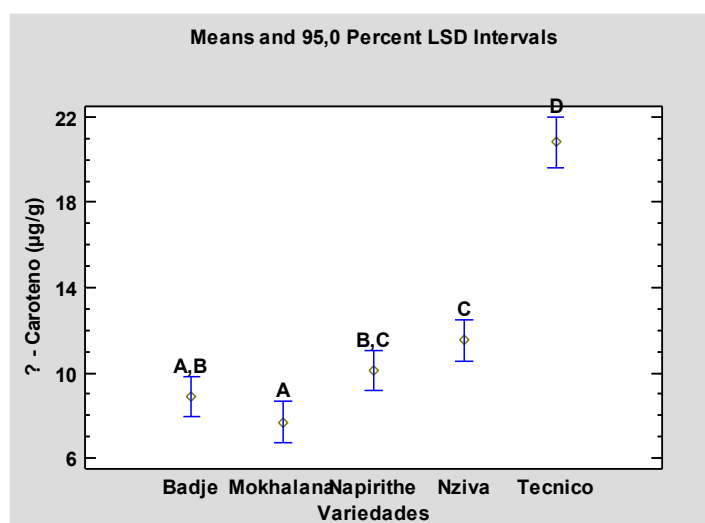
Source: Authors, 2025

4.7 B-CAROTENE CONTENT

With regard to β -carotene, a precursor pigment of vitamin A, the results show substantial differences ($F=57.11$). The highest content was observed in the variety Técnico (20.81 $\mu\text{g/g}$), followed by Nziva (11.52 $\mu\text{g/g}$), while Mokhalana (7.69 $\mu\text{g/g}$) presented the lowest value (table 02 and graph 06).

Approximate levels were found by DE OLIVEIRA (2009) who evaluated 28 hybrids and presented β -carotene content between 7 and 10 $\mu\text{g/g}$ of fresh cassava.

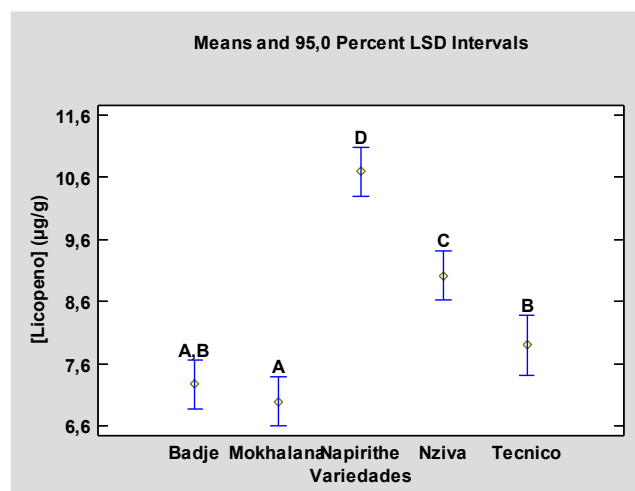
Similar to what was observed for carrots, where soil and management factors explained significant variations in carotenoid levels (ROSA et al., 2026), the results of this study indicate that agricultural practices can modulate the physicochemical composition of cassava.

Figure 6*β-carotene levels per sample*

Source: Authors, 2025

4.8 LYCOPENE CONTENT

In the lycopene parameter, an antioxidant pigment of high nutritional relevance, the variety Napirthe (10.69 μg/g) presented the highest content, followed by Nziva (9.02 μg/g) while Mokhalana (6.99 μg/g) showed the lowest value (graph 07). The differences were significant ($F=37.58$), showing greater antioxidant capacity of the Napirthe variety (table 02), which may be related to genetic characteristics or the physiological state of the roots at the time of harvest. For Silva et al. (2014), in a study carried out on cassava in the Branca, Amarela and Rosada varieties, lycopene values ranging from 0.01 to 19.47% in the three varieties studied, these results are different from those found in this research. The need for public policies to improve the quality and preservation of staple foods has been highlighted in regional studies, highlighting the importance of interventions along the value chain (ROSA et al., 2025a).

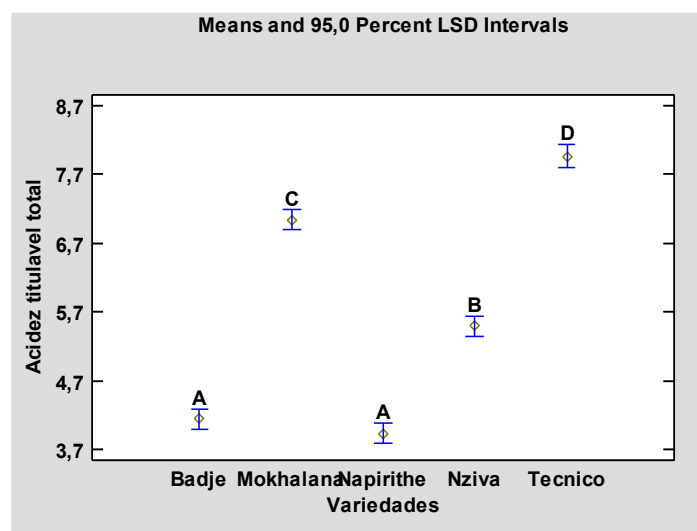
Figure 4*Lycopene Values Findings*

Source: Authors, 2025

4.9 ACIDITY CONTENT

Finally, the titratable acidity showed significant variations ($F=329.00$), with the highest value found in the Técnico (7.97%) and Mokhalana (7.04%) varieties, the lowest was found in Napirithé (3.94%), as shown in table 02. This behavior demonstrates an inverse relationship with pH, where higher acidity corresponds to lower pH value, reflecting metabolic differences in the accumulation of organic acids.

CHISTÉ & COHEN (2011) reported mean RTA values of 0.0548%. The analyses of cassava titratable acidity made by DE LUNA, et al, (2013), found a content of 1.4 ± 0.57 , these contents are very low than that found in this study.

Figure 5*Total Titratable Acidity Content*

Source: Authors, 2025

5 CONCLUSION

The present study allowed the physicochemical and nutritional characterization of five cassava varieties (Badje, Mokhalana, Napirithe, Nziva and Técnico) cultivated in the province of Nampula, Mozambique, showing significant differences between the genotypes for most of the parameters evaluated. Although the moisture and total solids did not present statistically significant variation, the contents of ash, pH, cyanide, β -carotene, lycopene and titratable acidity differed in a highly significant way, demonstrating the influence of the varietal factor on the composition of the roots.

The varieties Badje, Napirithe and Técnico stood out for their higher ash content, indicating greater mineral potential. The variety Técnico had the highest content of β -carotene, suggesting special nutritional interest as a source of provitamin A, while Napirithe and Nziva had higher levels of lycopene, reinforcing the antioxidant potential of these varieties. On the other hand, cyanide levels varied among the varieties, underscoring the importance of proper processing to ensure food safety.

In general, the results demonstrate that there is relevant physicochemical and nutritional diversity among the local varieties of cassava cultivated in Nampula, which opens perspectives for the **targeted selection of genotypes** according to the objective of use, whether for direct consumption, industrial processing or nutritional improvement. Thus, the valorization and scientific characterization of these varieties contribute to programs for improvement, food security and technological use of cassava in Mozambique.

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DIMENSIONS OF AGRICULTURAL MODERNIZATION: A MULTIVARIATE APPROACH TO TECHNOLOGICAL LEVELS IN RONDÔNIA, BRAZILIAN AMAZON

DIMENSÕES DA MODERNIZAÇÃO AGROPECUÁRIA: UMA ABORDAGEM MULTIVARIADA SOBRE OS NÍVEIS TECNOLÓGICOS EM RONDÔNIA, AMAZÔNIA BRASILEIRA

DIMENSIONES DE LA MODERNIZACIÓN AGRÍCOLA: UN ENFOQUE MULTIVARIADO DE LOS NIVELES TECNOLÓGICOS EN RONDÔNIA, AMAZONÍA BRASILEÑA



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ABSTRACT

This study aimed to characterize rural establishments in the state of Rondônia based on records from the 2017 Agricultural Census, using multivariate statistical analysis methods to determine the municipal technological level based on factor scores. The methodological foundation consisted of applying Factor Analysis and Cluster Analysis techniques. Six latent factors were identified—named Plantation, Soil, Technical Instruction, Livestock, Dairy Production, and Rural Modernization—which, together, explained 82.5% of the total variability of the analyzed data. The cluster analysis, validated by K-means and hierarchical methods, revealed that the division into two distinct groups adequately represents the productive heterogeneity of the state. Regarding the technological level (ITEA), it was found that the municipalities are distributed only between the medium and low categories, with no localities at extreme levels (high or very low). The municipality of Pimenteiras do Oeste obtained the highest technological index, standing out as a reference for agricultural modernization in the region. It is concluded that multivariate modeling is a robust and suitable tool to support regional diagnoses and guide public policies aimed at sustainable rural development in Rondônia.

Keywords: Agriculture. Multivariate Statistics. Rural Properties. Technological Levels.

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RESUMO

Este trabalho objetivou caracterizar os estabelecimentos rurais do Estado de Rondônia a partir dos registros do Censo Agropecuário de 2017, utilizando métodos de análise estatística multivariada para determinar o nível tecnológico municipal com base em escores fatoriais. A fundamentação metodológica consistiu na aplicação das técnicas de Análise Fatorial e de Agrupamento (Cluster). Foram identificados seis fatores latentes — denominados Plantação, Solo, Instrução Técnica, Pecuária, Produção Leiteira e Modernização Rural — que, em conjunto, explicaram 82,5% da variabilidade total dos dados analisados. A análise de cluster, validada pelos métodos K-means e hierárquico, revelou que a divisão em dois agrupamentos distintos representa adequadamente a heterogeneidade produtiva do estado. No que tange ao nível tecnológico (ITEA), verificou-se que os municípios se distribuem apenas entre as categorias médio e baixo, com ausência de localidades em níveis extremos (alto ou muito baixo). O município de Pimenteiras do Oeste obteve o maior índice tecnológico, destacando-se como referência de modernização agropecuária na região. Conclui-se que a modelagem multivariada é uma ferramenta robusta e adequada para subsidiar diagnósticos regionais e nortear políticas públicas voltadas ao desenvolvimento rural sustentável em Rondônia.

Palavras-chave: Agropecuária. Estatística Multivariada. Propriedades Rurais. Níveis Tecnológicos.

RESUMEN

Este estudio tuvo como objetivo caracterizar los establecimientos rurales en el estado de Rondônia con base en los registros del Censo Agrícola de 2017, utilizando métodos de análisis estadístico multivariado para determinar el nivel tecnológico municipal con base en puntuaciones factoriales. La base metodológica consistió en la aplicación de técnicas de Análisis Factorial y Análisis de Conglomerados. Se identificaron seis factores latentes — denominados Plantación, Suelo, Instrucción Técnica, Ganadería, Producción Lechera y Modernización Rural— que, en conjunto, explicaron el 82,5% de la variabilidad total de los datos analizados. El análisis de conglomerados, validado por los métodos K-means y jerárquico, reveló que la división en dos grupos distintos representa adecuadamente la heterogeneidad productiva del estado. Con respecto al nivel tecnológico (ITEA), se encontró que los municipios se distribuyen solo entre las categorías media y baja, sin localidades en niveles extremos (alto o muy bajo). El municipio de Pimenteiras do Oeste obtuvo el índice tecnológico más alto, destacándose como referencia para la modernización agrícola en la región. Se concluye que el modelado multivariante es una herramienta robusta y adecuada para respaldar los diagnósticos regionales y orientar las políticas públicas dirigidas al desarrollo rural sostenible en Rondônia.

Palabras clave: Agricultura. Estadística Multivariante. Propiedades Rurales. Niveles Tecnológicos.

1 INTRODUCTION

The state of Rondônia, covering a territorial extension of 237,765.347 km² (IBGE, 2021), requires a broad livestock and agrarian program related to production and consumption itself, reinforcing the state economy, through the national and international export of its breeding and cultivation.

Seeking this production with high profitability, the agribusiness sector strives to demand innovations that contribute to the modernization of agricultural activity that result in greater productivity. Adequate use of technological tools, with a scientific and statistical basis, increases the productivity of the sector and reduces its production cost. In this sense, several scientific studies have been carried out (Sena, 2010; Santos *et al.*, 2017; Simões *et al.*, 2017).

Santos *et al.* (2017) evaluated the technological level of cattle production systems in the Brazilian Amazon. Using official data from the IBGE, they calculated 15 indicators of technology adoption for each of the municipalities of the legal Amazon, the state of Mato Grosso and the municipalities of the state of Maranhão located west of the 44° meridian, a total of 775 municipalities, which were submitted to factor analysis by principal components to estimate the technological index of cattle raising in these regions. The authors found that the state of Mato Grosso has the largest number of municipalities with cattle ranching with the highest technological level, followed by Rondônia, Tocantins and the state of Pará.

Simões *et al.* (2017) investigated the technological heterogeneity of dairy farming in Minas Gerais, through factor analysis of the data and cluster analysis. Based on 15 variables of technology and production scale, based on the Agricultural Census, they built a Dairy Livestock Modernization Index for the 66 micro-regions of Minas Gerais. They concluded that the factor analysis allowed the elaboration of three explanatory factors of the technological level and the scale of milk production and that the cluster analysis enabled the construction of four technology clusters, making it possible to infer that the grouping of micro-regions based on information from the Agricultural Census is coherent with the current reality and can be used to guide public policies.

Factor analysis is a multivariate statistical modeling, which is used to measure the common variability between a set of variables, seeking to reduce the number of these variables, through summarization with latent, unobservable factors (Corrar *et al.*, 2017), while Cluster analysis (clustering) refers to a wide spectrum of methods that attempt to subdivide a set of data and/or variables into subsets (clusters) that are separated into pairs and not empty. The subsets reproduce via union (Bezdek, 1981). A cluster is usually formed by grouping similar data samples around a center, called a centroid or prototype cluster (Mota; Damasceno and Leite, 2018). In view of the above, the work aims to use multivariate factor

and cluster analysis to characterize the records of the agricultural census of rural establishments in the State of Rondônia and to determine the technological level based on factor scores. *XcX*

2 THEORETICAL FRAMEWORK

2.1 CATTLE AND AGRARIAN PRODUCTION IN THE STATE OF RONDONIA

Rondônia exports almost all of its beef production, quarterly, on average, about 75 thousand to 90 thousand tons of beef, generating a positive effect of US\$ 1.1 billion, from January to September 2025. The state received a declaration of a foot-and-mouth disease-free zone, achieving certification without vaccination since 2021 by the World Organization for Animal Health (WOAH), increasing the demand for beef (Idaron, 2025).

In this sense, we can also consider that the sanitary condition of the local herd is the result of an advantageous public-private partnership, appropriately certified by international systems, attracting more and more rigorous markets. The gross value of agricultural production in Rondônia for 2021 was estimated at 19.1 billion reais, a result 12.9% higher than that obtained in 2020 (Pfeifer *et al.*, 2021).

In relation to Agrarian Production, according to data from the National Supply Company – Conab, Rondônia showed a growth of 18.6% in the bulk of grain production in the 2022/2023 harvest. Rondônia stood out with above-average values, reaching a 16.5% increase. It produced 790.1 million tons in the previous harvest and the Conab study predicted an increase to 936.9 million at the end of the 2023/24 harvest. In the grain harvest in 2024, productivity levels were also grandiose, with an estimated increase of 19.2% compared to the figures of the previous period (Conab, 2024). In this new grain harvest (2025/2026), production levels in Rondônia continue to expand, with an estimate of reaching 5.6 million tons, an increase of 3.1% compared to the volume harvested in the previous period. (Conab, 2026).

2.2 TECHNOLOGICAL LEVELS OF AGRICULTURAL PRODUCTION

Technology is a permanent need around the world, and has also sensitized the agricultural field, being one of the important areas for the Brazilian economy, attracting innovations to ensure a high level of production and profits. Producers who invest in technology and innovation had a higher profitability, as productivity increased with technological optimization, where their efficiency indicators in the sector reached high rates (Carvalho, 2022).

The receptivity of rural producers has also been resisted regarding the implementation of innovative tools, until the moment that they get to know and orient themselves better on the subject. By discovering that production is facilitated, and often expanded, generating more income, more organized and better quality work, this blockage of the new is minimized (Carvalho, 2022).

Software, drones, applications, and other innovation systems developed for the livestock sector allow accurate measurements of results (Gasques *et al.*, 2017). For example, maintaining the vaccination history of animals, cattle registration form, weighing records, coverage registration, batch movement, birth registration of new calves and other significant data, provide the breeder with full access to all information to manage his production. The administrative and functional control of cattle breeding benefits the producer in decision-making, regarding the management, sale and purchase of animals, resolving losses and automatically maximizing profits.

Consequently, in the agrarian sector, technological modernization leveraged agricultural production, with an increase in productivity, which in aggregate terms, in the time that production increased 4.5 times, the use of inputs advanced a little more than 15%, which can be explained by the evolution of total factor productivity (TFP), which grew almost four times between 1975 and 2015 (Gasques *et al.*, 2017). Improving the quality of the final product, with stricter monitoring of agricultural practices and the use of advanced harvesting and processing techniques help ensure that products reach consumers with a high standard of quality and safety.

High profitability with environmental sustainability in the use of data intelligence such as precision agriculture tools timely in real time, monitoring the operation of farm machines, visualizing alerts, fuel level, speed and average productivity of machinery. In this way, the agricultural sector unifies a large-scale agriculture, while being sustainable, rotating crops, using biological insecticides and natural fertilizers. So that these actions contribute to a healthy soil, which is capable of meeting the demands of cultivation without compromising the next generations.

2.3 STATISTICAL MODELING – FACTOR ANALYSIS

Factor Analysis is a modeling that aims to expose a set of variables based on a smaller number of indices or factors and, during the procedure, obtain a broad understanding and/or comprehension of these variables (Manly and Alberto, 2019).

In summary, Factor Analysis represents a multivariate random process through the creation of new variables, from the original variables and, usually in smaller numbers, which

correspond to the commonalities of the process, leaving the hypothetical ones not to be described by the factorial model. To test the feasibility of using factor analysis in a data set, it is possible to perform, among others, the Bartlett Sphericity Test, the Sample Adequacy Measure (MAA) and the Kaiser-Meyer-Olkin (KMO) (Mingoti, 2005; Hair *et al.* 2009).

2.3.1 Cluster Modeling (Clustering)

Cluster analysis can be defined as the organization of a set of objects (usually represented by feature vectors, i.e., points in a multidimensional space into groups based on the similarity between them. In other words, it means that grouping objects is the method of partitioning a set of data into subsets (groups) so that the objects in each group (preferably) share common attributes, usually proximity in similarity to some measure of similarity or distance (Castro; Ferrari, 2016).

Intuitively, objects belonging to the same group are more similar to each other than objects belonging to different groups. In this way, a group can be determined as a function of internal cohesion (homogeneity) and external isolation (separation) of its objects (Castro; Ferrari, 2016).

In summary, cluster analysis is a set of multivariate techniques whose main purpose is to aggregate objects based on the characteristics they have, i.e., it does aggregation based on distance (proximity), the resulting clusters of objects should then exhibit high internal homogeneity, within the clusters, and high external heterogeneity, between the clusters (Hair *et al.*, 2009).

2.3.2 Types of Cluster Analysis

Many algorithms have been proposed for cluster analysis, however, hierarchical and partition techniques are the most used, and will be briefly described in this work.

Hierarchical techniques, most of the time, are used in exploratory analyses of the data with the objective of identifying possible groupings and the probable value of the number of groups (Mingoti, 2005). This technique produces a dendrogram, starting with the calculation of the distances from each object to all other objects, groups are then formed by a process of agglomeration or division. With conglomeration, all objects start out on their own in groups of one, and the nearby groups are then gradually merged until finally all objects remain in the same group (Manly; Alberto, 2019).

The clustering technique, on the other hand, uses partitioning, with objects being able to move in and out of groups at different stages of the analysis. There are variations in the algorithms used, but the basic approach involves first choosing centers from more

or less occasional groups, with objects then allocated to their nearest center, i.e., new centers are then calculated, and these reflect the means of the objects in the groups (Manly; Alberto, 2019). In this way, an object is moved to a new group as follows:

Whether the object is closer to that group center than to the center of its present group. Any group that is close is merged, scattered groups are split, etc., following some set rules. The process continues iteratively until stability is achieved with a number of predetermined groups. Usually a domain of values is experimented with for a final number of groups (Manly; Alberto, 2019, p. 164).

Commonly used by scholars among non-hierarchical clustering (partition) schemes, the *K-means* clustering method relates objects within multiple groups, so that *intra-cluster* variation is minimized by the sum of squares of Euclidean distances between the elements and their centroids (Johnson; Wichern, 2002).

3 METHODOLOGY

3.1 DATA

The present study was carried out with data from the Brazilian Institute of Geography and Statistics (IBGE), in the state of Rondônia, covering its 52 municipalities, using information from the 2017 Agricultural Census, the most recent found in the database of this agency. The variables that were analyzed are adapted from Santos *et al.* (2017) and Simões *et al.* (2017) and the naming of the indicators are presented in Table 1.

Table 1

Definition of the variables used to characterize the technological level of agricultural establishments in the State of Rondônia

V1 - Pasture Areas	Proportion of pasture areas in relation to the total area of agricultural establishments (%)
V2 - Disease Control	Proportion of establishments that carry out disease control in relation to the total number of establishments with livestock (%)
V3 – Crops	Proportion of establishments with crops in relation to the total number of agricultural establishments (%)
V4 - Soil preparation	Proportion of establishments that carry out soil preparation in relation to agricultural establishments (%)
V5 – Livestock	Proportion of establishments with livestock in relation to the total of agricultural establishments (%)
V6 - Electrical Power	Proportion of establishments with electricity in relation to the total number of agricultural establishments (%)
V7 – QL	Locational Quotient (LL) of the municipality in relation to livestock in the state of Rondônia
V8 - Water resources	Proportion of establishments with water resources in relation to the total number of agricultural establishments (%)
9 - Milked cows	Number of cows milked annually in relation to the number of agricultural establishments with cattle.

V10 - Production trade	Proportion of establishments with commercialization of production in relation to the total number of agricultural establishments (%)
V11 - Soil Correction	Proportion of establishments that carry out soil correction in relation to the total number of agricultural establishments (%)
V12 - Animal Nutrition	Proportion of livestock establishments that supplement with feed, grains and agro-industrial by-products (%)
V13 – Mineral salt	Proportion of establishments with cattle rearing that supplement with mineral salt (%)
V14 – Technical Guidance	Proportion of establishments receiving technical assistance in relation to total agricultural establishments (%)
V15 – Fertilization	Proportion of establishments that carry out fertilization in relation to the total number of agricultural establishments (%)
V16 – Irrigation	Proportion of establishments that carry out irrigation in relation to the total number of agricultural establishments (%)
V17 - Milk production	Amount of cow's milk produced (Thousand liters) in relation to the number of establishments that produce cow's milk.
V18 – Internet	Proportion of establishments with internet in relation to the total number of agricultural establishments (%)
V19 - Tractors and agricultural implements	Proportion of establishments with tractors and agricultural implements in relation to the total number of agricultural establishments (%)
V20 - Email	Proportion of agricultural establishments that have e-mail in relation to the total number of agricultural establishments (%)

Source: Prepared by the authors (2026).

The variables called indicators were calculated as percentages, with the exception of V7, V9 and V17, with the variable V7, - Locational Quotient (QL) of the municipality in relation to cattle raising, which was calculated according to Santos *et al.* (2017) by:

$$Ql = \frac{\left(\frac{VBP_{ij}}{VBP_j}\right)}{\left(\frac{VBP_{iRO}}{VBP_{RO}}\right)}, \quad (1)$$

where: it is the gross value of the production of activity i, in the case of cattle, in municipality j; VBP_{ij}

VBP_j it is the total gross value of agricultural production;

VBP_{iRO} it is the gross value of cattle production in Rondônia;

VBP_{RO} is the gross value of agricultural production in Rondônia.

The variable V9 - Milked cows, was calculated by the ratio of the number of cows milked annually in relation to the number of establishments with cattle and the variable V17 - Milk production, was calculated by the ratio of the amount of cow's milk produced (Thousand liters) in relation to the number of agricultural establishments that produce cow's milk.

The technological index of agricultural establishments (ITEA) was calculated from the weighted average of the factors by the proportion of explanation of the total variance associated with each of them, adapted from Santana, 2007 and Santos *et.al.*, 2017, according to Expression 9.

$$ITEA = \frac{\sum_{j=1}^n w_j * FP_{ij}}{\sum_{j=1}^n w_j} \quad (2)$$

where, ITEA is the index of the i-th municipality; w_j is the proportion of variance explained by the j-th factor and FP_{ij} is the value of the i-th standardized factorial score associated with the i-th municipality. The factorial score was standardized for the acquisition of positive values between -1 and 1 (Santos *et al.*, 2017). The standardization of the scores and the calculation of the ITEA followed the parameters validated in previous studies in the area (Silva *et al.*, 2026a). From the ITEA values, four technological levels were established:

- i) $ITEA \geq 75$ (high);
- ii) $50 \leq ITEA < 75$ (medium);
- iii) $25 \leq ITEA < 50$ (low);
- iv) $0 < ITEA < 25$ (very low).

The levels were defined in relation to the set of municipalities analyzed, thus, a municipality classified as high level does not imply agricultural establishments with high technological indexes, only that its level is higher in relation to the other municipalities in the sample.

3.2 DATA ANALYSIS

3.2.1 Descriptive Statistics

The data from the 2017 Census of Agriculture were initially analyzed through the procedures of descriptive statistical analysis, calculating the mean and the maximum and minimum values (Andrade; Ogliari, 2013).

3.2.2 Modeling

After the initial analyses, the Factor Analysis technique was applied to find the possible factors within the records of rural establishments in the state of Rondônia, using within the technique the resource of rotation of the factors to obtain the interpretability of each factor.

Factor analysis had its initial development based on the result of Charles Spearman's work, according to the factor analysis model, which establishes that:

$$X_i = a_{i1} F_1 + a_{i2} F_2 + \dots + a_{im} F_m + e_i, \quad (3)$$

where:

X_i it is the i th test score with zero mean and unit variance;

a_{i1} a are loads of factors for the i th test; a_{im}

F_1 a F_m are m common uncorrelated factors, each with zero mean and unit variance;

e_i It is a specific factor only for the i -th test that is not correlated with any of the common factors and has a mean of zero.

With this model,

$$\begin{aligned} \text{Var}(X_i) &= 1 = a_{i1}^2 \text{Var}(F_1) + a_{i2}^2 \text{Var}(F_2) + \dots + a_{im}^2 \text{Var}(F_m) + \text{Var}(e_i) \\ &= a_{i1}^2 + a_{i2}^2 + \dots + a_{im}^2 + \text{Var}(e_i), \end{aligned} \quad (4)$$

where:

$a_{i1}^2 + a_{i2}^2 + \dots + a_{im}^2$ they are called the commonality of (the part of their variance that is related to common factors), and $\text{Var}(e_i)$ it is called the specificity of X_i (the part of their variance that is not related to common factors) (Manly; Alberto, 2019).

It can also be shown that the correlation between and is $X_i X_j$

$$r_{ij} = a_{i1} a_{j1} + a_{i2} a_{j2} + \dots + a_{im} a_{jm}. \quad (5)$$

Therefore, two test scores can only be highly correlated if they have high loads on the same factors. Moreover, since commonality cannot exceed one, it is necessary that $-1 \leq a_{ij} \leq +1$ (Manly; Alberto, 2019).

The criteria described in Mingoti (2005) were used to estimate the number of m factors. The choice of the number of factors is essential and aims to replace the set of original variables with factors, and it is natural that the number of factors is lower than the number of variables analyzed (Corrar *et al.*, 2017). Thus, instead of working with 100% of the total variability of the data, only a total portion of the data explained by factors was analyzed.

To verify the rotation of these factors, the *Varimax method* was applied, which, according to Fávero *et al.* (2021) is the most widely used method and seeks to minimize the number of variables that have high loads on a factor, simplifying the interpretation of factors. Next, the Bartlett Sphericity Test, the Sample Adequacy Measure (MAA) and the Kaiser-Meyer-Olkin (KMO) tests were applied (Mingoti, 2005; Hair *et al.* 2009).

3.2.2.1 Bartlett Sphericity Test

Bartlett's sphericity test allows verifying, for this number of degrees of freedom and a given level of significance, whether the value of the statistic is greater than the critical value of the statistic. $\chi^2_{Bartlett}$

We can affirm that Pearson's correlations between pairs of variables are statistically different from 0 and for this reason factors can be extracted from the original variables, thus being the appropriate analysis according to Fávero; Belfiore, (2021) is given by:

$$\chi^2_{Bartlett} = - \left[(n-1) \left(\frac{2k+5}{6} \right) \right] \ln|D|, \quad (6)$$

with degree of freedom, where: $\frac{k.(k-1)}{2}$

n is the sample size;

k is the number of variables;

$|D|$ is the determinant of the correlation matrix, which has a chi-square distribution with degrees of freedom.

3.2.2.2 Sample Adequacy Measure (MAA)

The Sample Adequacy Measure (MAA) serves to calculate the degree of intercorrelation between the variables and the adequacy of the factor analysis (Hair *et al.*, 2009), a (MAA) is considered acceptable and essential when $.MAA > 0,5$

If the MAA result shows a low value, we can detect the variables responsible for this effect. The MAA analysis is comparable to the KMO, in which the variables found within the unacceptable domain must be excluded in order to later apply the factor analysis, that is, it is considered Good, acceptable and unacceptable to proceed with the factor analysis without the removal of this variable (Hair $MAA \geq 0,750,5 \leq MAA < 0,75$ $MAA < 0,5$ *et al.* 2009).

3.2.2.3 Kaiser-Meyer-Olkin Test (KMO)

The KMO measure evaluates the adequacy of the factor analysis, being calculated as described in Fávero and Belfiore, (2021) by:

$$KMO = \frac{\sum_{l=1}^K \sum_{c=1}^K \rho_{lc}^2}{\sum_{l=1}^K \sum_{c=1}^K \rho_{lc}^2 + \sum_{l=1}^K \sum_{c=1}^K \varphi_{lc}^2}, l \neq c, \quad (7)$$

where:

l and represent, respectively, the rows and columns of the correlation matrix c ρ , the terms represent the partial correlation coefficients between two variables. While Pearson's correlation coefficients are also called zero-order correlation coefficients, φ partial correlation coefficients φ ρ are also known as higher-order correlation coefficients (Fávero; Belfiore, 2021).

With variation between and , where is the correlation coefficient between variables and the partial correlation coefficient, in which, the lower the partial correlations, the closer the index is to 1 (Johnson; Wichern, 2002). In the literature on the interpretation of KMO indices, authors report that it is considered Good, acceptable and unacceptable to perform factor analysis on the data sample (Kaiser, 1958; Castro and Mota, 2022). This index compares the amplitude of the correlations observed between the variables with the dimension of the partial correlations, since the latter shows the degree of relationship between two variables by suppressing the influence of the others. $0.1R^2_{ij}x_{ij}KMO \geq 0,750,5 \leq KMO < 0,75KMO < 0,5$

The values of the KMO index that indicate that Factor Analysis is appropriate vary from author to author. For Hair *et al.* (2009) are acceptable values between 0.5 and 1.0, so below 0.5 indicates that factor analysis is unacceptable.

3.2.2.4 Factor Retention

The Kaiser-Guttman factorial retention criterion, described in (Damásio, 2012), was used. This factor retention criterion is one of the most widely used, also called the eigenvalue criterion greater than 1. To verify the reliability of the factor analysis. This criterion proposes a quick, concrete measurement of the number of factors to be retained and each retained factor has an eigenvalue that refers to the total variance explained by this factor.

3.2.2.5 Hierarchical methods and *k-means algorithm*

The hierarchical cluster analysis methods were used for the elaboration of the dendrogram and the *k-means algorithm*. In k-means-generated partitioning, each object refers to the centroid group closest to it. The standard *k-means* algorithm acts through an iterative realignment technique as follows: the initial centroids of the groups are formed randomly or by randomly selecting certain objects from the database itself. Once this step is completed, the distance between the objects of the base and each centroid is calculated, which can generate a repositioning of the centroids and a new allocation of objects to groups (Castro; Ferrari, 2016).*k*

The data were analyzed using the following software: R *Development Core Team* (2024) and Jamovi (2024).

4 RESULTS AND DISCUSSIONS

4.1 GENERAL DESCRIPTIVE ANALYSIS OF THE STATE OF RONDÔNIA

The Agricultural Census carried out by the Brazilian Institute of Geography and Statistics (IBGE) in 2017 made it possible to assess the technological level of rural properties in the state of Rondônia. This characterization is relevant to understand the particularities of these agricultural establishments. The descriptive statistics of the 20 variables related to rural properties through qualitative modeling are described below.

For V1 - Pasture area, the agricultural establishments in the state had an average of 69%, with Vilhena being the municipality with the smallest pasture area, 36%, and Teixeiraópolis with the largest pasture area, 90%. In item V11 - Soil correction, the average achieved was 11% and with the highest value was the municipality of Vilhena with and the lowest value with 3% was Governor Jorge Teixeira.

According to Rosa Neto (2021), Vilhena's GDP stands out in services, corresponding to 42.3% of the state total, since this municipality has agricultural production as its main economic aptitude, this value consumed in services is strongly related to agriculture, as is the case with soybeans and corn, as it encompasses the commercialization of machinery, implements, inputs and other related items. As for Teixeiraópolis, having a large area of pastures, it is justified, as it is a dairy municipality with a daily production of 38 thousand liters (Emater-RO, 2017), with the main economic activity being cattle raising and dairy production.

Checking the variable number of milked cows - V9, the average was 7.83, with Ouro Preto do Oeste presenting the maximum value in relation to this variable 15.21, confirming that the municipality is a large dairy producer (IDARON, 2025). Pimenta Bueno, on the other hand, had the lowest value of 2.59 milked cows according to the 2017 census (IBGE, 2021). For the variable V17 - Milk production, the average value of production in the state was 22.63 thousand liters. The municipality of Ouro Preto do Oeste had the highest milk production, with 30.75 thousand liters and Nova Brasilândia D'Oeste the lowest with 14.29 thousand liters. In 2023, Rondônia saw a significant increase in milk production, consolidating itself as a leader in the North region (IBGE, 2024).

Analyzing the variable V6 - Electricity, the average value was 91%, where Teixeiraópolis reached the highest volume 98% and Primavera de Rondônia the lowest 56%. When item V7 - Livestock Locational Quotient was evaluated, the average was 1.03, with emphasis on the municipality of Parecis with 1.31 and a low QL for Cabixi 0.41. The Locational Quotient according to Haddad (1989) and Santana (2007) is a measure frequently used in regional economic studies to assess whether a municipality has specialization in a specific activity or sector.

As for the variable Proportion of establishments with livestock in relation to the total of agricultural establishments in percentage, there was an average value for the state of RO of 93.27% in this item the municipality with the highest percentage of properties focused on livestock was Governador Jorge Teixeira, reaching 99.47% of the properties, while the municipality with the lowest livestock activity was Guajará-Mirim, reaching 64.95%. In theme V12 - Animal nutrition, the average achieved was 43% and the highest and lowest values were the municipalities of Pimenteiras do Oeste and Machadinho D'Oeste with 76% and 16%, respectively. In the use of mineral salt - V13, the average was 85%, with higher and lower values for the municipalities of Nova Mamoré, 96% and Vilhena, 54%.

For component V2 - Disease control, the average value was 89%, where the municipalities with the highest and lowest values were Parecis and Chupinguaia with 99% and 66%, respectively. In item V3 - Crops, the municipalities highlighted were Cerejeiras and Parecis with 34% and 0% respectively. In relation to Soil Tillage - V4, an average of 28% was verified, with maximum values of 73% for Primavera de Rondônia and minimum of 5% for Theobroma. On the other hand, the variable V8 - Water resources reached an average of 80% in the state, and Theobroma due to its fertile soils, concatenated to favorable climatic conditions and the abundance of river resources presented the highest value (94%), while Alto Alegre do Parecis the lowest value 47% in relation to the availability of this variable. According to the State Secretariat for Environmental Development (Sedam), Rondônia has increased the area dedicated to fish farming and currently has about 16 thousand hectares of water mirror.

Observing the variable V15 - Fertilization, an average of 17% was found for the state. Alto Alegre do Parecis with a maximum value of 61% and Governador Jorge Teixeira with a minimum value of 3% regarding fertilization in these municipalities. Regarding the variable V16 - Irrigation, the average reached was 9%. Nova Brasilândia D'Oeste 37% had the highest use of this resource, on the other hand, Pimenta Bueno obtained the lowest value of and 1% compared to the other municipalities.

The variable V10 - Trade of production obtained an average of 90%. Being the municipality of São Felipe do Oeste with the highest 100% commercialization of production in rural establishments and the lowest value for Chupinguaia 53%. In relation to the Receipt of Technical Guidance -V14, the average verified was 22%. The municipality of Pimenteiras 57% received the highest amount of guidance according to the census, while Campo Novo de Rondônia received the lowest technical guidance.

As a result of technological modernity, an average of 30% was observed for the variable Internet access - V18. The municipality of São Felipe do Oeste reached 54%, being

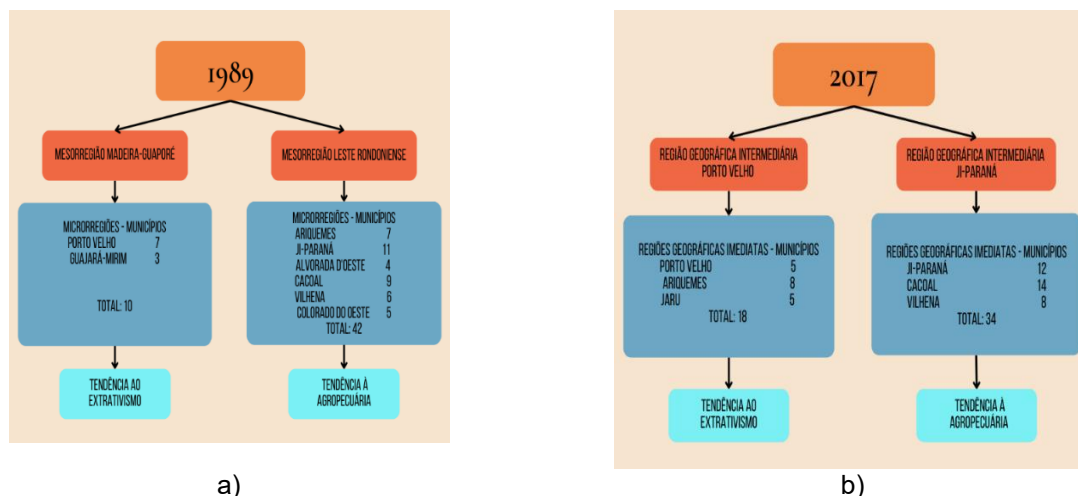
considered the highest use and access to this technology, while Candeias do Jamari reached 11%, the lowest value observed. For variable V19 - Tractors and Implements, the average use in Rondônia was 16%, with Pimenteiras do Oeste with 76% and Urupá with 2%, the municipalities with the highest and lowest values, respectively. Regarding the possession of E-mail - V20, rural properties registered an average of 4%, a very low average value in line with the importance of using new technologies in the current scenario. The municipality of Pimenteiras do Oeste 15% was the one that most used this resource, while Vale do Anari presented a minimum value of 1% for the use of E-mail.

4.2 DESCRIPTIVE ANALYSIS BY INTERMEDIATE REGIONS OF THE STATE OF RONDÔNIA

The mesoregions and microregions of Brazil have constituted the regional geographic division of the country in force since 1989, according to the composition prepared by the Brazilian Institute of Geography and Statistics (IBGE). This division was replaced by the new regional division in 2017 (IBGE, 2017). As mentioned by Cavalcante (2011), in 1989, the State of Rondônia had mesoregions with extractive and agricultural characteristics (Figure 1). Today, these regions are known as intermediate and immediate regions and have undergone a slight change, with a decrease in extractivism and a small growth in the agricultural sector. The central part of the state has Ji-Paraná as its second largest city, while the southern cone stands out for its promising agricultural dominance.

Figure 1

Institutional changes in the State of Rondônia according to information from the IBGE. (a) Geographical division of 1989. b) Geographical breakdown of 2017



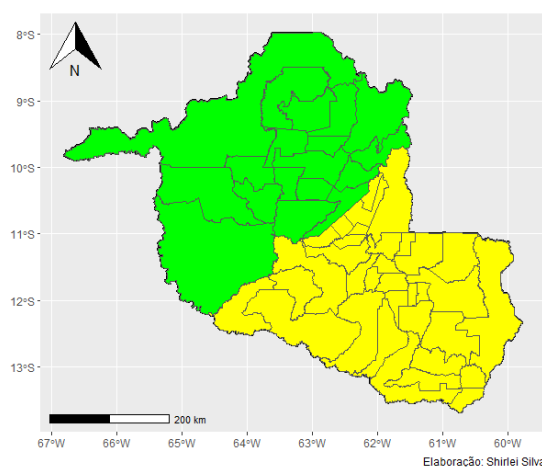
Source: Adapted from Cavalcante (2011).

The state of Rondônia is composed of 52 municipalities, grouped into two intermediate geographic regions: Porto Velho; and Ji-Paraná. These two regions were subdivided, each of them into three geographic regions immediate to the main municipalities belonging to them.

The cartographic representation of the two main regions of the state of Rondônia can be seen in Figure 2, in this cartogram it is also verified the subdivision of the state into its 52 municipalities.

Figure 2

State of Rondônia subdivided into two intermediate geographic regions: Porto Velho in green and Ji-Paraná in yellow



Source: Prepared by the authors (2026).

4.2.1 Intermediate Geographic Regions

The intermediate geographic region of Porto Velho houses 18 municipalities and that of Ji-Paraná 34. To perform the analyses, the intermediate geographic regions were classified by separating them into two colors for better visualization and characterization of the descriptive statistics. The municipalities housed in the intermediate geographic region of Porto Velho in green (Figure 2) are: Alto Paraíso, Ariquemes, Buritis, Cacaúlândia, Campo Novo de Rondônia, Candeias do Jamari, Cujubim, Governador Jorge Teixeira, Guajará-Mirim, Itapuã do Oeste, Jaru, Machadinho D'Oeste, Monte Negro, Nova Mamoré, Porto Velho, Rio Crespo, Theobroma and Vale do Anari.

The intermediate region of Porto Velho, according to Table 2, has an average of 68% of pasture area -V1 in relation to the establishments in Rondônia, with Porto Velho being the municipality with the smallest pasture area, with 45% and Jaru with the largest pasture area 88%. The variable V2 - Disease control had an average of 89%, where the municipalities with the highest and lowest values were Nova Mamoré and Porto Velho with 96% and 77%, respectively.

In item V3 - Crops, with an average of 5%, the municipalities highlighted were Alto Paraíso and Cacaúlândia, with 12% and 2%. In item V4 - Soil preparation, an average of 19% was reached, with a maximum of 41% for Candeias do Jamari and a minimum of 5% for Itapuã do Oeste. In V5 - Livestock, the average found was 93% and the municipalities were Governador Jorge Teixeira with 99% and with 65% for Guajará-Mirim.

Table 2

Average, maximum and minimum values observed for each variable of the agricultural establishments of Rondônia in the Intermediate Geographic Region of Porto Velho - RGIPV in data obtained from the agricultural census - IBGE 2017

Variables	Average	Municipalities	
		With the highest average	With lower average
V1- Pasture Areas	68%	88% -Jaru	45% - Porto Velho
V2- Disease control	89%	96% - Nova Mamoré	77% - Porto Velho
V3- Crops	5%	12% - Alto Paraíso	2% - Cocoa
V4- Soil preparation	19%	41% - Candeias do Jamari	5% - Itapuã do Oeste
V5- Livestock	93%	99% - Governor Jorge Teixeira	65% - Guajará-Mirim
V6- Electric power	90%	98% - Governor Jorge Teixeira	68% - Guajará - Mirim
V7- QL	1,05	1.28 – Nova Mamoré	0.60 – Cujubim
V8- Water resources	81%	94% - Theobroma	50% - Guajará- Mirim
V9-Milked cows	8,29	14.42 – Governor Jorge Teixeira	4.08 – Alto Paraíso
V10 - Production trade	91%	99% - Governor Jorge Teixeira	82% - Cocoa
V11- Soil Correction	9%	22% - Itapuã do Oeste	3% - Governor Jorge Teixeira

V12- Animal Nutrition	43%	67% - Cocoa	16% - Machadinho do Oeste
V13- Mineral salt	85%	96% - Nova Mamoré	69% - Porto Velho
V14- Technical guidance	19%	44% - Guajará-Mirim	6% - Campo Novo de Rondônia
V15- Fertilization	10%	18% - Rio Crespo	3% - Governador Jorge Teixeira
V16- Irrigation	4%	10% - Candeias do Jamari	1% - Cocoa
V17- Milk production	23,62	30.66 – Nova Mamoré	17.91 – Buritis
V18- Internet	21%	39% - Nova Mamoré	11% - Candeias do Jamari
V19- Tractors and implements	13%	33% - Rio Crespo	5% - Governador Jorge Teixeira
V20- Email	2%	7% - Candeias do Jamari	1% - Anari Valley

QL = Livestock locational quotient, V9 = Head/Establishments with cattle, V17 = Milk production in Thousand liters.

Source: Prepared by the authors (2026).

For the variable V6 - Electricity, the average value reached was 90%, where Governador Jorge Teixeira obtained 98%, while Guajará-Mirim presented a minimum value of 68%. However, for item V7 - Locational quotient, the average was 1.05, with highlights for the municipalities of Nova Mamoré with 1.28 and 0.60 for Cujubim. Now, in the variable V8 - Water resources, the average was 81% and highlights for Theobroma with 94% and the lowest value for Guajará-Mirim with 50%. In terms of the number of V9 - Cows milked annually, the average was 8.29, and the municipality of Governador Jorge Teixeira reached the highest value in relation to this variable: 14.42, on the other hand, Alto Paraíso had the lowest proportion of the number of cows milked during the year, with a value of 4.08.

The variable V10 - Production trade had an average of 91% and the municipalities with the highest value 99% and the lowest value 82% were Governador Jorge Teixeira and Cacaúlândia, respectively. In the variable V11 - Soil correction, the average was 9% and values higher than 22% and lower than 3% were in the respective municipalities of Itapuã do Oeste and Governador Jorge Teixeira. For the variable V12 - Animal nutrition, the average measured was 43% and its highest and lowest values were in the municipalities of Cacaúlândia and Machadinho do Oeste, with their respective values of 67% and 16%. In the use of mineral salt - V13, the average obtained was 85% and the municipalities with the highest and lowest values were Nova Mamoré with 96% and Porto Velho with 69%.

As for the municipality of Porto Velho, the items that contributed most to the GDP were services and industry, with a combined share of 73.4%. Agriculture had a share of only 3.6% in the municipality's GDP (Neto, Araujo and Silva, 2022), thus it is understood that the low agricultural participation in 2017 reflects the low use of mineral salt in agricultural establishments in Porto Velho.

In terms of Technical Guidance - V14, the average was 19% and the corresponding municipalities with the highest value of 44% was Guajará-Mirim and with the lowest value of

6% was Campo Novo de Rondônia. The variables V15 - Fertilization with an average of 10% and V16 - Irrigation with an average of 4%, denote in their results that agriculture in Rondônia is still in its infancy, however, in vigorous development, as it currently represents an expansion of 7.7% of the planted area, with an estimated production of 4.1 million tons, 8.7% higher than that of the last harvest.

The average productivity is estimated at four thousand kilograms per hectare, 0.9% higher than that obtained in the 2022/2023 harvest (EMBRAPA RONDÔNIA, 2024), with the municipalities with the highest value Rio Crespo 18% and the lowest Governador Jorge Teixeira 3% in fertilization and Candeias do Jamari with 10% and Cacaúlândia with 1% for variable irrigation. In V17 - Milk production, the municipalities corresponding to the highest and lowest values were Nova Mamoré with 30.66 thousand liters and Buritis with 17.91 thousand liters respectively and presented an average production of 23.62 thousand liters.

Regarding the variable Internet access - V18, the average was 21%, with a value higher than 39% for Nova Mamoré and a lower value of 11% for Candeias do Jamari. In relation to the variable V19 - Tractors and agricultural implements reached an average of 13% and the municipalities with the highest value of 33% in Rio Crespo and the lowest value of 5% in Governador Jorge Teixeira. For variable V20 - E-mail, the average was 2%, with the highest value for Candeias do Jamari with 7% and the lowest in Vale do Anari with 1%.

The municipalities of the intermediate geographic region of Ji-Paraná in yellow (Figure 2) are: Alta Floresta D'Oeste, Alto Alegre do Parecis, Alvorada D'Oeste, Cabixi, Cacoal, Castanheiras, Cerejeiras, Chupinguaia, Colorado D'Oeste, Corumbiara, Costa Marques, Espigão D'Oeste, Ji-Paraná, Ministro Andreazza, Mirante da Serra, Nova Brasilândia D'Oeste, Nova União, Novo Horizonte do Oeste, Ouro Preto do Oeste, Parecis, Pimenta Bueno, Pimenteiras do Oeste, Presidente Médici, Primavera de Rondônia, Rolim de Moura, Santa Luzia do Oeste, São Francisco do Guaporé, São Miguel do Guaporé, Seringueiras, Teixeirópolis, Urupá, Vale do Paraíso and Vilhena.

The intermediate region of Ji-Paraná, as shown in Table 3, presented an average of 70% of pasture area - V1, in the establishments of Rondônia, with Vilhena being the municipality with the smallest area of pastures, with 36% and Teixeirópolis with the largest area of pastures 90%. The variable V2 - Disease control had an average of 90%, where the municipalities with the highest and lowest values were Parecis and Chupinguaia with 99% and 66%, respectively. In item V3 - Crops, with an average of 9%, the municipalities highlighted were Cerejeiras, with 34% and Parecis, with 0%. For variable V4 - Soil tillage, the average observed was 32%, with maximum values of 73% for Primavera de Rondônia and minimum of 9% for Pimenta Bueno. For V5 - Livestock, the average found was 94%. The

municipality of Vale do Paraíso reached a value of 99% for the Proportion of establishments with livestock in relation to the total of agricultural establishments, while Vale do Paraíso obtained 86%, being considered the lowest value in the State.

Table 3

Average, maximum and minimum values observed for each variable of the agricultural establishments of Rondônia in the Intermediate Geographic Region of Ji-Paraná - RGIJP in data obtained from the agricultural census - IBGE 2017

Variables	Average	Municipalities	
		With the highest average	With lower average
V1- Pasture Areas	70%	90% - Teixeiraópolis	36% - Vilhena
V2- Disease control	90%	99% - Parecis	66% - Chupinguaia
V3- Crops	9%	34% - Cherry Trees	0% - Parecis
V4- Soil preparation	32%	73% - Rondônia Spring	9% - Bueno Pepper
V5- Livestock	94%	99% - Paradise Valley	86% - Nova Brasilândia D'Oeste
V6- Electric power	91%	98% - Teixeiraópolis	56% - Rondônia Spring
V7- QL	1,01	1.31 – Parecis	0.41 – Cabixi
V8- Water resources	79%	94% - Parecis	47% - Alto Alegre dos Parecis
V9-Milked cows	7,58	15.21 - Ouro Preto do Oeste	2.59- Bueno Pepper
V10 - Production trade	90%	100% - São Felipe do oeste	53% - Chupinguaia
V11- Soil Correction	12%	31% - Vilhena	4% - Urupá
V12- Animal Nutrition	44%	76% - Vilhena	20% - Brazil nut trees
V13- Mineral salt	85%	95% - Parecis	54% - Vilhena
V14- Technical guidance	24%	57% - Pimenteiras do Oeste	9% - Rubber trees
V15- Fertilization	21%	61% - Alto Alegre dos Parecis	5% - Urupá
V16- Irrigation	11%	37% - Nova Brasilândia D'Oeste	1% - Corumbiara
V17- Milk production	22,10	30,75 - Ouro Preto do Oeste	14,29 - Nova Brasilândia D'Oeste
V18- Internet	34%	54% - São Felipe do Oeste	20% - Chupinguaia
V19- Tractors and implements	17%	76% - Pimenteiras do Oeste	2% - Urupá
V20- Email	5%	15% - Pimenteiras do Oeste	1% - Parecis

QL = Livestock locational quotient, V9 = Head/Establishments with cattle, V17 = Milk production in Thousand liters.

Source: Prepared by the authors (2026).

Analyzing the variable V6 - Electricity, it was found that the average was 91%, where Teixeiraópolis had the highest volume with 98% and Primavera de Rondônia 56% the lowest. Regarding item V7 - Livestock locational quotient, the average was 1.01, with highlights for the municipalities of Parecis with 1.31 and the municipality of Cabixi with 41%. Now for variable V8 - Water resources, the average observed was 79%, with the municipality of Parecis having the highest availability of this resource in the state with 94% and Alto Alegre do Parecis the lowest with 47%.

In terms of the quantity of V9 - Milked cows, the average was 7.58, with the municipality of Ouro Preto do Oeste having the highest amount of this variable: 15.21, on the other hand, Pimenta Bueno obtained only 2.59. For variable V10 - Production trade, the average value obtained was 90% and the municipalities with the highest and lowest value were in São Felipe do Oeste 100% and Chupinguaia 53%, respectively.

Studying the variable V11 - Soil correction, an average of 12% was observed. The municipality with the highest value was Vilhena 31%, which uses the highest soil correction in its establishments analyzed and the lowest use was in Urupá with 4%. In the variable - V12 Animal nutrition with an average of 44%, it can be seen that the municipality with a high value, a total of 76%, was Vilhena and a low Castanheiras 20%. For the use of mineral salt - V13, the average was 85% and the municipalities with the highest and lowest values were Parecis with 95% and Vilhena with 54%.

Having received Technical Guidance - V14 reached the general average of 24% and the municipalities with the highest value were Pimenteiras do Oeste 57% again and the lowest value Seringueiras 9%. In the use of fertilization -V15, the average was 21%, and the municipalities with the highest value 61% in Alto Alegre do Parecis and the lowest value 5% in Urupá. In the use of Irrigation - V16, the average value was 11% and the municipalities with the highest value 37% were perceived in Nova Brasilândia D'Oeste and with the lowest value 1% in Corumbiara. It is worth noting that the municipality of Pimenteiras do Oeste stood out with higher values in two more variables; V19 - Tractors and implements with 76% and E-mail records - V20, with a value of 15% compared to the other municipalities.

In item V17 - Milk production (thousand liters), the general average of the geographic region of Ji-Paraná was 22.10 and with a lower value of 14.29 it was for the municipality of Nova Brasilândia do Oeste and the highest value for Ouro Preto do Oeste with 30.75 thousand liters of milk production. For the variable Internet access - V18, the average was 34% and the municipality of Chupinguaia had the lowest result 20%, with the highest access for São Felipe do Oeste with 54%. In item V19 - Tractors and agricultural implements, the average value was 17% and Urupá was the municipality that showed the lowest quantities of these implements, 2%. In the E-mail -V20 record, the average and accesses are still low, with a result of 5% and the municipality of Parecis had the worst record with 1%.

After the data were treated with descriptive statistics, factor analysis was initiated by applying the univariate and multivariate normality tests. For the univariate normality test, the Shapiro-Wilk test (Degroot; Schervish, 2002; Lopes *et al.*, 2021, Castro; Mota, 2022) and verified by the test that the factorial model can be adjusted.

4.3 FACTOR ANALYSIS OF THE TECHNOLOGICAL LEVEL OF RURAL PROPERTIES IN THE STATE OF RONDÔNIA

The factor analysis was applied twice to the database of agricultural establishments in Rondônia, in view of the results, the estimation of the orthogonal factor model was analyzed by the principal component method (Castro; Mota, 2022). However, only the second factor analysis was interpreted due to the low indices generated by the KMO (*Kaiser-Meyer-Olkin*) and MAA (Sample Adequacy Measure) tests in the first analysis. Following the cut-off criterion in which $MAA < 0.5$ is unacceptable to proceed with the factor analysis, it was necessary to remove the following variables, PROCESSING FACILITY, CATTLE HERD, TELEPHONE, VEHICLES, STORAGE UNITS and ORGANIC PRODUCTION. After cutting the variables, the statistics of the Bartlett sphericity test, KMO test and MAA were checked again. The overall value of the MAA was 0.704 and the variables are shown in Table 4.

Table 4

Result of the Sample Adequacy Measure - MAA

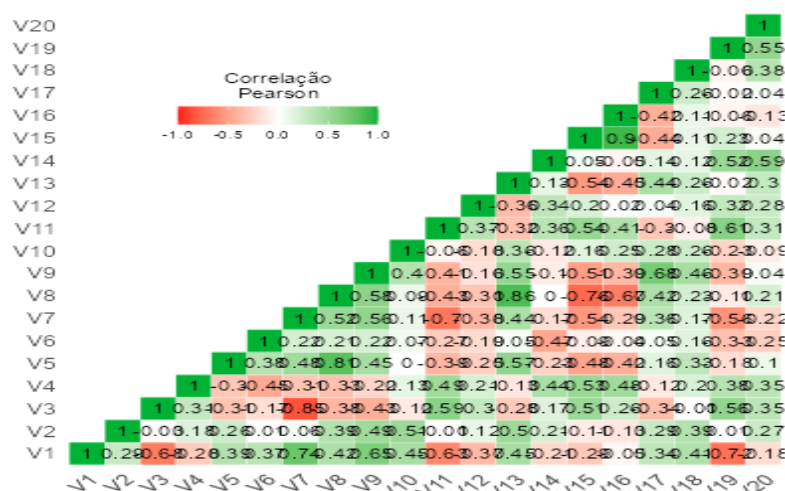
Variables	MAA	Variables	MAA
V1- Pasture Areas	0,783	V11- Soil Correction	0,734
V2- Disease control	0,638	V12- Animal Nutrition	0,595
V3- Farming	0,798	V13- Mineral salt	0,730
V4- Soil preparation	0,863	V14- Technical guidance	0,713
V5- Livestock	0,645	V15- Fertilization	0,689
V6- Electric power	0,730	V16- Irrigation	0,646
V7- QL	0,803	V17- Milk production	0,567
V8- Water resources	0,682	V18- Internet	0,675
V9- Milked cows	0,695	V19- Tractors and implements	0,629
V10 - Production trade	0,757	V20- Email	0,695

Source: Prepared by the authors (2026).

The new correlation matrix met the necessary assumptions to affirm that the data set is suitable for the use of the technique, as can be seen in Figure (3) of the numerical correlation matrix.

Figure 3

Graphical representation of Pearson's correlation matrix of data from agricultural establishments in Rondônia'



Source: Prepared by the authors (2026).

Pearson's correlation matrix is fundamental in factor analysis because it reveals the pattern of linear relationships between variables, indicating the direction and strength of these associations. High correlations suggest that the variables can be explained by the same underlying factor, while very low correlations indicate inadequacy for factor analysis, since the factors would not sufficiently explain the observed variables (Field, 2013).

As the objective of factor analysis is to reduce dimensionality, grouping correlated variables, Pearson's matrix serves as a basis to identify which of them move together. Methods such as Exploratory Factor Analysis (EFA) and Principal Component Analysis (PCA) use this matrix to extract factors that represent common variance. The reliability of the factors can be verified by the residual correlation matrix, in which low correlations indicate a good explanation of the data (Hair, 2009; Field, 2013).

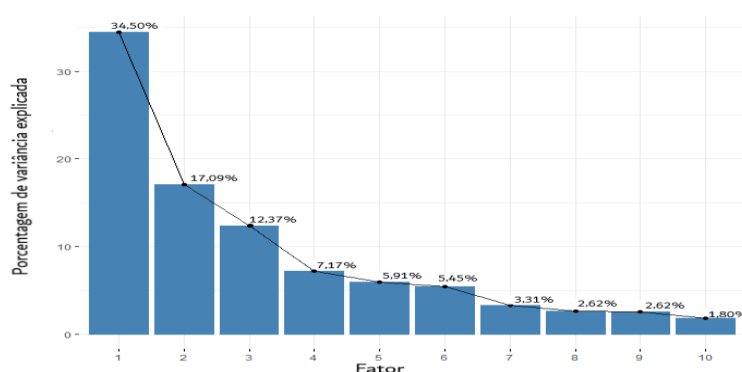
After checking the assumptions of minimum correlation between the variables, Bartlett test, KMO and MAA, exploratory factor analysis was initiated using the minimum residue and *varimax rotation method*. Rotation was applied to highlight the most relevant variables, increasing their charges (positive or negative) and reducing the less significant ones, bringing them closer to zero. The Bartlett test was significant at 1% probability, and the KMO test presented a value of 0.7921, indicating that the data sample is adequate for factor analysis.

According to the Kaiser-Guttman criterion, only the first 6 factors have eigenvalues greater than 1 in the confirmation of the number of adequate factors, the *screeplot* graph (Figure (4)) was generated.

It is worth noting that determining the number of factors in a Factor Analysis (FA) is a crucial step, as it directly affects the interpretation and validity of the results (Hair, 2009). These six factors explain 82.50% of the total variability of the data.

Figure 4

Screeplot with proportional distribution of eigenvalues from the factor analysis of data from agricultural establishments in Rondônia



Source: Prepared by the authors (2026).

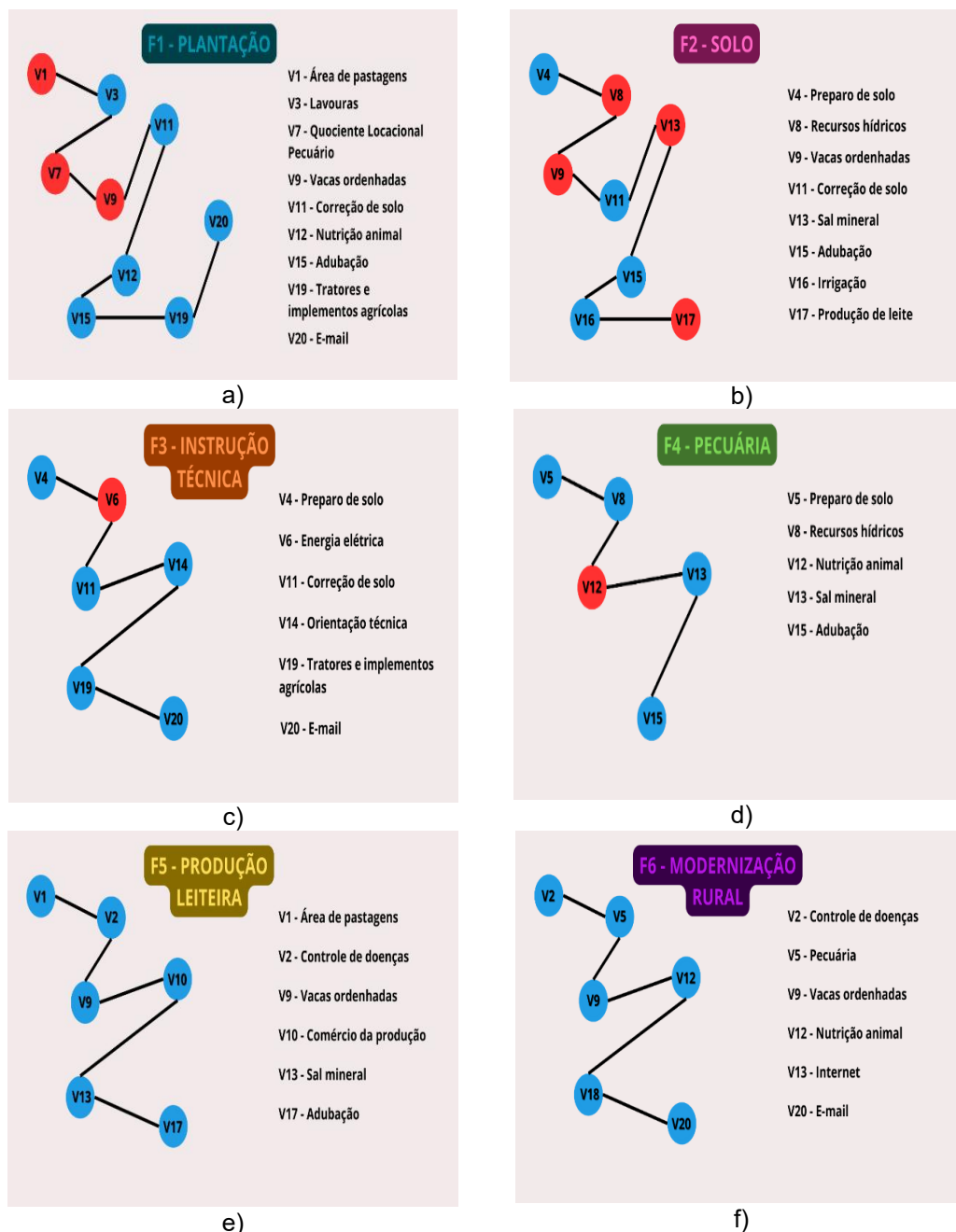
The distribution of variables in their respective factors in the study in question are 6 factors, namely: Factor 1 PLANTATION, Factor 2 SOIL, Factor 3 TECHNICAL INSTRUCTION, Factor 4 LIVESTOCK, Factor 5 MILK PRODUCTION and Factor 6 RURAL MODERNIZATION.

Analyzing the demonstrations of the distributions of factor loadings of the variables in their own factors, it is possible to notice positive and negative loadings that are represented in Figures (5) in red and blue respectively.

The factor loadings together with the commonality of each variable are presented in Table (5). Factor 1, because it has characteristics linked to the agricultural sector, was named PLANTATION (Figure 5a), which refers to the percentage of pasture area, crops, locational quotient, milked cows, soil correction, animal nutrition, irrigation, tractors and agricultural implements and e-mail. This factor tends to be a general factor with significantly high loads on these variables, explaining most of the variance.

Figure 5

Detail of the factors with their respective factor loadings. a) Factor 1 – Plantation. b) Factor 2 – Soil. c) Technical instruction. d) Livestock. e) Milk production. f) Rural modernization



Source: Prepared by the authors (2026).

Factor 2, because it has characteristics linked to the soil preparation sector, was denoted SOLO, attested to 17.09% of the total variability of the data (Figure 5b). Presenting technical characteristics, Factor 3 compiled the variables presented in Figure 5c) receiving the attribution of TECHNICAL INSTRUCTION, explained 12.37% of variance of the data.

With particularities in animal husbandry, factor 4 – LIVESTOCK, explained 7.17% of the total variance (Figure 5d). In Rondônia, the feeding of the herds occurs strictly based on pastures (natural and/or planted) that establish the main form of land occupation for livestock

purposes. In the municipalities of Rondônia, according to our study, on average 69.30% of the total area of livestock farms is occupied by pastures.

Table 5

Factor loadings after orthogonal rotation and the respective communalities

Variables	Factor						Commonality
	1	2	3	4	5	6	
V1	-0,771				0,372		0,898
V2					0,598	0,303	0,535
V3	0,825						0,755
V4		0,463	0,568				0,616
V5				0,684		0,326	0,761
V6			-0,619				0,458
V7	-0,884						0,911
V8		-0,532		0,783			0,998
V9	-0,406	-0,425			0,545	0,359	0,809
V10					0,872		0,842
V11	0,627	0,320	0,332				0,636
V12	0,340			-0,419		0,345	0,487
V13		-0,321		0,745	0,450		0,926
V14			0,811				0,713
V15	0,335	0,851		-0,308			0,946
V16		0,937					0,948
V17		-0,511			0,433		0,565
V18						0,807	0,771
V19	0,668		0,516				0,734
V20	0,334		0,552			0,429	0,687

Source: Prepared by the authors (2026).

On the other hand, Factor 5, which has productive aspects, being categorized as MILK PRODUCTION, explained 5.91% of data variability and integrates the variables shown in Figure 5e). Among the 52 municipalities analyzed, it was found that 15.6% have more than 70% of their surface area occupied by pasture. These pastures are used by most rural properties, as only 4 out of 10 agricultural establishments use their areas with crops.

Comprising the technologies of mechanized milking, access to the internet with the use of e-mail, computing in tables and spreadsheets the livestock treatment of disease control and food record of the animals, Factor 6 with peculiarities of technological modernity, explained 5.45 of the variation of the data and was assigned RURAL MODERNIZATION (Figure 5f).

Specifically, in the results of the rotational factor analysis, factor 1 explains 34.50% of the total variance, followed by factors 2 and 3 that together explain 29.46% and 18.53% explained by the total of factors 4, 5 and 6 remaining, as shown in Table (6), with the exception of factor 1, the others explain progressively smaller portions of variance. These factors are based on the residual amount of variance. The objective of rotating the factorial matrix was

to redistribute the variance from the first factors to the others, in order to make the interpretation simpler and more meaningful.

Explained variance indicates the proportion of total variability in the data that is illustrated by each factor and by the model as a whole (Lattin *et al.*, 2011). Through factor analysis and with the use of *varimax rotation*, the six factors that best represented the information of the agricultural establishments in Rondônia were characterized. Subsequently, the factor and standardized scores from 0 to 100 were calculated to compose the technological index of agricultural establishments (ITEA), the weighted average of the factors was used by the proportion of explanation of the total variance associated with each of the standardized factors (Santos *et al.*, 2017). Thus, the standardized factor scores were processed in each of the six factors within the 52 municipalities. Based on the NETA values, the municipalities were classified into technological levels. They were classified only in two levels, medium ($50 \leq \text{ITEA} < 75$) and low ($25 \leq \text{ITEA} < 50$). No municipality with a high ITEA above 75 was verified and none was classified as very low (< 25).

Table 6

Explained variability of data from agricultural establishments in Rondônia

Factors	Eigenvalues	Variance explained (%)	Variance accumulated (%)
1 - Planting	6,9002	34,50%	34,50%
2 – Solo	3,4171	17,09%	51,59%
3 - Technical instruction	2,4749	12,37%	63,96%
4 - Livestock	1,4341	7,17%	71,13%
5 – Milk production	1,1828	5,91%	77,05%
6 – Rural modernization	1,0909	5,45%	82,50%

Source: Prepared by the authors (2026).

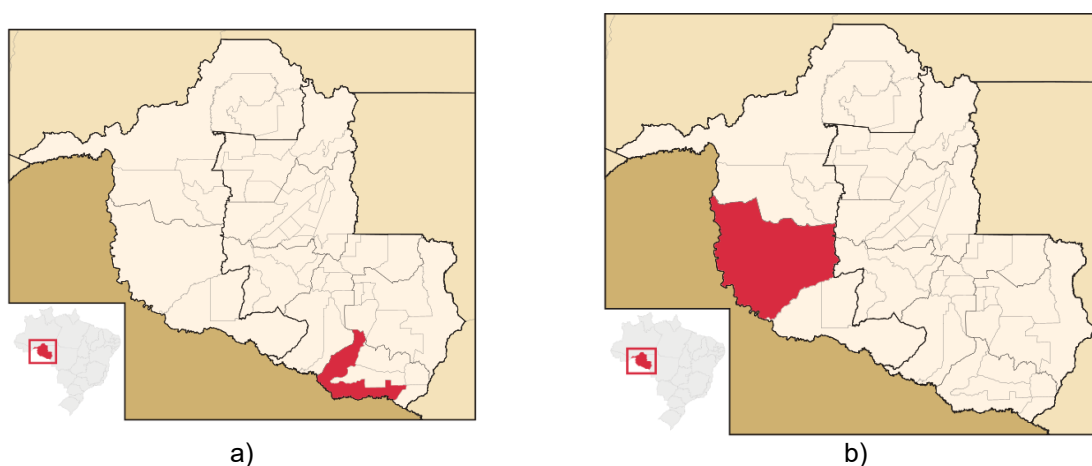
Pimenteiras do Oeste had the highest technological level with ITEA 70.45, followed by Cerejeiras 63.44, Alto Alegre do Parecis 58.68, Cabixi 57.01 and Nova Brasilândia do Oeste 51.01. The strong association between these indicators is due to the fact that they represent technologies with a higher level of adoption by regional producers in crop and pasture cultivation systems. In these municipalities, the cattle herd is concentrated in family farming establishments. It is composed of production units with an average size of 36.91 hectares, with a predominance of temporary and permanent crop areas (44.35%) and pastures occupying an average of 16.17% of the total area of the establishments. It is a system that combines agriculture and livestock as a strategy for income diversification in the production unit, involving the production of milk for self-consumption and the sale of the surplus to dairy products.

It is worth mentioning that Pimenteiras do Oeste (Figure 6a) is the first municipality in terms of GDP per capita in the state with a value of R\$ 115,753.94. In comparison with other municipalities, it occupies the position of 149 among the 5570 municipalities in the country. The percentage of foreign revenues in 2023 was 90.68%, which placed it in fifth position among the 52 municipalities in the State of Rondônia, with an area of 6,014.733 km², which places it in twelfth position in the State. Located on the banks of the Guaporé River, it was created on December 27, 1995 by State Law No. 645. In a territorial division dated 1988, the district of Pimenteiras was in the municipality of Cerejeiras. Thus, it remained in a territorial division dating from 1993, dismembered from Cerejeiras and Cabixi in 1995, changing its name to Pimenteiras do Oeste (IBGE, 2021).

The 304 agricultural establishments analyzed occupy 207,432 hectares and generate work for 1,281 people. In total, they have 257 tractors, 91 seeders, 78 harvesters and 34 limestone fertilizers/distributors, representing 151.32% of machines in relation to the number of properties (IBGE, 2021).

Figure 6

Details of the Municipalities of Rondônia: a) Pimenteiras do Oeste b) Guajará-Mirim



Source: IBGE (2021).

However, 47 municipalities are categorized with low ITEA. Guajará-Mirim (Figure 6b) had the lowest technological index of 28.55. Located on the border with Bolivia, divided by the Mamoré River, it has a vast green area, composed practically of native vegetation and natural reserves, it has a GDP per capita of R\$ 22,462.79. The municipality has 602 agricultural establishments, which occupy 70,487 hectares and employ 2,780 people, but has only 91 tractors, equivalent to 15.12% of the properties and practically no other agricultural implements, which contributed to its low technological performance in the ITEA

The indicators make visible two important aspects regarding local rural properties. The first is the hegemony of extensive grazing and agricultural cultivation systems, the results of which are the average stocking rate of pastures of only 1.58 AU/ha in 2012 with a projection of 1.95 AU/ha in 2031 and that of agricultural cultivation with a projection of an occupation of 620 thousand hectares of planted area, data from Idaron and the Association of Soybean and Corn Producers of Rondônia (Aprosoja) (Idaron, 2024). The second aspect is of an environmental nature, as the need for environmental regularization is evident, in order to comply with the provisions of Federal Decree No. 11,015, which addresses the environmental regularization of rural establishments (Brasil, 2022).

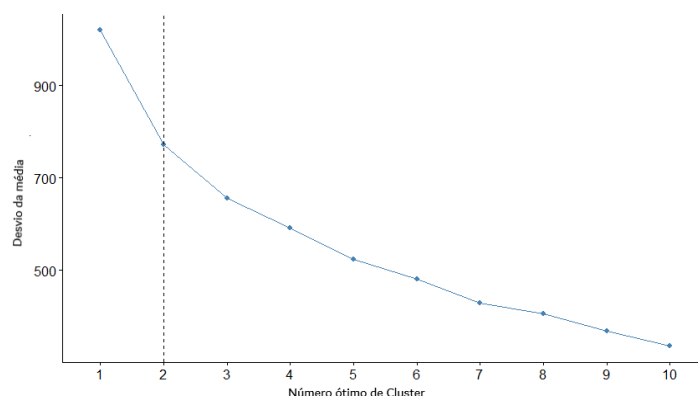
The production systems of rural establishments in Rondônia consist of a heterogeneous technology, this sign is due to the fact that at the same time we find properties with production strategies with very different levels of technology adherence. Among the 52 municipalities studied, 5 were classified as having a medium technological index. All municipalities with the highest levels belong to the intermediate geographic region of Ji-Paraná, composed of 34 municipalities, reaching 14.71% of representativeness with medium level in the total of municipalities in the state.

4.4 CLUSTER ANALYSIS OF AGRICULTURAL ESTABLISHMENTS IN THE STATE OF RONDÔNIA

As for the number of clusters, the solution with two *clusters* proved to be better in all processing. This statement is based on the *Mclust* command () that graphically presents the optimal cluster number (Figure 7) and also validated by means of the *Elbow* method, with the demonstration of the position of a curve (elbow) in the graph, considered as an indicator of the appropriate number of *clusters*. Checking the *screeplot* we can observe a deceleration in the slope, so the ideal number of clusters according to the *Elbow* method is 2 (two).

Figure 7

Detail of the optimal number of clusters through the Scree plot



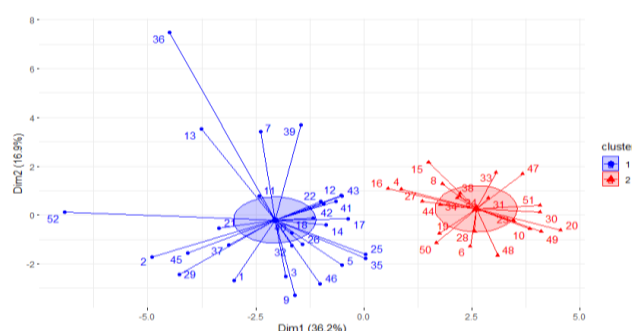
Source: Prepared by the authors (2026).

The cluster analysis indicates that the division into two clusters represents well the differences between the municipalities, with cluster 2 showing greater distinction in relation to the others. Figure 8 confirms this separation, demonstrating a consistent formation of the groups based on Euclidean distance.

In cluster 1, the *K-means algorithm* grouped 29 municipalities, including Alta Floresta D'Oeste, Alto Alegre do Parecis, Ariquemes, Cabixi, Cacoal, Cerejeiras, Guajará-Mirim, Machadinho D'Oeste, Nova Brasilândia D'Oeste, Pimenteiras do Oeste, Porto Velho, Rolim de Moura, Vilhena and others, as illustrated in Figures 8 and 9a.

Figure 8

Detail of the frequency of municipalities in each cluster



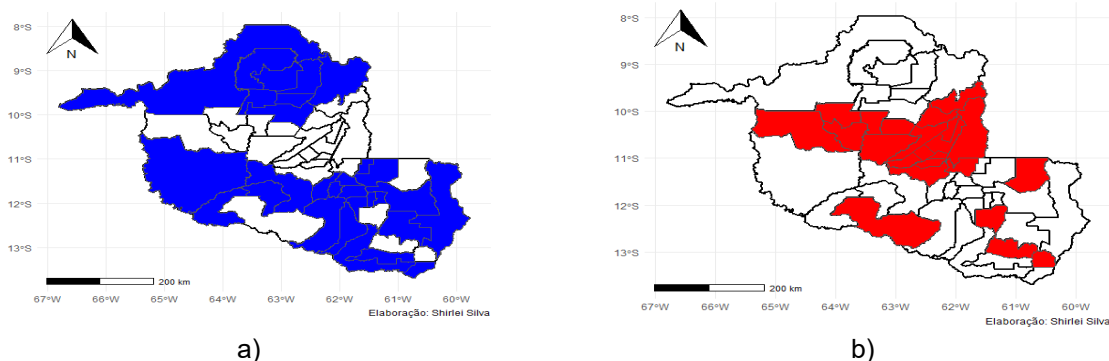
Source: Prepared by the authors (2026).

However, *cluster 2* allocated 23 municipalities: Alvorada do Oeste (4), Buritis (6), Cacaúlândia (8), Campo Novo de Rondônia (10), Colorado D'Oeste (15), Corumbiara (16), Espigão D'Oeste (19), Governador Jorge Teixeira (20), Jaru (23), Ji-Paraná (24), Mirante da Serra (27), Monte Negro (28), Nova Mamoré (30), Nova União (31), Ouro Preto do Oeste (33), Parecis (34), Presidente Médice (38), São Francisco do Guaporé (44), Teixeiraópolis (47),

Theobroma (48), Urupá (49), Vale do Anari (50) and Vale do Paraíso (51), as shown in Figures (8 and 9b).

Figure 9

Cluster positioning detail a) Spatial image of the municipalities belonging to cluster 1. b) Spatial image of the municipalities belonging to cluster 2

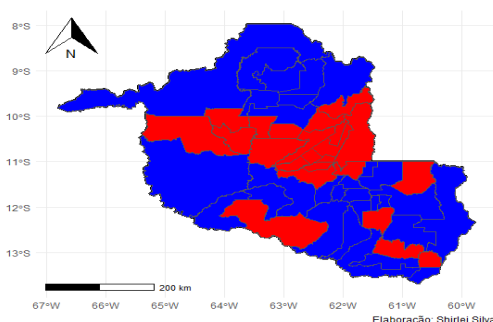


Source: Prepared by the authors (2026).

We can observe through Figure (10) that *cluster 2* was concentrated in one location of the state practically covering the central region, with only 5 dispersed municipalities, but maintaining the similarities of the other 18, however *cluster 1* with extractive characteristics was gathered at the extremities of the state. This analysis was carried out in order to make a survey on some important characteristics of the municipalities of Rondônia and to verify their location in relation to the classification of technological levels.

Figure 10

Spatial image of the subdivision of Rondônia into 2 clusters



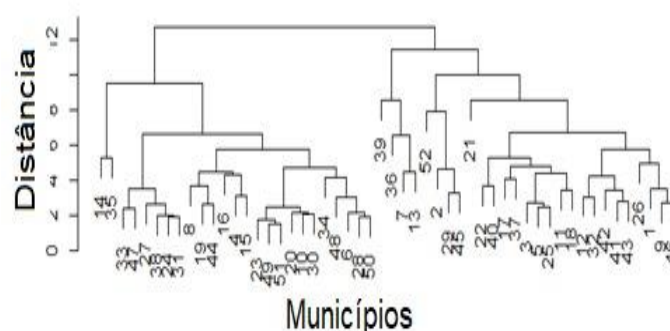
Source: Silva *et al.* (2026).

The measure of dissimilarity used was the Euclidean distance, and the complete linkage method was used to compose the clusters. The cut made in the axis of the dissimilarity of the dendrogram was at height 1.5, which demonstrated the composition of 2 probable groups and based on the dendrogram observed in Figure (11), it was verified,

through the agglomerative grouping with complete linkage, considering the dissimilarity between the closest pair of objects, although the complete linkage tends to produce convenient and homogeneous groupings, these are not necessarily taken by the natural modality of the data. The complete linkage can be highly sensitive to discrepancy in the data (Lattin *et.al.*, 2011). Considering 27 municipalities with a representation of 51.92% of the total of 52 municipalities for cluster 1 obtained by hierarchical analysis. In the second Cluster, 25 municipalities were indicated, with a representativeness of 48.08% of the total, showing a small change after the use of a hierarchical method of grouping.

Figure 11

Rondônia dendrogram of 2 clusters



Source: Prepared by the authors (2026).

The 5 municipalities that presented the highest technological level are distributed as follows, Pimenteiras do Oeste, Cerejeiras, Alto Alegre dos Parecis, Cabixi and Nova Brasilândia do Oeste, are located in cluster 1, using the *K-means Algorithm* and hierarchical grouping method. Thus, it is understood that they retain greater similarity among themselves in terms of the performance of the technological level indicators for the agricultural establishments of Rondônia, observing distinct peculiarities from the others. When observing the results of the clusters, the distributions showed similarities in the two analyses, where only two municipalities changed, Chupinguaia (14) and Pimenta Bueno (35) that were in cluster 1 by *K-means* and in the hierarchical were for cluster 2.

It should be added that cluster analysis is an important tool for pattern recognition and data mining, with *K-means* being advantageous for its simplicity and scalability, while hierarchical clustering provides detailed insights through dendrograms, but can be computationally expensive for large datasets" (Tan; Steinbach; Kumar, 2018).

It was found that both cluster analyses can be used due to the small amount of data referring to the agricultural census of rural establishments in the State of Rondônia, in future works it is intended to test this analysis for different measures of distance between the

clusters, to verify if there is a change in the location of the municipalities, because for this analysis only the Euclidean distance was used.

The spatial distribution of the clusters in Rondônia corroborates the findings of Silva *et al.* (2026b). The formation of Cluster 1, which brought together 29 municipalities, reveals an interesting spatial dynamic at the extremities of the state of Rondônia. Although this group brings together municipalities with extractive characteristics, it is in it that the five localities with the highest Technological Indexes of Agricultural Establishments (ITEA) are found: Pimenteiras do Oeste, Cerejeiras, Alto Alegre dos Parecis, Cabixi and Nova Brasilândia do Oeste.

The highlight of Pimenteiras do Oeste, with an ITEA of 70.45, is not an isolated data from its financial reality. The municipality has the highest GDP per capita in the state (R\$ 115,753.94), occupying a position of national prestige (149th place among the 5,570 Brazilian municipalities). The correlation between wealth and technology is evidenced by the ownership of machinery; the municipality has 151.32% of machines in relation to the number of properties, which indicates that many establishments have more than one essential implement (tractors, seeders or harvesters). This level of investment is reflected in Factor 6 (Rural Modernization), where the use of e-mail and the internet becomes a management tool, and not just a leisure tool.

In direct opposition, Guajará-Mirim (also in Cluster 1, but at the lower end of the scale) has the lowest technological index (28.55). Despite having 602 establishments, it has only 91 tractors (15.12% of the properties), evidencing subsistence agriculture or low added value, contrasting with the greatness of Pimenteiras.

Cluster 2, which covers the central region of Rondônia, demonstrates homogeneity at medium/low levels, suggesting that, despite the proximity to hubs such as Ji-Paraná, technological dissemination still faces structural or rural extension barriers.

This technological heterogeneity confirms that agribusiness in Rondônia operates at two speeds. On the one hand, municipalities that have integrated farming with livestock as a strategy for income diversification; on the other hand, regions that maintain extensive grazing with a low stocking rate (average of 1.58 AU/ha in 2012). The transition to the "High Technological Level" level (ITEA > 75), which has not been reached by any municipality, depends on the conversion of Factor 3 (Technical Instruction) into ubiquitous practices in the field

5 CONCLUSION

The application of multivariate statistical modeling on the records of the Agricultural Census allowed the rigorous identification of the heterogeneity and technological duality that characterize the 52 municipalities of Rondônia. The rotational factor analysis (*varimax*) proved to be robust and sufficient, condensing the original variables into six fundamental factors. Plantation, Soil, Technical Instruction, Livestock, Dairy Production and Rural Modernization, which together explain 82.50% of the accumulated variance of the sector. The results reveal a scenario of selective modernization. Spatially, the intermediate geographic region of Ji-Paraná presents levels of technification higher than those of the Porto Velho region, corroborating trends of productive consolidation already observed in the Eastern Amazon. The validation of the *cluster* analysis using the *K-means* and hierarchical methods confirmed the formation of two main clusters, evidencing patterns of similarities that can guide personalized regional interventions

It was verified with the study that all the municipalities of Rondônia were classified only in the medium and low levels of technological development. Although the municipality of Pimenteiras do Oeste stood out with the highest ITEA (70.45), no municipality reached the "high level" level ($ITEA \geq 75$). This predominance of intermediate and reduced indices should not be seen only as a productive limit, but as a clear window of opportunity for the intensification of investments in rural extension, technological diffusion and credit policies aimed at innovation.

In summary, the use of multivariate analysis proved to be adequate and essential to manage the complexity of rural establishments in the state. The transition to higher technological levels will require a coordinated effort to convert the factors of Technical Instruction and Rural Modernization into accessible practices, especially for family farming, ensuring that Rondônia's economic growth is accompanied by productive efficiency and environmental sustainability. It is concluded that multivariate modeling is a robust and adequate tool to support regional diagnoses and guide public policies aimed at sustainable rural development in Rondônia.

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PRODUCTION AND CHARACTERIZATION OF A FERMENTED BEVERAGE FROM PINEAPPLE (*Ananas comosus*) PEELS

PRODUÇÃO E CARACTERIZAÇÃO DE UMA BEBIDA FERMENTADA UTILIZANDO CASCAS DE ABACAXI (*Ananas comosus*)

PRODUCCIÓN Y CARACTERIZACIÓN DE UNA BEBIDA FERMENTADA UTILIZANDO CÁSCARAS DE PIÑA (*Ananas comosus*)



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ABSTRACT

The objective of this work was to evaluate the use of pineapple peels in the production of a fermented beverage, contributing to the valorization of agro-industrial waste and the development of more sustainable food products. During fermentation, pH and °Brix analyses were performed at 12-hour intervals. The fermented beverage was analyzed for lactic acid bacteria counts and determination of coliforms at 35°C and 45°C, *Salmonella*, anaerobic mesophilic bacteria, and molds and yeasts. A sensory acceptance test and purchase intention assessment of the fermented beverage made with pineapple peels were conducted in comparison with a commercial fermented beverage. The results for sensory evaluation, and purchase intention of the two samples were subjected to analysis of variance (ANOVA) and Tukey's test at a 5% significance level. Fermentation time did not cause a significant difference ($p < 0.05$) in °Brix and pH when the latter increased from 48 h to 72 h, and from 72 h to 96 h. The attributes of flavor, overall evaluation, and purchase intention showed a significant difference ($p < 0.05$) between the fermented beverage evaluated and the commercial product. The fermented beverage with pineapple peels had higher scores and differed statistically ($p < 0.05$) from the commercial product. The attributes of flavor and appearance showed a higher percentage of scores above 6, being within the acceptance range. However, purchase intention was considered low since only 21.67% of tasters would possibly buy the beverage. It was possible to obtain a fermented beverage with pineapple peels that is hygienically safe for human consumption, with the presence of lactic acid bacteria between 10^8 and 10^9 CFU/ml, indicating a possible probiotic activity.

Keywords: Circular Economy. Utilization of Agro-Industrial Waste. Upcycling. Sustainable Food Processing. Valorization of Agro-Industrial Waste.

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Lattes: <https://lattes.cnpq.br/5103513129427876>

RESUMO

O objetivo deste trabalho foi avaliar o aproveitamento das cascas de abacaxi na elaboração de uma bebida fermentada, contribuindo para a valorização de resíduos agroindustriais e para o desenvolvimento de produtos alimentícios mais sustentáveis. Durante a fermentação foram realizadas análises de pH e °Brix no intervalo de 12 horas. Na bebida fermentada foi realizada contagem de bactérias lácticas e determinação de coliformes a 35°C e 45°C, *Salmonella*, mesófilos anaeróbicos e bolores e leveduras. O teste de aceitação sensorial e da intenção de compra da bebida fermentada com cascas de abacaxi foi realizada em comparação com uma bebida fermentada comercial. Os resultados de avaliação sensorial e intenção de compra das duas amostras foram submetidos à análise de variância (ANOVA) e teste de Tukey a 5% de significância. O tempo de fermentação não ocasionou diferença significativa ($p < 0,05$) nos °Brix e no pH quando este aumentou de 48 h para 72 h, e de 72 h para 96 h. Os atributos sabor, avaliação global e intenção de compra apresentaram diferença significativa ($p < 0,05$) entre a bebida fermentada avaliada e o produto comercial. A bebida fermentada com cascas de abacaxi apresentou maiores notas e diferiu estatisticamente ($p < 0,05$) do produto comercial. Os atributos sabor e aparência apresentaram maior porcentagem das notas acima de 6, estando dentro da faixa de aceitação. Contudo, a intenção de compra foi considerada baixa visto que apenas 21,67% dos provadores possivelmente comprariam a bebida. Foi possível obter uma bebida fermentada com cascas de abacaxi higienicamente segura para o consumo humano com a presença de bactérias lácticas entre 10^8 e 10^9 UFC/ml indicando uma possível atividade probiótica.

Palavras-chave: Economia Circular. Aproveitamento de Resíduos Agroindustriais. *Upcycling*. Processamento Sustentável de Alimentos. Valorização de Resíduos Agroindustriais.

RESUMEN

El objetivo de este trabajo fue evaluar el aprovechamiento de las cáscaras de piña en la elaboración de una bebida fermentada, contribuyendo a la valorización de residuos agroindustriales y al desarrollo de productos alimenticios más sostenibles. Durante la fermentación, se realizaron análisis de pH y °Brix en intervalos de 12 horas. En la bebida fermentada se efectuó el recuento de bacterias lácticas y la determinación de coliformes a 35°C y 45°C, *Salmonella*, microorganismos mesófilos anaerobios, así como mohos y levaduras. La evaluación de aceptación sensorial y de intención de compra de la bebida fermentada a partir de cáscaras de piña se realizó en comparación con una bebida fermentada comercial. Los resultados de la evaluación sensorial e intención de compra de las dos muestras fueron comparados utilizando análisis de varianza (ANOVA) y teste de Tukey con un nivel de significancia del 5%. El tiempo de fermentación no ocasionó diferencias significativas ($p < 0,05$) en los °Brix ni en el pH cuando este aumentó de 48 h a 72 h y de 72 h a 96 h. Los atributos sabor, aceptación global y intención de compra presentaron diferencias significativas ($p < 0,05$) entre la bebida fermentada producida y el producto comercial. La bebida fermentada elaborada con cáscaras de piña presentó mayores puntuaciones y fué estadísticamente diferente ($p < 0,05$) del producto comercial. Los atributos sabor y apariencia mostraron un mayor porcentaje de puntuaciones superiores a 6, situándose dentro del rango de aceptación. Sin embargo, la intención de compra fue considerada baja, dado que solo el 21,67% de los evaluadores probablemente comprarían la bebida. Fue posible obtener una bebida fermentada a partir de cáscaras de piña higiénicamente segura para el consumo humano, con la presencia de bacterias lácticas entre 10^8 y 10^9 UFC/mL, lo que indica una posible actividad probiótica.

Palabras clave: Economía Circular. Aprovechamiento de Residuos Agroindustriales. *Upcycling*. Procesamiento Sustentable de Alimentos. Valorización de Residuos

1 INTRODUCTION

Hunger and food waste are two of the main challenges faced by Brazil, constituting a relevant paradox in the national scenario. Although the country produces about 140 million tons of food annually and is among the largest agricultural exporters in the world, there are still millions of people in a situation of food insecurity (Leonel et al., 2014). The increase in demand for fruits and vegetables is associated with population growth and changes in eating habits (Sagar et al., 2018).

The processing of fruits and vegetables is often associated with the generation of large volumes of waste, which can represent between 25% and 30% of the raw material *in natura* (Weyya et al., 2024). These residues constitute a rich source of bioactive compounds, dietary fibers, sugars, organic acids, and minerals, to which several health benefits are attributed, including antioxidant activities, among others (Sagar et al., 2018). The proper use of waste from vegetables can contribute to sustainable development, aiming to mitigate environmental impacts and promote human health through the incorporation of bioactive substances in food (Sagar et al., 2018).

Among the agro-industrial residues, pineapple has a high potential for use. The edible fraction of the fruit corresponds to a reduced portion of the plant, and approximately 77% of its composition (skin, stem, leaves, crown, and stems) is considered residue (Souza et al., 2021). During processing, these residues can represent between 40% (Ferreira et al., 2017) and 50% (w/w) of the fruit (Weyya et al., 2024). Pineapple peel stands out as one of the main by-products, with high nutritional value, with significant levels of minerals (4.74%) and fibers (17.92%). In addition, it is a source of compounds with antioxidant potential and can favor the growth of beneficial microorganisms, such as bacteria of the genus *Lactobacillus*, indicating potential application in products with functional characteristics (Nunes ; Silva, 2025).

Currently, the use of these residues in relation to the consumption of *fresh* and processed fruit is incipient. These are often disposed of in landfills or burned, contributing to negative environmental impacts (Diniz, 2017; Vieira et al., 2020). To date, the literature has focused mainly on the extraction of the enzyme bromelain and, secondarily, on the use of these residues for the production of phenolic antioxidants, organic acids, bioethanol, biogas and fibers. In addition, the sugar content present in these materials makes them suitable as a substrate for fermentation processes, enabling, for example, the production of vinegar (Roda et al., 2016).

In this context, the use of waste from the processing of fruits and vegetables, whether in the reformulation of traditional products or in the development of new products, presents

itself as a promising alternative to reduce environmental impacts (Ketnawa et al., 2012). Pineapple peels can be used in the production of fermented beverages, due to their sugar content, which serve as a substrate for microorganisms, resulting in the formation of bioactive compounds. An example is aluá (or aruá), a fermented, slightly acidic, low-alcohol beverage produced in different regions from raw materials such as pineapple, corn, rice, and bananas (Cerero-Calvo et al., 2022; Fernandes, 2021).

In view of the above, this work aimed to evaluate the potential of using pineapple peels in the elaboration of a fermented beverage, contributing to the valorization of agro-industrial residues and to the development of more sustainable food products

2 THEORETICAL FRAMEWORK

2.1 PINEAPPLE PRODUCTION, WASTE AND AGRO-INDUSTRIAL RECOVERY

Projections indicate a significant expansion of pineapple (*Ananas comosus* (L.) Merr.) production by 2030 (Vieira et al., 2020), following global trends in healthy food consumption. Brazil stands out as one of the world's leading producers, with production concentrated in the Northeast, North, and Southeast regions, responsible for the largest share of national production (EMBRAPA, 2018). The fruit and vegetable agroindustry is one of the main sources of organic waste generation, representing a significant environmental and economic challenge (Sagar et al., 2018).

The concept of *food waste valorization* has gained prominence in the scientific literature, being defined as the set of strategies aimed at converting food waste into products with higher added value, including functional ingredients, bioproducts, and bioenergy (Galanakis, 2012; Mirabella et al., 2013). Fruit residues are recognized as rich sources of bioactive compounds, such as phenolics, carotenoids, dietary fibers, and organic acids, which have antioxidant, antimicrobial, and anti-inflammatory properties (Sagar et al., 2018). In this way, the reuse of these materials represents an opportunity for the development of functional and sustainable foods.

Inadequate management of this waste can generate relevant environmental impacts, including soil and water contamination, in addition to the emission of greenhouse gases (Borges, et al., 2025). On the other hand, its valorization contributes to the transition from a linear production model to a model based on the circular economy, in which waste is reintegrated into the production system (Geissdoerfer et al., 2017).

In the Brazilian context, public policies such as the National Solid Waste Policy (PNRS) and initiatives aimed at low-carbon agriculture reinforce the importance of valuing agro-industrial waste (Borges, et al., 2025).

2.2 POTENTIAL OF PINEAPPLE PEEL IN THE ELABORATION OF FERMENTED BEIDAS

In general, pineapple has about 89.9% water, 0.3% proteins, 0.5% lipids, 5.8% carbohydrates, 3.2% fibers and 0.3% minerals (Borges et al., 2004). Studies indicate that the peel may have higher levels of nutrients than the pulp. According to Gondim et al. (2005), 100 g of pineapple peel contains approximately 76.95 g of moisture, 1.51 g of protein, 11.04 g of lipids, 6.85 g of fiber and 2.90 g of carbohydrates, in addition to minerals such as calcium (123.94 mg), potassium (236.70 mg), iron (2.18 mg) and magnesium (26.24 mg), evidencing its high nutritional value. The content of dietary fibers and minerals is especially noteworthy, which play a fundamental role in the maintenance of human health, being associated with the regulation of intestinal transit, the prevention of chronic diseases and adequate metabolic functioning. In addition, the presence of phenolic compounds gives the peel antioxidant properties, expanding its potential for application as a functional ingredient. Several studies have explored the use of pineapple peel and other residues in different technological applications such as juice production (Borges et al. (2004; Imandi et al. (2008), ethanol (Tanaka et al., 1999), bromelain (Ketnawa et al., 2012), and flour (Ketnawa et al., 2010; Leonel et al., (2014) contributing to the aggregation of value to by-products reducing environmental impacts.

Regarding the application in fermentation processes, pineapple peel has particularly favorable characteristics, such as high fermentable sugar content, adequate moisture and the presence of bioactive compounds. Other authors have also highlighted the potential of this material and specifically of the peels as a substrate for different fermentation routes, obtaining various products such as alcoholic beverages (Paixão et al., 2018), a beverage similar to aluá (Teixeira, 2018), wine (Herrera, 2011) and vinegar (Reyes, 2015). Fermentation is a biotechnological process widely used for food preservation and transformation, involving the action of microorganisms that convert organic substrates into compounds of interest (Cerero-Calvo et al., 2022). In addition to increasing the shelf life of foods, fermentation can improve their sensory and nutritional characteristics.

Fruit-based fermented beverages have gained prominence due to their functional potential, especially due to the presence of beneficial microorganisms and bioactive metabolites (Marco et al., 2017). Lactic fermentation, in particular, is widely used in the production of functional foods, as lactic acid bacteria contribute to microbiological stability and can exert beneficial health effects (Freire et al., 2021; Reis et al., 2021). In this sense, fermentation emerges as a sustainable strategy for the valorization of these materials, allowing the obtaining of products with higher added value.

Among the traditional beverages obtained from the fermentation of pineapple residues, tepache stands out, a Mexican beverage with a characteristic sensory profile and functional potential, poorly characterized, produced from the spontaneous fermentation of the fruit peel (Sarmiento et al., 2022; Silva, 2023; Leite, 2022). Recent studies indicate that fermented beverages based on agro-industrial waste can represent a promising alternative for the development of sustainable foods, aligning technological innovation, valorization of by-products, and health promotion (Galanakis, 2012; Marco et al., 2017).

3 METHODOLOGY

3.1 ELABORATION OF THE FERMENTED DRINK

The process of making the fermented drink using pineapple peels was carried out according to Leite (2022), with some modifications. To make the syrup, 145g of granulated sugar and 1.5L of filtered water were mixed and boiled for 15 minutes. It was then cooled to room temperature. The pineapple was washed with a neutral detergent and with the aid of a brush, and the fruit was disinfected by immersing the fruit in a 200 ppm solution for 15 minutes. Then, the fruit was peeled manually, the peels along with the ginger, cloves and cinnamon were placed inside a previously washed and disinfected glass. Next, the syrup was added on top of the shells so that they were fully immersed. The container was closed with the lid, wrapped with aluminum foil and taken to the greenhouse (Ethik) at 30°C for 48 hours. After this period, the contents of the glass were sieved and the liquid transferred to plastic bottles. The bottles were kneaded manually to expel their internal air, favoring anaerobic fermentation in the following 48 hours of fermentation in the oven at 30°C. After this process, the fermented pineapple peel beverage was stored in the refrigerator until microbiological and sensory analyses were carried out (2.5 hours). The ginger was sanitized by immersion for 10 minutes in a solution of 0.3% alcohol vinegar. The glass and all the utensils used were washed with detergent and disinfected by immersion for 15 minutes in sodium hypochlorite solution (200 ppm).

3.2 PHYSICOCHEMICAL EVALUATION OF FERMENTED BEVERAGE

The evaluation of pH and °Brix was carried out according to the physicochemical methods for food analysis of the Adolfo Lutz Institute (2008). pH and °Brix were measured in 12-hour periods, in triplicate. These two values were used to calculate the daily average.

3.3 MICROBIOLOGICAL EVALUATION OF THE BEVERAGE

All microbiological analyses were performed on the 10 replicates of the fermented beverage and all analyses were performed in duplicate. The analyses for lactic acid bacteria, coliforms at 35° C, coliforms at 45° C, *Salmonella* sp., Standard Count for heterotrophic anaerobic microorganisms mesophilic and molds and yeasts were carried out following the methodology of the Manual of methods of microbiological analysis of food and water by Silva et al., (2017).

3.4 SENSORY ANALYSIS

To perform the acceptance test, 60 untrained tasters were randomly recruited. For this, each taster received two samples of 25 ml each, the fermented pineapple drink and a commercial product called kombucha. The two samples were served in disposable cups coded with three-digit random numbers and submitted to sensory evaluation of the attributes: taste, color, appearance and global evaluation, using a structured nine-point hedonic scale where "1-disliked extremely", "2-disliked very much", "3-disliked moderately", "4-disliked slightly", "5-disliked/disliked", "6-liked slightly", "7-liked moderately", "8-liked it very much" and "9-liked it very much". The two samples were also evaluated, by the same tasters, regarding purchase intention using the structured scale where "1-certainly would not buy the product", "2- possibly would not buy the product", "3- maybe would buy / maybe not buy", "4- possibly buy the product" and "5-certainly buy the product" (MINIM, 2010; MEILGAARD et al., 2006). The sensory evaluation test was approved by the Research Ethics Committee (REC) under Protocol 5.922.453.

3.5 EXPERIMENTAL DESIGN AND STATISTICAL ANALYSIS

10 replicas of the fermentation of pineapple peels were prepared to carry out all microbiological and physicochemical analyses. The results of pH, °Brix, sensory acceptance and purchase intention were submitted to Tukey's test at 5% significance, and statistically evaluated through Analysis of Variance (ANOVA), using the Past program (Hammer, Ø; et al , 2001).

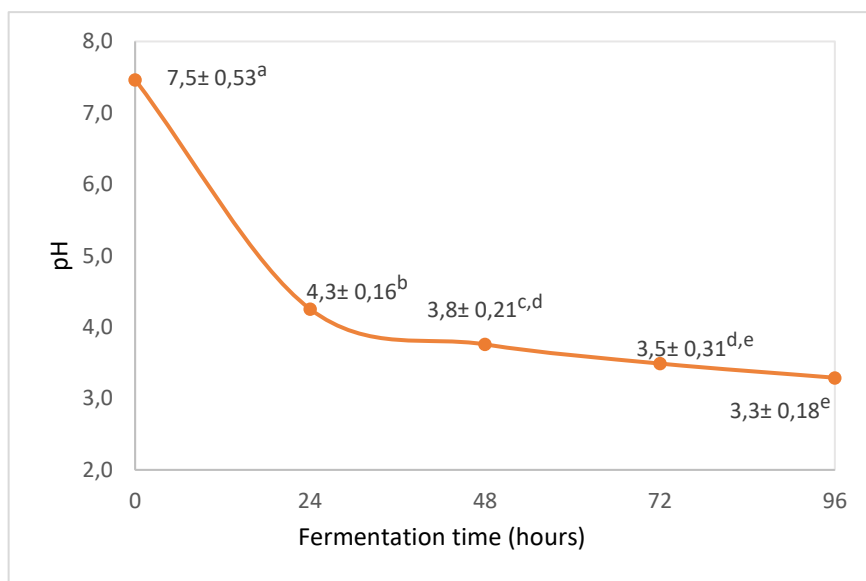
4 RESULTS AND DISCUSSIONS

4.1 PHYSICOCHEMICAL CHARACTERIZATION

Figures 1 and 2 show the mean values accompanied by their respective standard deviations for the pH and °Brix parameters.

Figure 1

Variation in pH during fermentation of the drink made from pineapple peel over 4 days. The values represent mean $\pm$ standard deviation ($n = X$). Means followed by the same letter did not differ significantly from each other by Tukey's test ($p > 0.05$).



Source: prepared by the authors.

The results show a reduction in pH and total soluble solids ($^{\circ}$ Brix) throughout fermentation, indicating microbial metabolic activity. The pH decreased from 7.5 ± 0.53 to 3.3 ± 0.18 in 96 hours (Figure 1), with statistically significant differences between the times ($p < 0.05$) from 0 to 48 hours. This acidification is associated with the production of organic acids, especially lactic acid, from the consumption of sugars by lactic acid bacteria and yeasts, evidencing the action of microorganisms such as *Lactobacillus* (Machado, 2020). Similar values were reported by Leite (2022), who observed pH lower than 4 after 48 h of fermentation in pineapple by-product beverages.

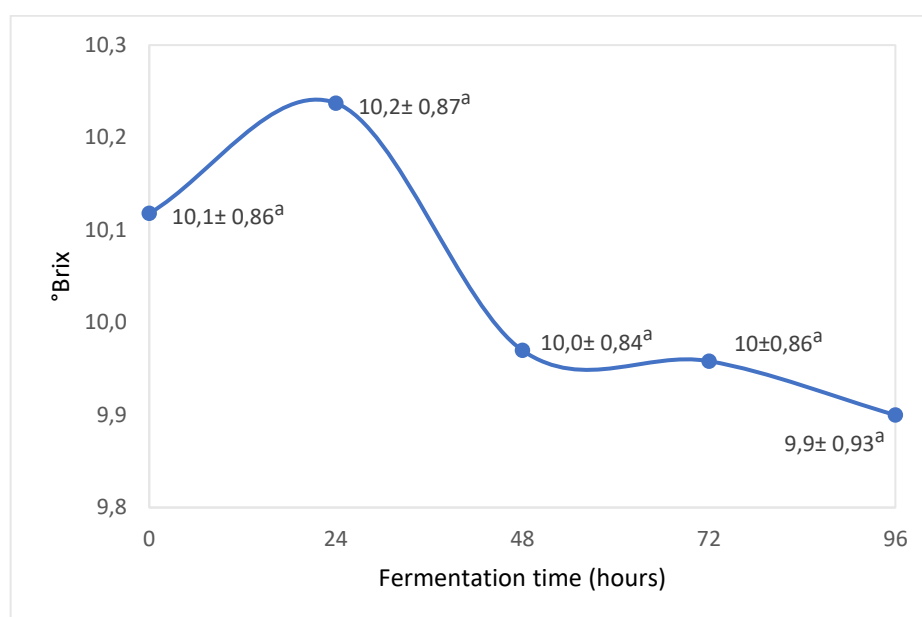
There was no statistically significant difference ($p > 0.05$) between the $^{\circ}$ Brix values, although a trend of reduction from 10.1 ± 0.86 to 9.9 ± 0.93 was observed at the end of the process (Figure 2), indicating the consumption of fermentable sugars. Similar results were reported by Sarmiento, et al., (2022), who observed a reduction to 9.5 $^{\circ}$ Brix after 72 h in tepache fermentation. The slight initial increase in $^{\circ}$ Brix (10.2 ± 0.87 on the first day) may be associated with the release of soluble compounds from the substrate matrix in the initial stages of fermentation, before the predominance of microbial consumption.

In general, the significant reduction in pH associated with the tendency to decrease $^{\circ}$ Brix confirms the occurrence of the fermentation process, and these parameters are influenced by the processing conditions (Leite, 2022) and widely used as indicators of microbial activity in fermented beverages, in addition to reflecting the production of

compounds of technological interest, such as organic acids and antimicrobial substances (Freire et al., 2021).

Figure 2

Variation of soluble solids (°Brix) during fermentation of the drink made from pineapple peel over 4 days. The values represent mean $\pm$ standard deviation ($n = X$). Means followed by the same letter did not differ significantly from each other by Tukey's test ($p > 0.05$).



Source: prepared by the authors.

4.2 MICROBIOLOGICAL ANALYSES

The samples obtained after 96 hours of fermentation were submitted to microbiological analyses in order to determine the lactic acid bacteria count and to evaluate the hygienic quality of the spontaneously fermented beverage, through the quantification of indicator microorganisms as shown in Table 1.

Table 1

Standard plate count of molds and yeasts, lactobacilli, facultative aerobic heterotrophs and Most Probable Number (MPN) for total coliforms of the fermented beverage made with pineapple peels

Sample	Molds and yeasts (CFU/ml)	Lactobacilli (CFU/ml)	Facultative aerobic heterotrophs (CFU/ml)	Total coliforms (MPN/ml)
1	$2.9 \cdot 10^5 \pm 5.95 \cdot 10^6$	$1.0 \cdot 10^6 \pm 1.64 \cdot 10^9$	$3.93 \cdot 10^4 \pm 3.95 \cdot 10^5$	<3
2	$1.78 \cdot 10^6 \pm 5.95 \cdot 10^6$	$1.57 \cdot 10^9 \pm 1.64 \cdot 10^9$	$9.50 \cdot 10^5 \pm 3.95 \cdot 10^5$	<3
3	$1.13 \cdot 10^6 \pm 5.95 \cdot 10^6$	$6.1 \cdot 10^8 \pm 1.64 \cdot 10^9$	$5.30 \cdot 10^4 \pm 3.95 \cdot 10^5$	<3
4	$1.92 \cdot 10^6 \pm 5.95 \cdot 10^6$	$7.16 \cdot 10^5 \pm 1.64 \cdot 10^9$	$2.37 \cdot 10^3 \pm 3.95 \cdot 10^5$	<3

5	$1.28 \cdot 10^7 \pm 5.95 \cdot 10^6$	$5.12 \cdot 10^9 \pm 1.64 \cdot 10^9$	$3.44 \cdot 10^5 \pm 3.95 \cdot 10^5$	<3
6	$8.45 \cdot 10^4 \pm 5.95 \cdot 10^6$	$6.52 \cdot 10^6 \pm 1.64 \cdot 10^9$	$4.30 \cdot 10^3 \pm 3.95 \cdot 10^5$	<3
7	$6.0 \cdot 10^5 \pm 5.95 \cdot 10^6$	$2.47 \cdot 10^8 \pm 1.64 \cdot 10^9$	$6.05 \cdot 10^5 \pm 3.95 \cdot 10^5$	<3
8	$1.0 \cdot 10^6 \pm 5.95 \cdot 10^6$	$2.12 \cdot 10^7 \pm 1.64 \cdot 10^9$	$2.26 \cdot 10^5 \pm 3.95 \cdot 10^5$	<3
9	$1.46 \cdot 10^7 \pm 5.95 \cdot 10^6$	$2.14 \cdot 10^8 \pm 1.64 \cdot 10^9$	$1.0 \cdot 10^6 \pm 3.95 \cdot 10^5$	<3
10	$1.0 \cdot 10^6 \pm 5.95 \cdot 10^6$	$4.96 \cdot 10^8 \pm 1.64 \cdot 10^9$	$2.36 \cdot 10^3 \pm 3.95 \cdot 10^5$	<3
Average	4,15·10 ⁶	9,28·10 ⁸	3,23·10 ⁵	<3

Source: prepared by the authors.

It is important to note that there is no specific category in Brazilian legislation that establishes microbiological standards for fermented beverages made from pineapple peels. Thus, the category of "juices and other beverages submitted to technological processes for microbial reduction that require refrigeration" was adopted as a reference, according to Normative Instruction No. 60, of December 23, 2019, of the National Health Surveillance Agency (ANVISA). For this category, the maximum limit established for molds and yeasts is 10^2 CFU/mL. In the present study, the mean observed was 4.15×10^8 CFU/mL, which is higher than the established limit. However, this extrapolation should be interpreted with caution, since yeasts are directly associated with the fermentation process, being able to develop in an acidic environment, a typical characteristic of acidophilic microorganisms. In this context, Aguilar (2022) highlights that *Saccharomyces cerevisiae* is one of the predominant yeasts in beverages such as tepache, contributing to its properties through the production of ethanol and CO₂.

Regarding the facultative aerobic heterotrophic microorganisms, the samples presented an average of 3.23×10^5 CFU/mL. According to Silva et al. (2017), the mesophilic microorganism count is widely used as an indicator of raw material quality and hygienic-sanitary conditions during food production and preservation. However, in the present study, the interpretation of this parameter should be relativized, considering that yeasts also developed in this culture medium. Thus, this count was associated with the fermentative microbiota, and was not considered in isolation as an indication of hygienic quality.

The results for total coliforms and coliforms at 45 °C were lower than 3 MPN/mL in all samples, indicating the absence of these microorganisms. These parameters are widely recognized as indicators of fecal contamination and inadequate hygienic-sanitary conditions (Silva; Almeida; Baratela-Simm, 2017). Thus, the results obtained reinforce that the production process of the beverage took place under adequate hygienic-sanitary conditions, in accordance with the current legislation.

The lactic acid bacteria count showed an average of 9.28×10^8 CFU/mL, showing high fermentative activity. According to Reis et al. (2021), foods with a probiotic claim should have concentrations between 10^8 and 10^9 CFU/mL of viable microorganisms. Although the values observed fall within this range, the lack of identification of the species and strains of lactic

acid bacteria prevents the attribution of probiotic properties to the drink, limiting this interpretation.

Lactic acid bacteria play a central role in the fermentation process, being able to inhibit the growth of undesirable microorganisms through the production of organic acids, hydrogen peroxide, alcohols, and other antimicrobial compounds (Silva, et al., 2020). Additionally, its action by homofermentative pathways, with the production of lactic acid and consequent reduction of pH, contributes both to the preservation of the food and to the improvement of sensory characteristics, such as flavor, aroma, and texture (Rodrigues, 2022).

Finally, it is noteworthy that the beverage was not subjected to heat treatment, which, on the one hand, preserves the microbiota present, but, on the other hand, requires the adoption of complementary conservation methods. In this sense, refrigeration plays a fundamental role in slowing microbial growth and controlling the advance of the fermentation process, contributing to the stability of the product (Granada; Zambiasi; Mendonça, 2004; Câmara, 2022).

4.3 SENSORY ANALYSIS

The results of the sensory evaluation and purchase intention are presented in Table 2 and in Figures 3, 4 and 5. A significant difference ($p < 0.05$) was observed between the samples for the attributes flavor, global evaluation and purchase intention, and the fermented beverage made with pineapple peels presented higher averages in these parameters.

Table 2

Sensory analysis and purchase intention of fermented beverage with pineapple peel and pineapple-flavored kombucha

Attribute	Sample of fermented beverages	
	Drink made with pineapple peels	Kombucha
Flavor	5.85a	4.42b
Color	6.5a	6.8a
Appearance	6.48a	6.72a
Overall assessment	6.0A	5.0b
Purchase intention	2.93a	2.2b

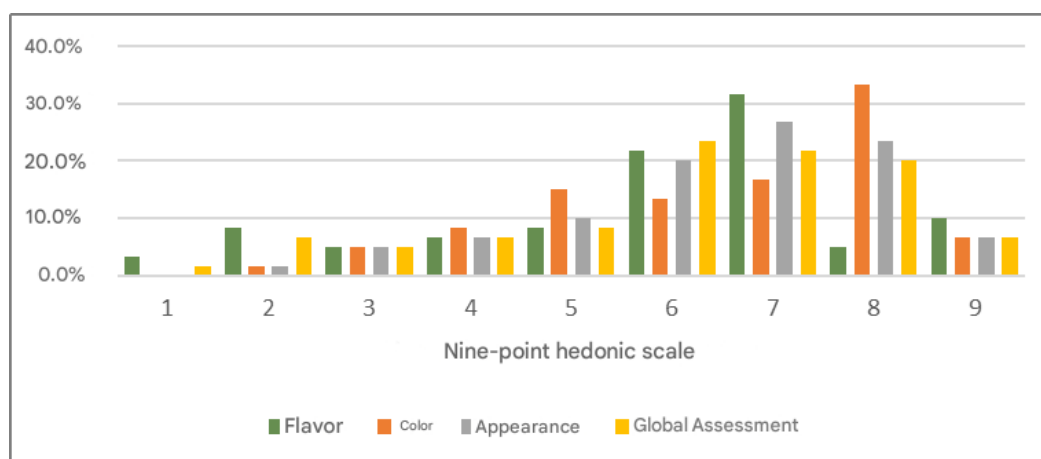
^{a,b}. Means with the same letter do not present a significant difference ($p < 0.05$).

Source: prepared by the authors

Although the score attributed to the flavor attribute was lower than 6 (I liked it slightly), the overall evaluation of the beverage developed in this study showed an average of 6, being in the acceptance range (Figure 3). This result suggests that, despite specific limitations in flavor, the overall perception of the product was positive, indicating potential for consumer acceptance.

Figure 3

Percentage of scores per attribute for the fermented beverage sample



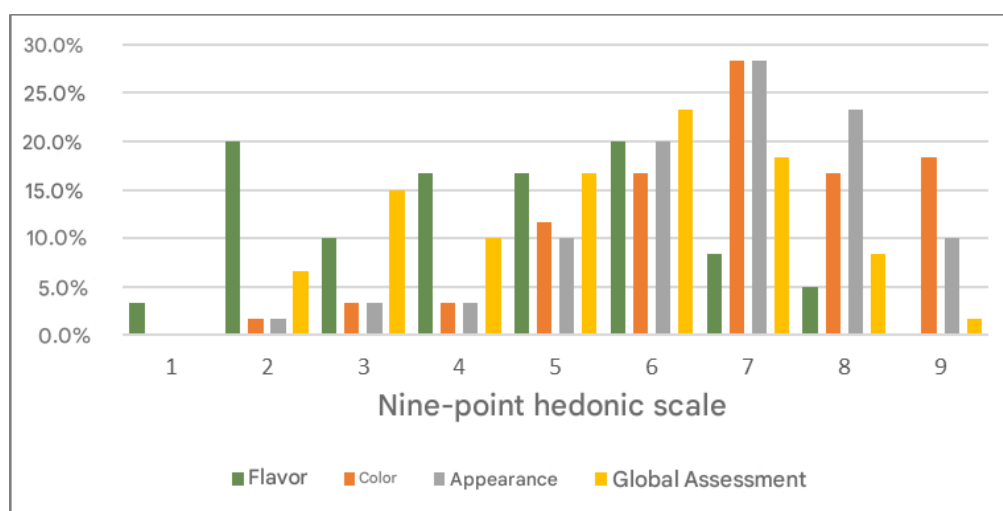
Hedonic scale: "1- I disliked it extremely", "2-I disliked it a lot", "3-I disliked it moderately", "4-I disliked it slightly", "5-I didn't like it/I didn't like it a lot", "6-I liked it slightly", "7-I liked it moderately", "8-I liked it a lot" and "9-I liked it very much".

Source: prepared by the authors.

For kombucha (Figure 4), it was observed that the color and appearance attributes concentrated 28.33% of the evaluations in "I liked it moderately", while the flavor attribute presented 20% of the answers in "I disliked it very much". In general, the sum of scores higher than 6 ranged between 13% and 63.3%, indicating greater variability in the sensory perception of this sample.

Figure 4

Percentage of scores per attribute for the pineapple-flavored kombucha sample



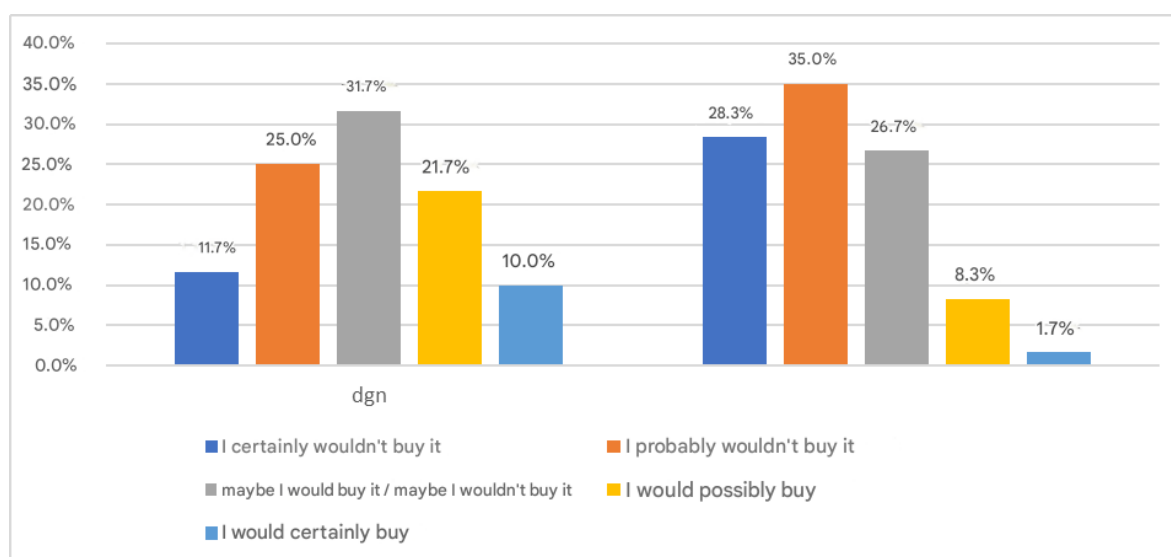
Hedonic scale: "1- I disliked it extremely", "2-I disliked it a lot", "3-I disliked it moderately", "4-I disliked it slightly", "5-I didn't like it/I didn't like it a lot", "6-I liked it slightly", "7-I liked it moderately", "8-I liked it a lot" and "9-I liked it very much".

Source: prepared by the authors.

The intention to purchase (Figure 5) showed that 31.67% of the tasters showed indecision regarding the purchase of fermented beverages made with pineapple peels. On the other hand, 35% of the evaluators indicated that they "would not possibly buy" kombucha. Although both samples showed low purchase intention, the beverage developed in this study showed superior performance, since 21.67% of the tasters indicated that they would "possibly buy" the product, while only 8.33% attributed this same evaluation to kombucha.

Figure 5

Percentage of scores per attribute for the fermented beverage sample



Source: prepared by the authors.

It is possible that the limited familiarity of the tasters with this type of product influenced sensory perception. Recorded observations, such as "I liked the sample of fermented beverage, it presented a citrus and gaseous flavor, very good" and "very tasty, sweet in the right measure, refreshing", indicate acceptance of typical sensory characteristics. On the other hand, comments such as "the drink had an acidic taste" and "I found the drink a little acidic", although pointed out as negative aspects, correspond to characteristics inherent to fermented beverages. Thus, it is likely that this factor has negatively influenced the results of acceptance and purchase intention.

5 CONCLUSION

It was possible to obtain a fermented beverage from pineapple peels with satisfactory hygienic-sanitary quality, evidenced by the absence of indicator microorganisms and the presence of lactic acid bacteria in concentrations of the order of 10^8 to 10^9 CFU/mL.

The beverage prepared in this study showed a significant difference ($p < 0.05$) in relation to the commercial product kombucha in the attributes flavor, global evaluation and purchase intention, with averages of 5.85; 6.0 and 2.03, respectively, indicating better performance in these parameters.

Despite this, the intention to buy was considered low, since the largest portion of the tasters showed indecision about the purchase of the product, while a smaller proportion indicated the possibility of buying, although at a higher frequency than that observed for kombucha.

In this way, future studies can deepen the sensory evaluation and the intention to purchase the drink, in order to better understand its acceptance. In addition, future studies are needed to identify the species and strains of lactic acid bacteria present in the drink, enabling the evaluation of its probiotic potential.

Finally, the results obtained show the potential of using pineapple peels in the elaboration of fermented beverages, contributing to the valorization of agro-industrial residues and to the reduction of environmental impacts

ACKNOWLEDGMENTS

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ESG IN PUBLIC ADMINISTRATION: A SYSTEMATIC REVIEW OF THE ENVIRONMENTAL PILLAR (2020–2025): STATE OF THE ART AND FUTURE TRENDS

ESG NA ADMINISTRAÇÃO PÚBLICA: UMA REVISÃO SISTEMÁTICA DO PILAR AMBIENTAL (2020–2025): ESTADO DA ARTE E TENDÊNCIAS FUTURAS

ESG EN LA ADMINISTRACIÓN PÚBLICA: UNA REVISIÓN SISTEMÁTICA DEL PILAR AMBIENTAL (2020–2025): ESTADO DEL ARTE Y TENDENCIAS FUTURAS



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ABSTRACT

The incorporation of the environmental pillar of ESG into public administration has progressed unevenly at the global level, despite the growing institutional recognition of governmental sustainability. This study presents a systematic literature review (SLR), conducted in accordance with the PRISMA 2020 protocol, aiming to map dimensions, indicators, methodologies, and trends related to the adoption of environmental ESG in the public sector. A total of 1,273 publications were retrieved from the Scopus, Web of Science, and IEEE Xplore databases (2020–2025), of which 1,006 were considered eligible after screening using the Rayyan platform. Bibliometric analysis, performed using VOSviewer and Bibliometrix/Biblioshiny, identified thematic clusters related to sustainable public procurement, green infrastructure, energy efficiency, environmental governance, and climate policies. The bibliographic analysis of 69 selected articles, organized into three thematic dimensions, revealed advances in the use of environmental indicators, composite frameworks (such as DPSIR and IPEEI), and innovative urban management practices. However, persistent challenges remain, including methodological standardization, the absence of robust regulatory frameworks, institutional gaps, and limited intersectoral integration, particularly in Latin American countries. This study proposes a research agenda focused on the development of integrated ESG assessment frameworks applicable to municipal management, with an emphasis on public engineering companies and urban infrastructure projects. The findings contribute to advancing discussions on governmental sustainability and to consolidating environmental ESG practices in the public sector. Overall, the results indicate a predominance of territorially oriented environmental indicators, a gap

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in the use of metrics applicable to public policies, and weak integration between ESG and urban governance.

Keywords: ESG. Public Administration. Sustainability. Sustainable Public Procurement. Government. Sustainable Policies. Systematic Review.

RESUMO

A incorporação do pilar ambiental do ESG na administração pública tem avançado de forma desigual em nível global, apesar do crescente reconhecimento institucional da sustentabilidade governamental. Este estudo apresenta uma revisão sistemática da literatura (RSL), conduzida de acordo com o protocolo PRISMA 2020, com o objetivo de mapear dimensões, indicadores, metodologias e tendências relacionadas à adoção do ESG ambiental no setor público. Um total de 1.273 publicações foi recuperado das bases de dados Scopus, Web of Science e IEEE Xplore (2020–2025), das quais 1.006 foram consideradas elegíveis após triagem utilizando a plataforma Rayyan. A análise bibliométrica, realizada com o uso do VOSviewer e do Bibliometrix/Biblioshiny, identificou clusters temáticos relacionados a compras públicas sustentáveis, infraestrutura verde, eficiência energética, governança ambiental e políticas climáticas. A análise bibliográfica de 69 artigos selecionados, organizados em três dimensões temáticas, revelou avanços no uso de indicadores ambientais, frameworks compostos (como DPSIR e IPEEI) e práticas inovadoras de gestão urbana. No entanto, persistem desafios, incluindo a padronização metodológica, a ausência de marcos regulatórios robustos, lacunas institucionais e limitada integração intersetorial, particularmente em países da América Latina. Este estudo propõe uma agenda de pesquisa voltada ao desenvolvimento de frameworks integrados de avaliação ESG aplicáveis à gestão municipal, com ênfase em empresas públicas de engenharia e projetos de infraestrutura urbana. Os achados contribuem para o avanço das discussões sobre sustentabilidade governamental e para a consolidação das práticas de ESG ambiental no setor público. De modo geral, os resultados indicam a predominância de indicadores ambientais orientados territorialmente, uma lacuna no uso de métricas aplicáveis às políticas públicas e uma fraca integração entre ESG e governança urbana.

Palavras-chave: ESG. Administração Pública. Sustentabilidade. Compras Públicas Sustentáveis. Governo. Políticas Sustentáveis. Revisão Sistemática.

RESUMEN

La incorporación del pilar ambiental del ESG en la administración pública ha avanzado de manera desigual a nivel global, a pesar del creciente reconocimiento institucional de la sostenibilidad gubernamental. Este estudio presenta una revisión sistemática de la literatura (RSL), realizada de acuerdo con el protocolo PRISMA 2020, con el objetivo de mapear dimensiones, indicadores, metodologías y tendencias relacionadas con la adopción del ESG ambiental en el sector público. Un total de 1.273 publicaciones fue recuperado de las bases de datos Scopus, Web of Science y IEEE Xplore (2020–2025), de las cuales 1.006 fueron consideradas elegibles tras el proceso de cribado utilizando la plataforma Rayyan. El análisis bibliométrico, realizado mediante VOSviewer y Bibliometrix/Biblioshiny, identificó clústeres temáticos relacionados con la contratación pública sostenible, la infraestructura verde, la eficiencia energética, la gobernanza ambiental y las políticas climáticas. El análisis bibliográfico de 69 artículos seleccionados, organizados en tres dimensiones temáticas, reveló avances en el uso de indicadores ambientales, marcos compuestos (como DPSIR e IPEEI) y prácticas innovadoras de gestión urbana. Sin embargo, persisten desafíos, incluyendo la estandarización metodológica, la ausencia de marcos regulatorios robustos, brechas institucionales y una limitada integración intersectorial, particularmente en países de América Latina. Este estudio propone una agenda de investigación orientada al desarrollo de marcos integrados de evaluación ESG aplicables a la gestión municipal, con énfasis en

empresas públicas de ingeniería y proyectos de infraestructura urbana. Los hallazgos contribuyen al avance de las discusiones sobre sostenibilidad gubernamental y a la consolidación de las prácticas de ESG ambiental en el sector público. En general, los resultados indican un predominio de indicadores ambientales con enfoque territorial, una brecha en el uso de métricas aplicables a las políticas públicas y una débil integración entre ESG y la gobernanza urbana.

Palabras clave: ESG. Administración Pública. Sostenibilidad. Contratación Pública Sostenible. Gobierno. Políticas Sostenibles. Revisión Sistemática.

1 INTRODUCTION

Since the publication of the Brundtland Report (1987), the concept of sustainable development has been consolidated as a foundation for global policies and strategies aimed at preserving natural resources and promoting social well-being. The United Nations Conference on Environment and Development (UNCED), held in Rio de Janeiro in 1992, reinforced the importance of integrating economic growth, social inclusion, and environmental protection, laying the groundwork for the UN 2030 Agenda and its 17 Sustainable Development Goals (SDGs).

In recent decades, the sustainability paradigm has also expanded into the corporate sphere, with the advancement of Environmental, Social, and Governance (ESG) criteria as a reference framework for measuring performance, risk, and transparency. In the public sector, however, the incorporation of these principles remains at an early stage, largely restricted to sector-specific programs or isolated environmental governance initiatives.

Public administration plays a strategic role in the transition toward a sustainable development model. The adoption of environmental criteria in public policies, procurement processes, and infrastructure projects represents an opportunity to align governmental investments with the international commitments undertaken by Brazil in relation to the SDGs and the Paris Agreement. In this context, public engineering and urban development companies—such as RIOURBE, within the Municipality of Rio de Janeiro—become central actors in translating environmental guidelines into concrete practices, particularly in the management of public works and urban regeneration initiatives.

Several authors highlight the role of local governments in consolidating sustainable policies and implementing ESG-oriented frameworks focused on environmental governance. Recent studies indicate that the effectiveness of such policies depends on administrative capacity, digital infrastructure, and institutional stability to operationalize sustainability indicators at the municipal level.

International literature also emphasizes that integrating ESG pillars into public management requires adaptive and responsive governance capable of articulating different levels of government, civil society, and the private sector. This multiscalar approach is essential for translating sustainability principles into tangible outcomes, particularly in cities marked by pronounced socio-environmental inequalities.

Nevertheless, there remains a significant gap in studies specifically addressing the application of the environmental pillar of ESG within public administration. To date, no systematic reviews have integrated environmental ESG and public administration with a focus on engineering and public works.

Most existing research concentrates on the corporate dimension of ESG, emphasizing business performance measurement and financial transparency, while overlooking the implementation of environmental indicators in public policies and infrastructure projects. In the public sector, ESG assumes distinct characteristics compared to the corporate environment, as it is not oriented toward maximizing economic value but rather toward generating public value, ensuring policy effectiveness, and serving the collective interest. While corporate ESG prioritizes financial metrics, reputational risks, and organizational performance, ESG in public administration is intrinsically linked to the formulation, implementation, and evaluation of sustainable public policies, institutional governance, and the provision of services and infrastructure with reduced environmental impact and greater social equity.

From this perspective, this study seeks to address the following research questions:

- a) How has the environmental pillar of ESG been incorporated into public administration policies and practices?
- b) What are the main challenges and barriers to implementing environmental criteria in public management?
- c) Which environmental indicators and metrics have been applied in studies focused on the public sector?

The overall objective of this article is to analyze the state of the art of the environmental pillar of ESG in public administration, identifying its main dimensions, indicators, and trends through a systematic review conducted in accordance with the PRISMA 2020 protocol. Specifically, the study aims to: map international scientific production on environmental ESG in the public sector between 2020 and 2025; identify and analyze recurring thematic clusters in the literature; examine methodologies and environmental indicators applied to public administration; compare international trends and approaches to ESG in public management; and propose a research agenda focused on the practical applicability of results for public engineering and urban development companies.

The originality of this article lies in presenting the first consolidated systematic review focused specifically on the environmental pillar of ESG within public administration and urban engineering. The study stands out for its robust database of over 1,200 articles and for integrating innovative tools such as Rayyan, VOSviewer, and Biblioshiny, which enabled in-depth bibliometric and bibliographic analyses. Furthermore, the work offers a relevant contribution by proposing practical recommendations for public administration, thereby expanding the applicability of its findings and addressing a significant gap in both national and international literature.

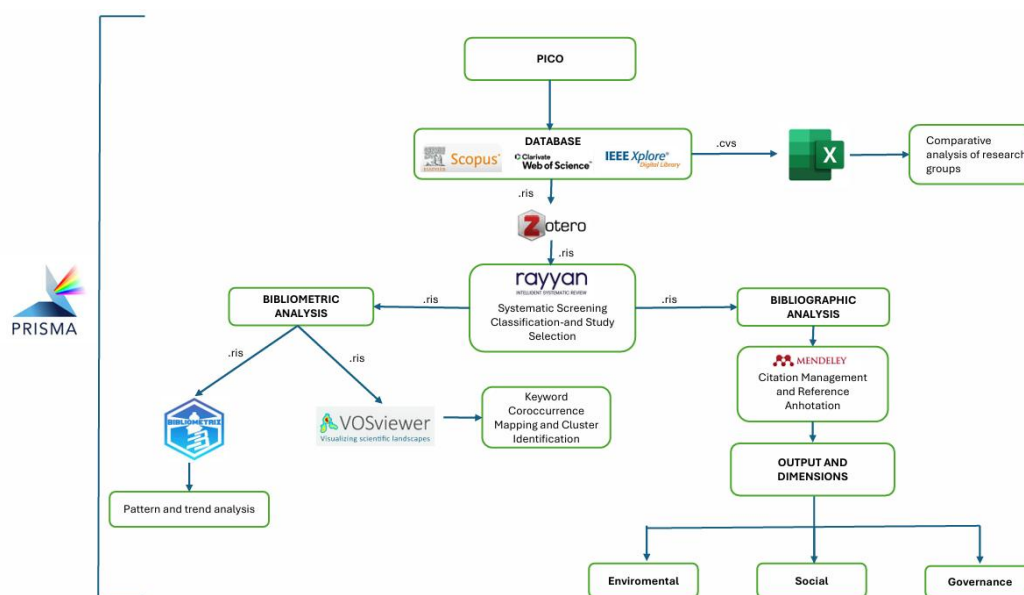
2 METHODOLOGY

The methodology adopted in this study integrates bibliometric and bibliographic approaches, guided by the principles of the PRISMA protocol (Preferred Reporting Items for Systematic Reviews and Meta-Analyses), with the objective of ensuring rigor, transparency, and reproducibility in the analysis of scientific literature on the incorporation of environmental ESG criteria in Public Administration, particularly in public engineering companies such as RIOURBE.

The choice of this methodological strategy is justified by the interdisciplinary and emerging nature of ESG, which encompasses fields such as engineering, public management, urban sustainability, corporate governance, and environmental policy. In this context, a systematic review process capable of mapping the state of the art, identifying conceptual gaps, and recognizing international trends in the application of ESG practices in the public sector becomes essential.

Figure 1

Methodological framework of the systematic review on ESG in Public Administration



2.1 PICO

According to the eligibility criteria defined by PRISMA Research, it is essential to clearly specify all elements and characteristics that compose the study. A well-established way to carry out this definition is through the PICO strategy, which is used to define the design and context of eligible studies. The PICO acronym (Problem, Intervention, Comparison, and Outcomes) represents a methodological tool that guides the formulation and refinement of the research question, allowing for the systematic evaluation of the

effectiveness and relevance of an intervention addressing a given problem. Thus, this approach ensures a comprehensive and precise analysis of the object under investigation, constituting an essential step in the development of structured questions for systematic reviews. The main components of this strategy are presented in Table 1.

Table 1

PICO strategy adopted in the study

Acronym	Organizing Question	Organizational Response
P (Problem)	What is the study about?	ESG in Public Administration
I (Intervention)	What will be proposed?	Adoption of environmental criteria and sustainability indicators in engineering projects
C (Comparison)	What will be the comparison?	Traditional models of Public Administration in ESG
O (Outcomes)	What are the intended outcomes?	Identification of dimensions, indicators, and research trends on environmental ESG in public management

Thus, the definition of the PICO strategy established the methodological parameters that guide this study on the environmental pillar of ESG in public administration. With this stage completed, the next section presents the procedures adopted for data collection, detailing the databases used and the applied search criteria.

2.2 DATA COLLECTION

The data collection stage was planned to ensure breadth and methodological consistency in the selection of studies on the environmental pillar of ESG in public administration. For this purpose, information sources, thematic groups, and search strategies were defined with the aim of identifying relevant and representative publications (Table 2). Searches were conducted in the Scopus, Web of Science, and IEEE Xplore databases. The keyword combinations used encompassed different approaches within the scope of sustainability applied to public management and urban engineering, allowing the compilation of a diverse set of records for the subsequent stages of the systematic review.

The applied criteria were:

Period: 2020–2025;

Languages: no restriction;

Document type: peer-reviewed articles, reviews, and proceedings;

Filters: only scientific publications within the scope of ESG, public policies, and sustainability.

The search strategies combined Boolean terms (AND/OR) across five thematic groups, representing ESG dimensions in public management.

Table 2

Definition of the Groups

Definition of the Group	
Group 1	Sustainability and Environmental Indicators
Group 2	ESG and Socio-Environmental Responsibility
Group 3	Public Management and Municipal Administration
Group 4	Urban Engineering and Public Works
Group 5	Planning and Sustainable Policies
Group 6	Urban Regeneration and Community

The data collection process was carried out systematically, applying the same keyword combinations across each of the selected databases. This strategy made it possible to identify significant variations not only among the thematic groups but also among the databases themselves. For example, Scopus presented the highest number of retrieved publications in virtually all groups, followed by Web of Science and, to a lesser extent, IEEE Xplore. These differences reflect both the profile and scope of each database as well as the level of scientific interest devoted to each topic, highlighting areas that are more consolidated and others that are still under development within the field of ESG in public administration. The following Table 3 presents the organization of the groups and the respective keyword combinations used at this stage of the research.

Table 3

Keywords defined by group and subgroups

Group	1	2	3	4
G1	"Sustainability"/ "public infrastructure"	"sustainability" / "environmental indicators"	"sustainable development" / "performance indicators"	"sustainability assessment" / "government"
G2	"social responsibility" / "public administration"	"public policy" / "ESG"	"ESG" / "Social responsibility"	"ESG" / "environmental responsibility"

G3	"municipal administration" / "sustainable development"	"local government" / "urban planning"	"public management" / "Municipal administration"	"public administration" / "policy implementation"
G4	"sustainability" / "infrastructure projects" / "public works"	"sustainable development" / "public works"	"urban infrastructure" / "sustainability" / "government"	"green infrastructure" / "public works"
G5	"sustainable development" / "public administration"	"sustainable urban planning" / "government"	"sustainability policy" / "government"	"urban planning" / "government" / "sustainability"
G6	"urban regeneration" / "social inclusion"	"urban renewal" / "community development"	"urban planning" / "community resilience"	"urban transformation" / "sustainable development" / "government"

During the first search stage, Boolean operators (AND, OR, NOT) were applied to combine the descriptors defined for each group, as presented in Table 2. This initial strategy resulted in 14,825 documents, as shown in Table 4, retrieved from the Scopus, IEEE Xplore, and Web of Science databases and exported in .ris format for bibliometric processing. However, the breadth of this search generated an excessive volume of records, many of which were duplicated, incomplete, or not aligned with the scope of the research, which would hinder systematic and precise analysis. In addition, during the screening phase in Rayyan, it was observed that approximately 15,000 records would require manual exclusion, making the screening process extremely time-consuming and prone to selection bias.

Table 4

Initial search results with six groups

Number of documents						
Database	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
Scopus Elsevier	2830	2000	986	173	1297	248
IEEE Explore	621	102	185	20	217	18
Web of Science	1509	3104	415	102	792	206
Total	4960	5206	1586	295	2306	472

This finding led to the need to refine the methodological design of the research, ensuring a balance between the breadth and relevance of the results. Therefore, a more selective approach was adopted, aimed at identifying keyword combinations that more accurately represented the intersection between sustainability, public management, and urban policies. The intention was to preserve the thematic depth of the review without

compromising its technical and analytical feasibility. Based on this revision of the strategy, the keyword combinations were redefined, seeking to eliminate redundancies and overlaps among the previously defined groups. The new keyword arrangement (Table 5) prioritized those with greater recurrence in international studies and stronger alignment with the objectives of this research, resulting in a more streamlined methodological structure that is more consistent with the reality of recent scientific production on ESG and sustainability in public administration. Thus, the original six groups were consolidated into five main groups, representing central analytical axes related to sustainability, governance, and public policies. The final keyword combinations applied to the databases and their respective results are presented in Table 6.

Table 5

Number of documents

Definition of the Group	
Group 1	“Sustainability”, “Environmental Indicators” and “Government”
Group 2	“ESG”, “Sustainability” and “Government”
Group 3	“Public Management”, “Municipal Administration” and “Environmental Sustainability”
Group 4	“Public Infrastructure” and “Sustainability”
Group 5	“Planning”, “Sustainable Policies” and “Government”

Table 6

Search results with five groups

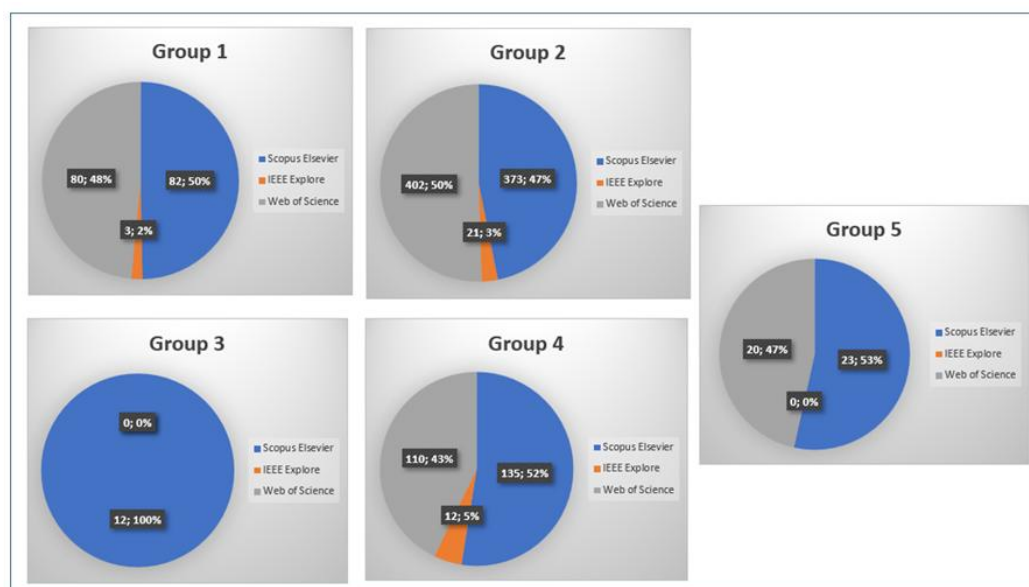
Database	Number of documents				
	Group 1	Group 2	Group 3	Group 4	Group 5
Scopus Elsevier	82	373	12	135	23
IEEE Explore	3	21	0	12	0
Web of Science	80	402	0	110	20
Total	165	796	12	257	43

Figure 2 presents the results obtained from the respective databases. It can be observed that Scopus was the database that returned the highest number of publications, followed by Web of Science and, to a lesser extent, IEEE Xplore. Among the tested keyword combinations, the set associating the terms “Sustainability”, “Environmental Indicators”, and

“Government” presented the largest volume of records, indicating a strong presence of studies linking sustainability and public management. A total of 1.273 documents were retrieved from the three databases.

Figure 2

Search results with five groups



Once the data collection stage was completed, it was possible to identify and compile the records necessary for the development of the systematic review on the environmental pillar of ESG in public administration. The procedures adopted allowed the publications to be organized according to the established criteria, enabling the initiation of the subsequent screening and analysis stages.

Before the beginning of the screening stage, explicit inclusion and exclusion criteria were defined in order to ensure methodological consistency and alignment of the set of analyzed studies with the objectives of the systematic review. Studies published in peer-reviewed scientific journals between 2020 and 2025 were included if they explicitly addressed the public sector or public policies and presented a direct relationship with the environmental pillar of ESG, environmental sustainability, or related frameworks applied to public administration, public works, or infrastructure. Studies with empirical, methodological, or review approaches that presented indicators, metrics, or analytical models related to the topic were also considered eligible.

Duplicate articles were excluded, as well as studies focused exclusively on the private or corporate sector without interface with public administration, publications that addressed ESG in a generic manner without an environmental focus, documents without access to full

text, non–peer-reviewed literature, and studies that did not demonstrate thematic alignment after reading titles and abstracts.

2.3 SCREENING

During the screening stage, the Rayyan software was used to organize and prepare the records collected in the previous phase (7). Initially, all retrieved articles were imported into the platform, which enabled a structured visualization of the material to be analyzed. Rayyan allows the automatic identification of duplicate records, facilitating the rapid and accurate exclusion of these items. After the removal of duplicates, the next step consisted of excluding studies that did not meet the scope defined for the research, based on the reading of titles and abstracts. Subsequently, the previously established eligibility criteria were applied, ensuring that only studies aligned with the objectives of the work were retained for the following stages. This entire process contributed to the systematization and refinement of the set of articles, making the subsequent analysis more efficient and focused. At the end of the screening process, the selected records were organized by thematic group.

The screening of studies was conducted independently by two reviewers, based on the reading of titles and abstracts, with support from the Rayyan platform. Any doubts regarding the eligibility of studies were discussed until consensus was reached, ensuring greater methodological rigor and reduction of selection bias.

As a result of this process, 523 duplicates and 265 records considered outside the scope of the research were eliminated. The final set, consisting of 1,006 unique articles, was then prepared for the subsequent stages of bibliometric and bibliographic analysis. The quantitative systematization of this refinement can be seen in Table 7, which details the processing of records in each thematic group, including the total number of identified documents, duplicates removed, excluded records, and the final number of articles selected for analysis.

Table 7

Detailed processing of records during the screening stage

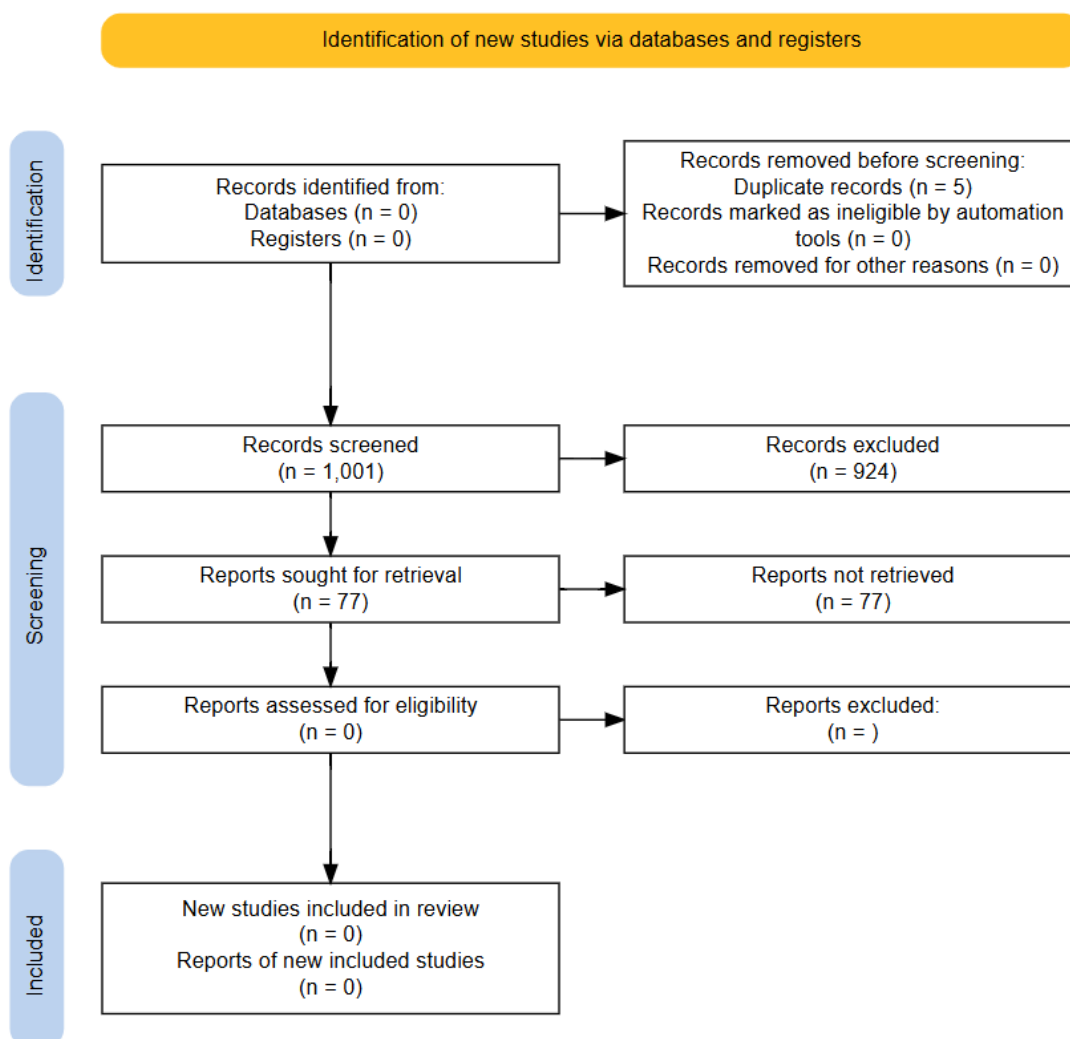
GROUP	Number of documents			
	Total	Duplicates	Deleted	Non-duplicates
1	165	54	27	137
2	796	328	165	630
3	12	0	0	12

4	257	133	69	188
5	43	8	4	39
TOTAL	1273	523	265	1006

At the end of the screening process, the PRISMA flow diagram presented in figure 3 (6) was automatically generated in Rayyan. This flow diagram describes the stages of identification, screening, eligibility, and inclusion of the analyzed studies, indicating the number of records identified in the databases, the records removed as duplicates, those excluded for not meeting the defined criteria, and the final number of articles included for bibliometric and bibliographic analysis.

Figure 3

PRISMA 2020 flow diagram



In summary, the screening process allowed for the careful selection of studies on the environmental pillar of ESG in public administration, according to the established criteria and

the methodological steps described. The result of this stage was the identification of a set of unique articles, duly organized for the bibliometric and bibliographic analyses that will be presented in the following chapters.

2.4 BIBLIOGRAPHIC ANALYSIS

The bibliographic analysis was conducted based on the set of 1,006 unique articles obtained after the screening stage. For this phase, criteria related to adherence to the central research topic, relevance to the proposed objectives, and an interdisciplinary approach involving engineering, public management, and urban sustainability were considered. After reading the titles, abstracts, and methodologies, a more in-depth qualitative assessment of the studies was carried out, considering as eligibility criteria the explicit focus on the public sector or public policies, the direct approach to the environmental pillar of ESG or equivalent environmental sustainability instruments, empirical or methodological application related to public management, public works, or infrastructure, and clarity in the definition of indicators, metrics, or analytical frameworks.

Based on these qualitative criteria, 69 articles were selected to compose the final set of analyzed studies. These articles were then organized and categorized according to the analytical dimensions of ESG (environmental, social, and governance), allowing for deeper discussion of indicators, methodologies, and trends related to the incorporation of ESG principles in public administration. The objective of this stage was to identify the main recurring themes, advances, and challenges present in the literature, as well as to support the reflections and recommendations presented in the following chapters.

The qualitative assessment of the studies was conducted independently by two reviewers, considering criteria of thematic adherence, methodological relevance, and analytical contribution, with final consolidation by consensus.

For the analysis of thematic clusters, the VOSviewer software was used, adopting the keyword co-occurrence analysis method, which allows the identification and visualization of relationships among the main terms present in the selected literature (8). The counting method employed was full counting, in which each keyword occurrence is fully counted for each publication in which it appears. To ensure greater relevance and robustness of the results, a minimum threshold of three occurrences was established for a term to be included in the generated co-occurrence maps.

The complementary bibliometric analysis carried out with the support of the Bibliometrix package, through the Biblioshiny interface, allowed detailed exploration of the collected data (9). Indicators such as scientific production by country, most relevant sources,

most frequent terms, and thematic maps were used, enabling the identification of trends, research hubs, and emerging themes. For the construction of the thematic model, parameters such as keyword clustering, degree of centrality, and theme development were considered, which allowed the classification of topics as motor, basic, emerging, and niche themes, according to their relevance and maturity in the literature.

This systematic review was not previously registered on specific protocol registration platforms, nor was a formal protocol developed prior to the beginning of data collection and analysis. The methodological steps were defined iteratively, based on the PRISMA 2020 guidelines, due to the exploratory and interdisciplinary nature of the study.

3 RESULTS

This chapter presents the main results obtained from the analyses carried out on the incorporation of the environmental pillar of ESG in public administration. Initially, the findings of the bibliometric analysis are presented, including graphs, tables, and maps that illustrate scientific production, recurring themes, and trends identified in the field of study. Subsequently, the results of the bibliographic analysis are detailed, organized according to the three ESG dimensions (environmental, social, and governance), highlighting the most frequent themes, observed advances, and challenges identified in the literature. This approach aims to provide a comprehensive and structured overview of the state of the art, supporting the discussions and recommendations presented in the following chapters.

3.1 THEMATIC CLUSTER ANALYSIS

This section presents the results of the thematic cluster analysis identified from the processing of the search groups defined in the bibliometric stage. For this analysis, the VOSviewer software was used, which enabled the development of keyword co-occurrence maps, author networks, and the identification of recurring thematic clusters in the literature on ESG in public administration. The use of this tool made it possible to visualize the connections between concepts, research areas, and trends, offering a structured understanding of how the different ESG axes are addressed in the analyzed studies. The generated maps and networks serve as the basis for the discussion of the main themes and relationships identified throughout the research. The individual analyses of each group are presented below:

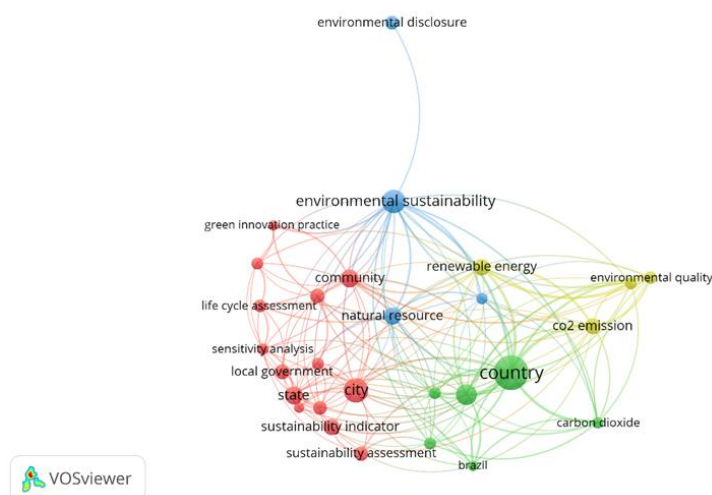
Group 1 – “Sustainability”, “Environmental Indicators” and “Government”

Group 1 brings together studies that address the standardization of metrics and the assessment of environmental performance in public policies. The works grouped within this thematic axis focus on topics such as environmental sustainability, performance indicators, innovative management practices, and the integration between government and environmental policies. This categorization allows the identification of the main trends and approaches adopted by the scientific literature when addressing the incorporation of the environmental pillar of ESG in public administration (10).

Figure 4 presents the keyword co-occurrence network of Group 1, highlighting “country” as the central term of the cluster. This node concentrates the highest number of connections, serving as a link between different themes related to environmental sustainability in public policies. Around “country,” terms such as “CO₂ emission,” “carbon dioxide,” “environmental quality,” and “Brazil” are grouped, composing a thematic axis focused on technical and environmental issues, especially those related to gas emissions and environmental quality. The red cluster, on the left, includes terms such as “city,” “state,” “local government,” “community,” “natural resource,” “sustainability indicator,” and “sustainability assessment,” forming a set associated with institutional and territorial themes. The yellow cluster, more peripheral, includes “renewable energy” and “environmental quality,” connecting to both the green and red clusters through “country.” The blue cluster, more isolated, contains “environmental disclosure,” with few direct connections to the central core.

This configuration shows that discussions on environmental sustainability in public administration within this group are strongly anchored in national-level approaches (“country”), while also articulating local and institutional dimensions, as well as technical aspects related to energy and emissions (10).

Figure 4



Group 2 – “ESG”, “Sustainability” and “Government”

Group 2 brings together studies that explore the integration of ESG criteria with sustainability and governmental action. The works within this cluster mainly address themes related to ESG performance in public organizations, transparency, ethical governance, and policies aimed at promoting sustainable practices in the public sector. The analysis of this group makes it possible to identify how ESG concepts have been incorporated into governmental strategies, highlighting the importance of performance measurement, information disclosure, and the transition toward more responsible management models aligned with environmental and social demands (11).

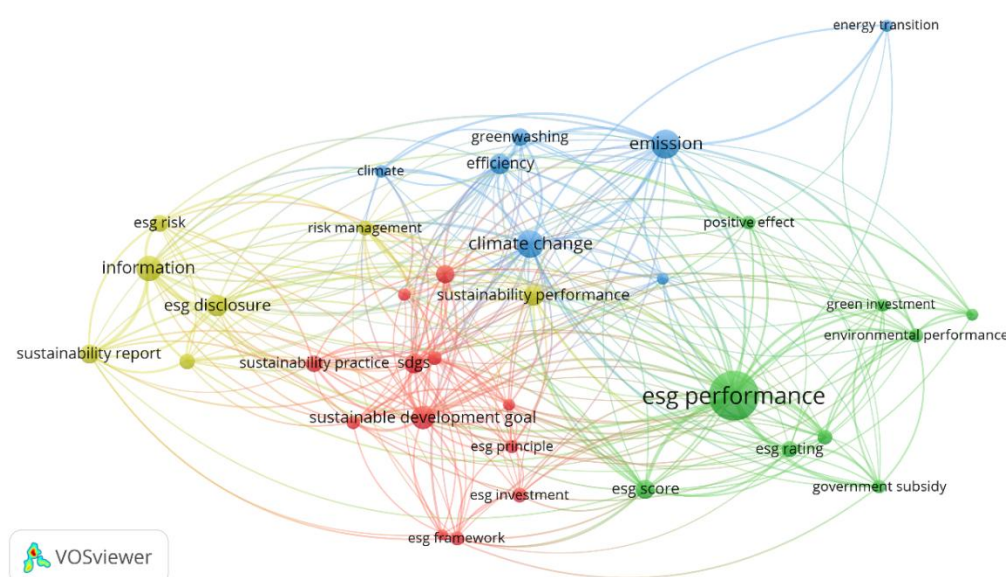
Figure 5 shows that the term “ESG performance” occupies the central position in the network, acting as the main articulator of discussions within Group 2. This node presents the highest number of connections, especially with terms such as “ESG score,” “environmental performance,” “government subsidy,” “ESG rating,” “ESG principle,” and “ESG investment,” forming a high-density green cluster. This indicates that ESG performance is the central axis of the publications, reflecting the focus on measurement, evaluation, and the impact of ESG practices in the public sector. On the left, the red cluster brings together terms such as “sustainability performance,” “sustainable development goal (SDG),” “ESG framework,” “ESG disclosure,” “sustainability report,” and “sustainability practice,” all strongly connected to “ESG performance” and “climate change.” This grouping highlights the importance of transparency, information disclosure, and the adoption of sustainable practices as fundamental elements for the consolidation of ESG in governmental organizations. In the upper part, the blue cluster connects terms such as “climate change,” “emission,” “efficiency,” “greenwashing,” “energy transition,” and “positive effect,” evidencing the relationship

between energy performance, mitigation of environmental impacts, and the transition to more sustainable models. The yellow cluster, more dispersed, includes terms such as “risk management,” “ESG risk,” “information,” and “climate,” linked to the red core, indicating the relevance of risk management and information flow for the effectiveness of ESG policies.

The network evidences a strong correlation between ESG performance, corporate sustainability, and energy transition, with “climate change” functioning as a link between the main groupings. This configuration reveals that discussions on ESG in public administration are centered on performance evaluation, transparency, and the integration of sustainable practices, while also addressing challenges such as risk management and adaptation to climate change (11).

Figure 5

Keyword co-occurrence network (VOSviewer) – Group 2



Group 3 – “Public Management”, “Municipal Administration” and “Environmental Sustainability”

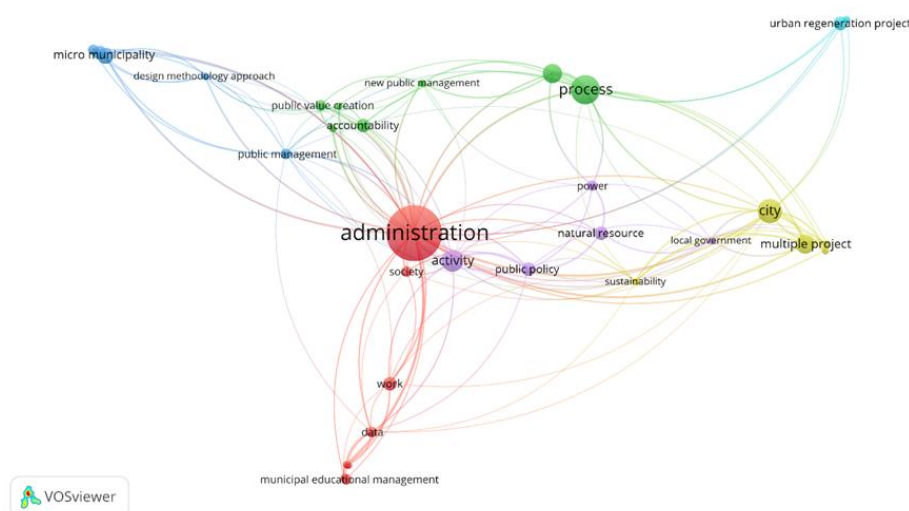
Group 3 brings together studies focused on municipal public management, social participation, transparency, and urban renewal. The works grouped within this thematic axis address administrative practices, accountability processes, public value creation, and the implementation of environmental policies at the local level. The analysis of this group allows for an understanding of how sustainability and governance strategies are operationalized within the context of municipal administrations, highlighting the role of cities and local governments in consolidating innovative and sustainable public policies (12).

Figure 6 presents the keyword co-occurrence network of Group 3, in which the term “administration” occupies the center of the network, being the largest node and the one with the highest number of connections. The red cluster, denser, brings together terms such as “administration,” “society,” “activity,” “work,” “care,” and “municipal educational management,” indicating a strong association between administrative practices and social dimensions. The green cluster, located at the upper part, groups terms such as “process,” “accountability,” “new public management,” and “public value creation,” connecting directly to the central core and to the yellow cluster, forming the managerial and public governance axis. The yellow cluster, on the right, contains terms such as “city,” “local government,” “multiple project,” and “urban regeneration project,” composing the segment focused on urban management and the implementation of local public policies. The lilac cluster, smaller and located below and to the right of the center, presents terms such as “public policy,” “sustainability,” “power,” and “natural resource,” functioning as a transition zone between the social and urban axes. The blue cluster, more dispersed, includes “municipality,” “micro municipality,” and “design methodology approach,” with low-density links to the center of the network.

The network reveals the strong centrality of the term “administration,” which connects themes of public management, social participation, and institutional sustainability. This configuration shows that, within the context of Group 3, discussions on ESG in public administration are strongly related to the operationalization of sustainability strategies at the municipal level, the valorization of social participation, and the implementation of innovative policies in cities and local governments (13).

Figure 6

Keyword co-occurrence network (VOSviewer) – Group 3



Group 4 – “Public Infrastructure” and “Sustainability”

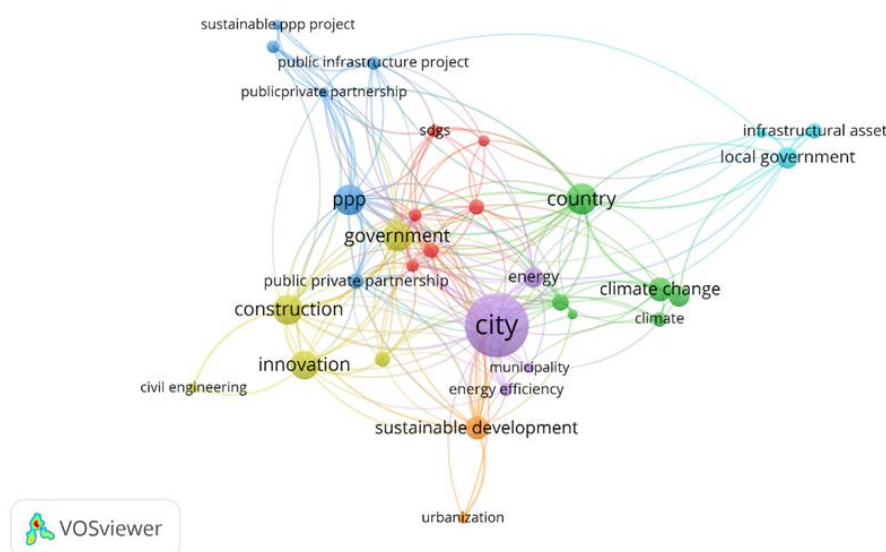
Group 4 brings together studies that address themes related to public infrastructure, energy efficiency, and environmental innovation. The works grouped within this thematic axis explore the role of government as a driving agent of sustainable practices, highlighting initiatives such as public–private partnerships, green infrastructure projects, and policies aimed at sustainable urban development. The analysis of this group allows for an understanding of how sustainability strategies are incorporated into public works and engineering projects, evidencing the importance of integrating technological innovation, public management, and adaptation to climate change (14).

Figure 7 presents the keyword co-occurrence network of Group 4, in which the term “city” occupies the center of the network, with high connection density and the highest number of links. To its left, the yellow cluster concentrates terms such as “innovation,” “construction,” “civil engineering,” “sustainable development,” “urbanization,” and “energy efficiency,” forming a block strongly associated with technological innovation and sustainable infrastructure. The light-blue cluster, in the upper left part, groups “PPP,” “government,” “public private partnership,” “public infrastructure project,” and “sustainable PPP project,” connecting to the central core and representing the axis of public policies and governmental partnerships. The green cluster, to the right of the center, includes “country,” “climate change,” “climate,” and “infrastructural asset,” composing the thematic group related to energy and climate adaptation. The red cluster, smaller and located between the blue and green clusters, brings together “SDGs,” “energy,” “government,” and “public private partnership,” functioning as a convergence zone between the political, energy, and environmental axes.

The map highlights the strong interconnection among “city,” “PPP,” “innovation,” “energy,” and “climate change,” emphasizing urban infrastructure and public–private partnerships as central elements in discussions on sustainability and energy efficiency (14).

Figure 7

Keyword co-occurrence network (VOSviewer) – Group 4



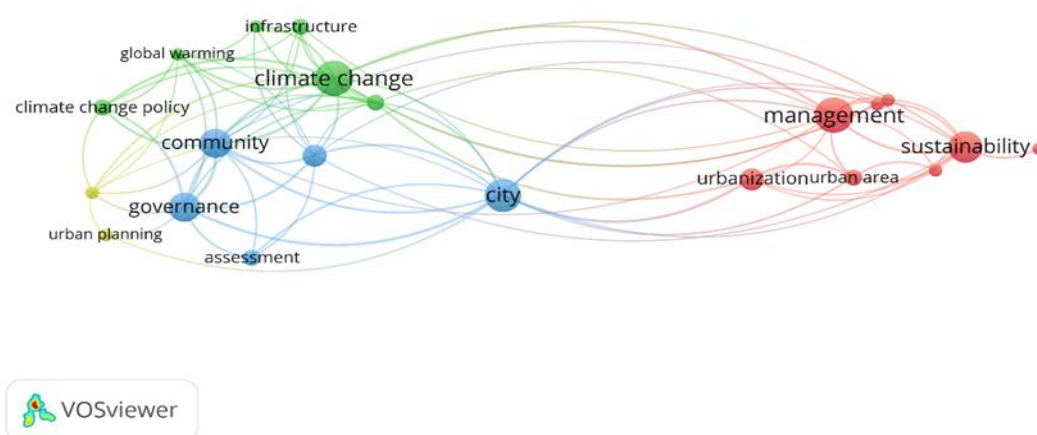
Group 5 – “Planning”, “Sustainable Policies” and “Government”

Group 5 aims to analyze how urban planning, sustainable policies, and governmental action are articulated to promote sustainability in cities. Based on the review of studies grouped within this thematic axis, the objective is to understand how strategic planning and public policy formulation have been used as tools to address challenges such as climate change and accelerated urbanization, highlighting the integration of different actors and levels of government, as well as the role of innovative instruments in this context (15,16).

Figure 8 shows the keyword co-occurrence network of Group 5, illustrating how central concepts are connected in discussions on urban planning, sustainable policies, and government. The term “climate change” occupies the central position in the network, connecting directly to thematic clusters such as “city,” “community,” “governance,” “urban planning,” and “assessment,” which form the public management and urban planning axis. Other groupings highlight “infrastructure,” “global warming,” and “climate change policy,” creating an interface between territorial planning and climate policies. Terms such as “management,” “sustainability,” “urbanization,” and “urban area” also appear, reinforcing the administrative and operational role of sustainable policies. The strongest links between “city,” “governance,” and “climate change” indicate the centrality of cities in the formulation of strategies aimed at addressing climate change. The graph presents a more open and less dense network, with long and dispersed connections, revealing the conceptual fragmentation still present in publications on sustainable planning and climate governance.

Figure 8

Keyword co-occurrence network (VOSviewer) – Group 5



The comparison among clusters reveals important differences regarding thematic focus and term centrality. It is observed that, while some groups strongly emphasize concepts related to sustainability, performance, and governance, others show a predominance of terms associated with the corporate context, such as “ESG performance” and “sustainability report,” highlighting the weight of corporate approaches in the literature. On the other hand, there is a low direct connection between ESG and public works, with few terms and links relating ESG practices to the execution of infrastructure and urban engineering projects, which indicates a relevant gap and reinforces the need to deepen research in this segment. The dominance of certain terms within the clusters, such as “city,” “country,” and “administration,” reflects the centrality of discussions on public policies and urban management. In addition, the keyword analysis highlights not only the centrality of cities and the strategic role of government in promoting innovative practices and sustainable policies, but also shows that there is still little integration among different approaches to the topic. This underscores the need for new perspectives, highlighting emerging themes such as smart cities and climate resilience, which have been gaining space in recent discussions on environmental ESG in public administration. This comparative analysis makes it possible to identify opportunities for future investigations, especially those aimed at expanding dialogue between ESG, public works, and governmental management policies.

This integrated view of the thematic clusters provides support for deepening the quantitative and qualitative analysis of the articles, which will be carried out using the bibliometric tools of Bibliometrix/Biblioshiny, allowing a more detailed exploration of trends,

advances, and challenges present in scientific production on environmental ESG in the public sector.

3.2 COUNTRY SCIENTIFIC PRODUCTION

The “Country Scientific Production” analysis aims to identify and present the geographical distribution of scientific production on ESG in public administration. Through this indicator, it is possible to visualize which countries stand out in terms of number of publications, revealing research hubs, regional trends, and potential gaps in the international literature. This approach contributes to understanding the global landscape of the topic, highlighting where discussions are more consolidated and pointing to opportunities for strengthening studies in less represented contexts.

Figure 9 presents the geographical distribution of scientific production on ESG in public administration, showing a significant concentration of publications in countries in North America, Europe, and Asia, with emphasis on more developed economies and those with a tradition in research on governance and sustainability. It is observed that these countries act as consolidated hubs of scientific production, reflecting greater institutional maturity, data availability, and incentives for research on ESG-related topics. In contrast, regions such as Latin America, Africa, and parts of Southeast Asia show a lower volume of publications, indicating relevant gaps in the literature and reinforcing the need to expand studies in diverse institutional contexts. This pattern highlights a geographical imbalance in knowledge production and points to opportunities for strengthening research applied to the public sector in developing countries, especially in the field of public policies and sustainable infrastructure.

Figure 9

Country Scientific Production

Country Scientific Production

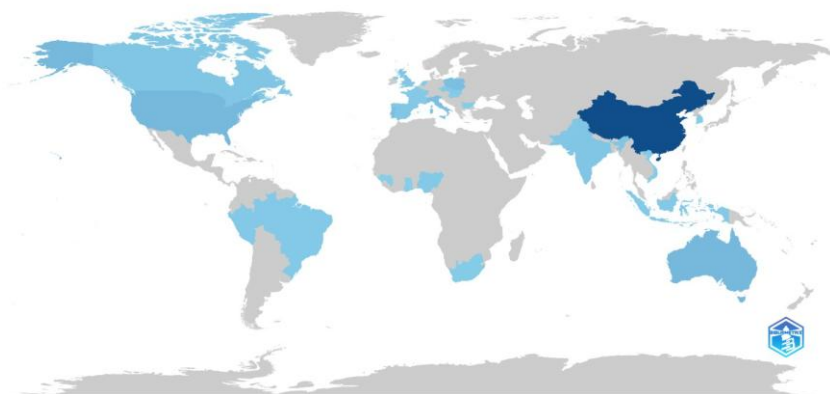


Table 8 details the distribution of scientific production by country, complementing the visualization presented in Figure 9. A strong leadership by China is observed, with 67 publications, highlighting the country's prominence in academic production related to ESG in public administration. Australia and the United States follow, each with 11 publications, followed by Italy, Poland, and Portugal, with 8 studies each. These results reinforce the concentration of scientific production in countries with greater institutional research capacity and a tradition in studies on governance, sustainability, and public policies. At the same time, the presence of countries from Latin America, Africa, and Southeast Asia with a lower number of publications—such as Brazil, Nigeria, Peru, Vietnam, and Ghana—highlights regional asymmetries in knowledge production, indicating relevant gaps and opportunities for the development of applied research on ESG in the public sector in emerging contexts.

Table 8

Country Scientific Production

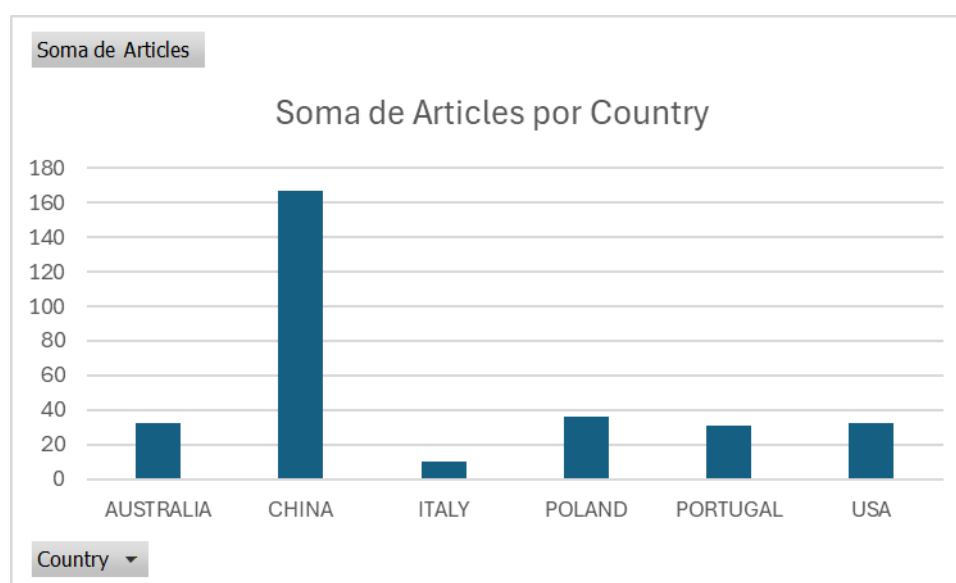
Country	Freq
CHINA	67
AUSTRALIA	11
USA	11
ITALY	8
POLAND	8
PORTUGAL	8
CANADA	5
INDIA	5
UK	5
PAKISTAN	4
SPAIN	4
BRAZIL	3
CZECH REPUBLIC	3
FRANCE	3
INDONESIA	3
NETHERLANDS	3
NIGERIA	3
PERU	3
SLOVAKIA	3
BULGARIA	2
HUNGARY	2
SOUTH AFRICA	2
SOUTH KOREA	2
VIETNAM	2
GHANA	1
GUINEA	1

The analysis of the “Country Scientific Production” chart and table reveals that scientific production on ESG in public administration is mainly concentrated in Asian and European countries. China clearly leads in the number of publications, followed by Australia, the United States, Italy, Poland, and Portugal, which also show significant participation. Countries such as the United Kingdom, Spain, Germany, and Italy stand out as important research hubs, while Brazil and other Latin American countries appear with low representativeness. This distribution indicates that discussions on environmental ESG are more consolidated in regions with greater investment in sustainable public policies and institutional innovation, while also pointing to opportunities to strengthen studies in less represented contexts, especially in Latin America.

3.3 COUNTRIES PRODUCTION OVER TIME

The “Countries Production Over Time” analysis (Figure 10) aims to present the evolution of scientific production on ESG in public administration over the years, highlighting how different countries have contributed to the advancement of research in this field. Through this indicator, it is possible to visualize temporal trends, identify periods of greater growth, and compare the prominence of each country in generating knowledge on sustainability and public governance.

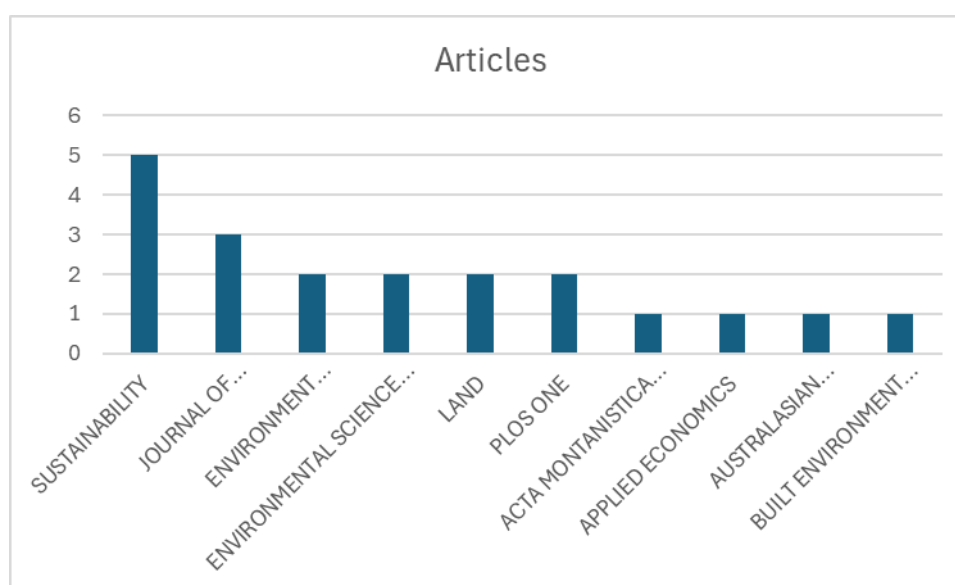
The analysis of the results from the “Countries Production Over Time” graph shows that China leads scientific production on ESG in public administration, with a significant number of publications throughout the analyzed years. European countries, such as Italy, Poland, and Portugal, also show relevant participation, followed by the United States and Australia. This distribution indicates that the discussion on environmental ESG is more consolidated in Asian and European countries, where there is greater investment in sustainable public policies and institutional innovation. On the other hand, a low representativeness of Brazil and Latin America is observed, which reinforces the need to expand regional research and studies applied to the Brazilian context. This scenario highlights opportunities for the development of local investigations, especially in public companies and urbanization projects, such as those conducted by RIOURBE.

Figure 10*Countries Production Over Time*

3.4 MOST RELEVANT SOURCES

The “Most Relevant Sources” analysis (Figure 11) aims to identify the journals and scientific periodicals that published the highest number of articles on ESG in public administration during the analyzed period. This indicator makes it possible to visualize which academic outlets concentrate discussions on sustainability, governance, and public policies, highlighting the international recognition of the topic and identifying the main channels for scientific dissemination in the field.

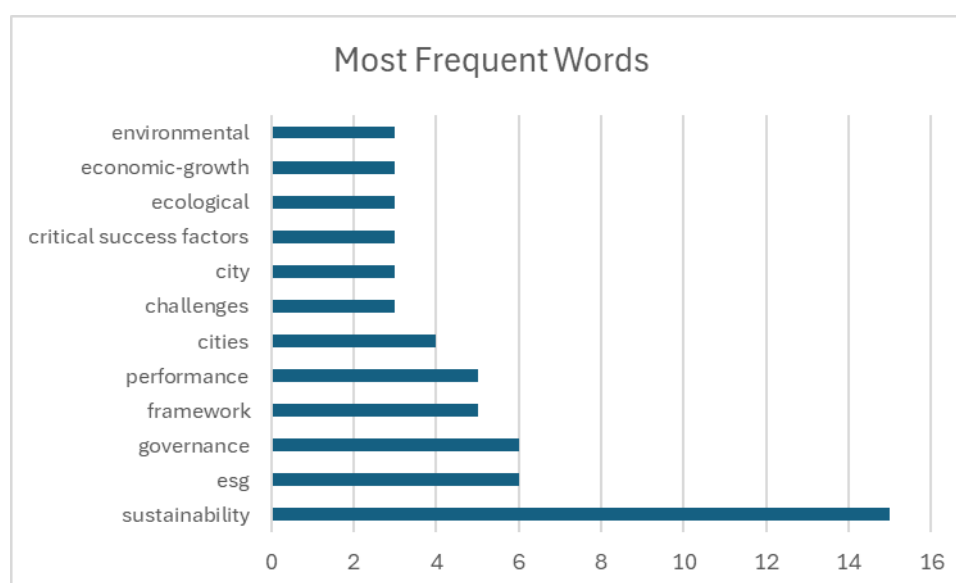
The analysis of the results from the “Most Relevant Sources” chart shows that the journal Sustainability leads in the number of articles published on ESG in public administration, followed by periodicals such as Journal of Environmental Science, Land, PLOS One, among others. This concentration in high-impact journals highlights the international recognition of the topic and the relevance of discussions on sustainability, governance, and public policies. It is observed that the predominance of international journals reinforces the consolidation of environmental ESG as a global agenda, while also highlighting the need to expand the presence of Latin American and Brazilian journals in this debate, which may contribute to the dissemination of local experiences and to the development of indicators adapted to the national context.

Figure 11*Most Relevant Sources*

3.5 MOST FREQUENT WORDS

The “Most Frequent Words” analysis (Figure 12) aims to identify the most recurrent terms in publications on ESG in public administration. This indicator makes it possible to visualize which concepts, themes, and approaches receive the greatest emphasis in the scientific literature, facilitating the understanding of trends, priorities, and research focuses in the field.

The analysis of the “Most Frequent Words” chart reveals that the most recurrent terms in publications on ESG in public administration are “sustainability,” “ESG,” “governance,” “performance,” “framework,” and “environmental,” indicating that the concepts of sustainability and environmental governance occupy a central position in the scientific literature on the topic. Other relevant terms, such as “cities,” “challenges,” and “economic growth,” point to a focus on urban policies, overcoming barriers, and economic impacts. This visualization reinforces the importance of sustainability as a conceptual axis and shows that academic debates are strongly linked to performance measurement, the structuring of frameworks, and the search for solutions to environmental and urban challenges.

Figure 12*Most Frequent Words***3.6 TREEMAP**

The “Treemap” analysis aims to visually and hierarchically present the most recurrent terms in publications on ESG in public administration. Through this tool, it is possible to quickly identify the central concepts and thematic groupings that dominate the field, facilitating the perception of relationships among the main themes, research trends, and opportunities for further exploration in specific areas.

Figure 13 (Treemap) shows that “sustainability” is the central and most recurrent concept in publications on ESG in public administration, followed by key themes such as “governance,” “framework,” “ESG,” and “performance,” which reflect the literature’s focus on performance measurement, methodological structuring, and environmental assessment. The chart also highlights the presence of emerging themes, such as “energy efficiency,” “climate resilience,” and “big data,” as well as challenges and barriers to the implementation of ESG practices, indicating that the field is expanding and seeking to integrate innovation, adaptation, and multidimensionality into public policies. This hierarchical visualization facilitates the identification of the main axes of discussion and points to opportunities for deeper investigation in specific areas.

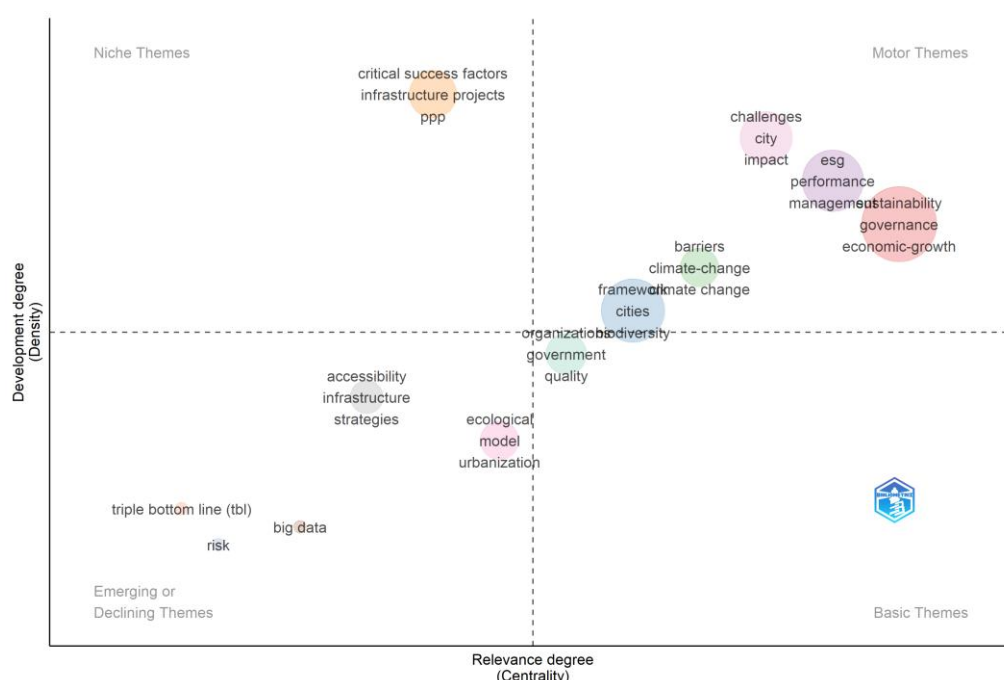
Figure 13*Treemap***3.7 THEMATIC MAP**

The thematic map presents a visual and structured overview of the main research axes on ESG in public administration, organizing the themes into four groups: motor, basic, emerging, and niche themes. This approach makes it possible to quickly identify which topics drive the field, which are consolidated, which are on the rise, and which have high potential for specialization. The map facilitates the understanding of the relationships among sustainability, governance, public policies, and institutional innovation, serving as a basis for in-depth discussions on priorities, challenges, and research opportunities in the context of environmental ESG in the public sector (Figure 14).

The thematic map shows the distribution of the main topics researched on ESG in public administration across four quadrants. In the motor themes quadrant are “challenges,” “city,” “impact,” “ESG performance,” “management,” “framework,” “governance,” “economic growth,” and “climate change,” indicating that these topics are central and drive the development of the field. The basic themes, located in the lower-right quadrant, include “organization,” “government,” “quality,” “assessment,” “urbanization,” and “ecological model,” representing broadly discussed and consolidated conceptual foundations. In the upper-left quadrant appear niche themes, such as “critical success factors,” “infrastructure projects,” and “PPP,” which are more specialized and less central approaches, but with potential for further development. In the lower-left quadrant are emerging or declining themes, such as “accessibility,” “infrastructure strategies,” “triple bottom line (TBL),” “risk,” and “big data,” which reflect areas that are growing or still seeking greater relevance and development within the scientific literature on environmental ESG in the public sector.

Figure 14

Thematic Map



3.8 SYNTHESIS OF BIBLIOMETRIC FINDINGS

Scientific production on the environmental pillar of ESG in public administration is recent and has shown accelerated growth since 2020, with a higher concentration of studies in Asian and European countries, especially China, Italy, Poland, Portugal, the United States, and Australia. Brazil and other Latin American countries still have low representativeness, indicating a regional gap. The central themes identified are sustainability, governance, performance, frameworks, and environmental indicators, which appear with high frequency in the publications. International journals lead the dissemination of studies, with emphasis on the journal Sustainability. Keyword co-occurrence maps and thematic clusters show that sustainable public procurement, green infrastructure, energy efficiency, and environmental governance are drivers of research and institutional innovation. Emerging themes such as smart cities, digital transition, and climate resilience are beginning to gain prominence, while areas such as urban planning and low-carbon policies still present conceptual dispersion. The data reveal the need for indicator standardization, institutional integration, and adaptation of methodologies to local realities, especially to strengthen the environmental ESG agenda in the Brazilian public sector.

3.9 BIBLIOGRAPHIC ANALYSIS

Based on the analysis of the 69 articles selected for in-depth qualitative analysis, recent literature on ESG in public administration demonstrates that sustainability in public

policies results from the balance between actions aimed at environmental protection, promotion of social inclusion, and strengthening of institutional governance. The three ESG dimensions—environmental, social, and governance—are addressed in an integrated and complementary manner and are fundamental to the effectiveness of sustainable and innovative public policies (1,2).

Environmental Dimension

The environmental dimension of ESG in public administration is mainly related to energy efficiency, waste management, green infrastructure, reduction of carbon emissions, and adoption of clean technologies. Practices such as sustainable public procurement, inclusion of environmental criteria in bidding processes and infrastructure projects, and the use of specific frameworks and indicators, such as DPSIR and IPEEI, are highlighted. These strategies are essential to align public policies with international sustainability commitments and to promote sustainable urban development, although challenges remain regarding the standardization of indicators and methodological adaptation to local realities, especially in public works and engineering companies (10,17–22).

Social Dimension

In the social aspect, studies emphasize the importance of community participation, social inclusion, quality of life, and social cohesion for the success of sustainable public policies. International experiences show that social mobilization, the enhancement of public spaces, and the promotion of adequate social infrastructure are decisive for strengthening social capital and promoting collective well-being. Inclusive and participatory public policies are essential to ensure equity and social justice, especially in urban and rural contexts marked by inequalities (13,23–26).

Governance Dimension

The governance dimension is mainly addressed in terms of transparency, ethics, accountability, administrative capacity, and institutional innovation. The literature highlights that integrating ESG criteria into public management strengthens governance, improves the attraction of responsible investments, and promotes more resilient cities. Practices such as sustainable public procurement, public–private partnerships, and the adoption of performance systems are identified as strategic to enhance administrative efficiency and stimulate innovation. Nevertheless, challenges such as the need for regulatory frameworks, technical capacity building, and intersectoral integration remain central to the effectiveness of sustainable policies in the public sector (12,22,26–28).

The analysis of the studies shows that the integration of environmental ESG with public works and engineering companies is fundamental to the effectiveness of sustainability

policies in the public sector. Practices such as the adoption of environmental frameworks (DPSIR, IPEEI), the use of specific indicators, and the implementation of sustainable public procurement (Table 9) have proven essential to align infrastructure projects with environmental requirements and international commitments (10,18,19,22,26,29–31). However, the literature indicates that this integration is still incipient, making it necessary to expand methodological standardization and adapt indicators to local realities in order to enhance results and the practical applicability of ESG in public works.

Table 9

Main environmental methodologies and frameworks applied to public administration

Methodology / Framework	Brief Description	Application in Public Works / ESG	References
DPSIR	Model that structures analysis into Driving Forces, Pressures, State, Impact, and Response.	Integrated assessment of environmental impacts in infrastructure projects and public policies.	(29–32)
IPEEI	Integrated Ecological Perception Index, combining environmental and institutional variables.	Measurement of sustainability in public works and urban planning.	(10,32)
Specific Environmental Indicators	Metrics such as energy efficiency, waste management, and use of renewable energy.	Monitoring of environmental performance in bidding processes, contracts, and execution of works.	(18,19,33)
Sustainable Public Procurement	Inclusion of environmental criteria in bidding and contracting processes.	Guidance of works and services toward sustainable and innovative practices.	(22,26,34,35)

Table 10 synthesizes the main topics frequently addressed in each ESG dimension, along with the references of the articles that discuss each theme:

Table 10

The three ESG dimensions and the topics commonly addressed within each of them

Dimensions	Frequent Topics	References
Environmental	Energy efficiency, waste management, green infrastructure, renewable energy, environmental indicators, emission reduction, regenerative territorial planning	(1–5,10,11,16–21,25,29–33,36–62)
Social	Community participation, social inclusion, quality of life, health, education, social cohesion, e-participation, social innovation	(13,23–25,27,57,58,63–72)

Governance	Transparency, ethics, accountability, administrative capacity, institutional innovation, public–private partnerships, performance systems, adaptive governance, sustainable procurement	(3,4,11,14,15,22,26–28,34–36,41,54,67,72–81)
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The table of ESG dimensions presented at the end of this chapter synthesizes the main recurring themes in the analyzed literature, allowing a clear visualization of how studies are distributed across the environmental, social, and governance dimensions. It shows that sustainability in public policies results from a balance between actions aimed at environmental protection, promotion of social inclusion, and strengthening of institutional governance. By bringing together the frequent topics and references of each dimension, the table serves as a guide for the subsequent chapters, which will further deepen the discussion of each ESG axis. Thus, this closing section reinforces the importance of an integrated and multidimensional approach, without exhausting the debate, as the issues raised will be detailed and addressed throughout the remainder of the work.

4 DISCUSSION

In this chapter, the main results obtained from the bibliographic analysis of the 69 articles selected for in-depth qualitative analysis are presented and discussed, following the methodological pathway detailed in the previous sections. The discussion is structured to address the three central questions that guide this study:

How has the environmental pillar of ESG been incorporated into public administration policies and practices?

What are the main challenges and barriers to the implementation of environmental criteria in public management?

Which environmental indicators and metrics have been used in studies applied to the public sector?

Based on the qualitative analysis, the aim is to deepen the understanding of the environmental, social, and governance dimensions, highlighting advances, limitations, and opportunities for the consolidation of ESG in public administration. The results presented below directly dialogue with the objectives of the article and contribute to the debate on governmental sustainability, public policies, and institutional innovation.

How has the environmental pillar of ESG been incorporated into public administration policies and practices?

The incorporation of the environmental pillar of ESG in public administration, as evidenced by the analysis of the 69 selected articles, occurs in a gradual and multifaceted manner, reflecting both advances and challenges. The studies show that public

administration has sought to align its policies and practices with ESG environmental principles mainly through the adoption of sustainable criteria in public procurement, the implementation of green infrastructure projects, and low-carbon policies. Initiatives such as the inclusion of environmental requirements in bidding processes, the prioritization of nature-based solutions in urban works, and the promotion of energy efficiency have gained increasing prominence, especially in cities committed to international sustainability goals.

In addition, transparency and environmental governance have been strengthened through the use of digital platforms for monitoring indicators and disclosing environmental data, promoting greater accountability and integrity in public management. The literature also highlights the strategic role of public engineering and urbanization companies, such as RIOURBE, in translating environmental guidelines into concrete practices, particularly in the execution of urban projects and public works.

Another relevant aspect is the effort to develop and adopt environmental frameworks and indicators specific to the public sector, enabling the measurement of environmental performance in governmental policies, programs, and institutions. Composite models, such as DPSIR and IPEEI, have been used to integrate environmental and institutional variables, supporting a more comprehensive assessment of sustainability in public actions.

In summary, the incorporation of the environmental pillar of ESG in public administration is marked by advances in sustainable procurement, innovation in infrastructure, strengthening of environmental governance, and the development of dedicated indicators. However, the process still faces challenges related to the standardization of practices, institutional integration, and adaptation of strategies to local realities—issues that are further explored in the following discussions.

b. What are the main challenges and barriers to the implementation of environmental criteria in public management?

The analysis of the articles reveals that, despite the advances observed in incorporating the environmental pillar of ESG into public administration, significant challenges and barriers persist in consolidating environmental policies based on these criteria. These barriers can be grouped into four major dimensions: normative and methodological; technical and operational; institutional and political; and symbolic and reputational.

In the normative and methodological sphere, the lack of standardization of environmental indicators and divergence among evaluation methodologies stand out, making it difficult to compare results and adopt best practices across different governmental contexts. From a technical and operational perspective, the shortage of teams trained in

environmental assessment and ESG limits the effective implementation of these policies, especially in municipalities with weaker administrative structures.

Institutional and political barriers include administrative discontinuity, resistance from internal actors to the adoption of new procedures, and lack of integration among sectors and levels of government. Symbolic and reputational barriers refer to greenwashing practices and the discursive use of ESG without technical backing, which may compromise the credibility of initiatives and hinder stakeholder engagement.

These challenges are similar to those identified in international contexts such as Malaysia, Italy, and China, where the lack of integrated governance and comparable indicators also undermines the effectiveness of public policies. To overcome them, the literature recommends the creation of regulatory frameworks and binding instruments, strengthening technical and institutional capacity, and expanding transparency and environmental accountability, fostering an organizational culture guided by results and evidence.

c. Which environmental indicators and metrics have been used in studies applied to the public sector?

The reviewed studies identify four major groups of ESG environmental indicators applicable to public management. The first group refers to emissions and energy, including greenhouse gas inventories, energy consumption, and the use of renewable sources. The second group covers natural resources, with indicators related to water quality, land use, and vegetation cover. The third group is related to waste and materials, including metrics for recycling and reuse of construction materials. Finally, the fourth group involves urban and social indicators, such as sustainable mobility, walkability, and air quality.

In addition to these groups, composite models such as DPSIR (Driving Forces, Pressures, State, Impact, Response) and IPEEI (Integrated Ecological Perception Index) have been applied to combine environmental and institutional variables, strengthening the integrated measurement of sustainability in public actions. In the Latin American context, the importance of using indicators adapted to municipal planning is emphasized, aiming to integrate urban policies, public works, and climate goals.

To conclude the results and discussion chapter, it is important to reflect on the main findings and their implications for advancing the ESG agenda in public administration. The analysis of the articles shows that, although there has been significant progress in incorporating the environmental pillar of ESG, the process is still marked by methodological, institutional, and operational challenges. The lack of standardized indicators, fragmentation of evaluation methodologies, and the need for integration among different sectors and levels

of government remain central obstacles to the consolidation of effective environmental policies. In addition, the literature indicates that strengthening environmental governance depends on expanding transparency, technical capacity building, and the adoption of binding frameworks capable of promoting an organizational culture guided by results and evidence.

Another relevant point is the importance of adapting environmental indicators to local realities, especially in the Latin American context, where the specificities of municipal planning and public works require flexible and integrated solutions. The discussion also reveals that the involvement of public engineering and urbanization companies, such as RIOURBE, can be decisive in translating environmental guidelines into concrete and replicable practices.

The comparative analysis between China and European countries reveals marked differences in approaches to environmental ESG in public administration. While China leads in publication volume and focuses strongly on technological innovation, energy efficiency, and climate transition policies, Europe stands out for its emphasis on governance, social participation, and integration of public policies. This difference reflects distinct institutional contexts: greater centralization and state investment in China, and robust regulatory frameworks and multistakeholder participation in Europe. These contrasts highlight opportunities for mutual learning, especially for developing countries such as Brazil, which can adapt best practices from both contexts.

For Brazilian municipalities, the study results point to the need to adapt environmental indicators and international frameworks to local realities, considering resource constraints, technical capacity, and urban specificities. In this context, public engineering and urbanization companies, such as RIOURBE, linked to the City of Rio de Janeiro, can play a strategic role in operationalizing environmental guidelines in public works and urban projects. International experience suggests that the adoption of sustainable public procurement, strengthening of environmental governance, and use of integrated indicators can drive the ESG agenda, provided there is capacity building and sectoral integration. Furthermore, Brazil's low representation in international scientific production reinforces the importance of fostering research and pilot projects in Brazilian cities, promoting innovative and replicable solutions, particularly those led by companies such as RIOURBE.

The study directly contributes to the advancement of public policies by offering a consolidated overview of methodologies, indicators, and innovative practices related to environmental ESG. By mapping international trends and identifying gaps in national literature, the work supports public managers in decision-making, regulatory framework development, and implementation of sustainable projects. The systematization of

frameworks such as DPSIR and IPEEI, along with the analysis of international experiences, provides inputs for the construction of more effective, transparent, and globally aligned sustainability policies.

Finally, the results suggest that the consolidation of ESG in public administration requires a multidimensional approach that articulates the environmental, social, and governance pillars, promoting integration between technical, political, and ethical dimensions of public action. This perspective opens the way for future research focused on the development of integrated frameworks, international comparative analysis, and practical application of ESG indicators in public projects—topics that will be further explored in the conclusions and directions for future work.

5 CONCLUSION AND FUTURE WORK

This study presents the first consolidated systematic review on the environmental pillar of ESG in public administration, covering different types of public bodies and state-owned enterprises. By integrating innovative methodologies and analyzing a robust database of more than 1,200 articles, the research contributes to the advancement of discussions on governmental sustainability and to the consolidation of environmental ESG practices in the Brazilian public sector.

The main gap addressed by this work lies in its focus on the application of environmental ESG in public works and municipal management, a topic that has been scarcely explored in both national and international literature, which has traditionally concentrated on the corporate dimension. By providing practical recommendations and frameworks adapted to the reality of Brazilian public bodies, the study broadens the debate and offers support for managers at different levels of public administration.

Based on the findings, it is recommended that Brazilian public administration bodies adopt environmental frameworks (such as DPSIR and IPEEI), specific indicators, and sustainable public procurement practices to align projects, policies, and administrative processes with environmental requirements and international commitments. It is essential that managers promote technical capacity building among teams, encourage integration between sectors, and seek to adapt international methodologies to local realities, considering urban, institutional, and regional particularities.

In the municipal context, public engineering and urbanization companies, such as RIOURBE, linked to the City of Rio de Janeiro, can play a strategic role in operationalizing environmental guidelines in public works and urban projects. The development of case studies and pilot projects within these organizations is recommended in order to analyze, in

a practical and contextualized manner, the challenges, opportunities, and outcomes of implementing ESG principles in local policies, projects, and administrative processes. Such an approach contributes to the advancement of academic knowledge and may serve as a reference for other Brazilian municipalities interested in adopting sustainable and integrated public management practices.

In this sense, this work directs the research agenda toward the development of in-depth case studies on the applicability of environmental ESG principles in municipal public administration, with particular attention to the experience of public companies such as RIOURBE. The analysis of adapted indicators, institutional integration, and the replicability of innovative solutions will be essential to strengthen the ESG agenda in the Brazilian public sector and will serve as the basis for the master's dissertation topic, expanding the impact of sustainability policies and promoting innovative and replicable solutions in different contexts.

Among the limitations of the study, the low representativeness of Brazilian research in international scientific production stands out, as well as the need for greater integration between sectors and levels of government. In addition, it is noted that the adaptation of international frameworks and indicators to the Brazilian context still requires further development, especially to reflect local specificities and to strengthen the practical application of ESG principles in public administration.

In summary, the results reinforce the importance of a multidimensional and integrated approach to consolidating environmental ESG in the public sector. Future research should further explore the practical application of ESG indicators in urban and administrative projects, expanding the impact of sustainability policies and promoting innovative and replicable solutions across different municipal and institutional realities.

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APPENDIX

Table 11

Ref.	Objective	Methodology	Results
(15,22)	Investigar como classificações externas de áreas desfavorecidas influenciam a formulação de políticas públicas sustentáveis locais na Suécia.	Estudo qualitativo baseado em entrevistas com representantes de governos locais, utilizando análise de conteúdo interpretativa.	Classificações externas limitam políticas locais autênticas. O estudo propõe abordagens mais sensíveis ao território, contribuindo para planejamento sustentável em regiões desfavorecidas.
(22)	Investigar se a contratação pública estimula a inovação em tecnologias de energia renovável nas empresas chinesas.	Estudo quantitativo com modelo de efeitos fixos bidirecional (TWFE), utilizando dados de patentes em energia renovável e registros de compras públicas.	Contratações públicas impulsionam inovação em energia renovável, especialmente em empresas menos politizadas, com baixo estoque de conhecimento, em setores poluentes e regiões pró-mercado.
	Desenvolver um modelo de integração ESG para governos locais, visando equilibrar crescimento econômico, justiça social e preservação ambiental.	Revisão sistemática da literatura sobre práticas ESG em governos locais, com análise crítica de estudos teóricos e casos bem-sucedidos.	A integração dos critérios ESG pode fortalecer a sustentabilidade urbana, melhorar a governança pública e atrair investimentos responsáveis, desde que haja apoio institucional e regulamentação adequada
(21)	Avaliar o impacto da política de cidades-piloto de baixo carbono (LCCP) sobre o desempenho ESG das empresas na China.	Estudo quantitativo com modelo de diferenças em diferenças (DID), usando dados corporativos e ambientais para avaliar impactos da política LCCP no desempenho ESG.	A política LCCP melhora significativamente o desempenho ESG das empresas em áreas com alta intensidade de emissões, ao aumentar a pressão ambiental de governos e sociedade; porém, há efeito de de crowding out com empresas localizadas nas cidades vizinhas.
(18)	Avaliar o impacto da política de cidades de demonstração de energia nova (NEDC) sobre o desempenho ESG das empresas na China.	Estudo quantitativo com abordagem de diferenças em diferenças (DID), utilizando a NEDC como experimento quase-natural.	A política NEDC teve efeito positivo significativo no desempenho ESG corporativo, especialmente em grandes empresas e setores de baixo carbono; empresas menores e de setores intensivos em carbono enfrentam desafios adicionais
	Avaliar a sustentabilidade de pequenas centrais hidrelétricas (SHP) nas Montanhas Qin-Ba, na China, sob a perspectiva ESG.	Estudo de caso com três estações SHP, utilizando 18 indicadores ESG e métodos de decisão multicritério: conjuntos linguísticos hesitantes fuzzy (HFLTS) e modelos de nuvem.	Todas as estações apresentaram nível “bom” de sustentabilidade, com maior contribuição da dimensão ambiental (E); indicadores como qualidade da água e manutenção da morfologia fluvial tiveram maior peso na avaliação

(34)	Explorar como comportamentos de liderança ética em organizações públicas influenciam a cultura organizacional e a conformidade com princípios ESG.	Pesquisa quantitativa com 155 servidores públicos na Malásia, utilizando questionário validado e análise com Smart PLS para testar relações entre liderança ética, cultura organizacional e violações de integridade.	A liderança ética reduz violações de integridade e fortalece a adesão aos princípios ESG, embora não tenha sido encontrada relação direta estatisticamente significativa entre cultura ética e conformidade ESG, indicando necessidade de estudos futuros.
(56)	Investigar o comportamento do índice ESG macroeconômico em países produtores de petróleo da OPEP e não-OPEP, e suas implicações para o desenvolvimento sustentável.	Estudo quantitativo com testes avançados de estacionariedade em painel, cobrindo o período de 1990 a 2020.	Nossa pesquisa sugere que os governos devem usar intervenções políticas para neutralizar choques externos ao comportamento macro ESG, de modo a alcançar o desenvolvimento sustentável e a estabilidade do desempenho a longo prazo
(55)	Analisar a regulamentação atual sobre pegada de carbono digital na Indonésia e propor medidas legais para sua redução.	Abordagem normativa e comparativa, com análise de políticas nacionais (ENDC, Net Zero Emission 2060) e estudo de práticas internacionais.	A pesquisa propõe a criação de regulamentações específicas para reduzir a pegada de carbono digital e exige que empresas elaborem relatórios ESG, alinhando-se aos compromissos climáticos da Indonésia até 2045 e 2060
(36)	Avaliar se as divulgações sobre edifícios verdes feitas por empresas na Indonésia estão sendo comunicadas de forma eficaz aos stakeholders.	Estudo quantitativo com análise de conteúdo de 94 observações entre 2020 e 2022, utilizando dados de websites, relatórios anuais e relatórios de sustentabilidade.	Websites lideram a divulgação ESG. Empresas platinum são mais transparentes. O estudo recomenda maior fiscalização e orientação governamental para ampliar práticas de divulgação no setor.
(82)	Investigar como fundos governamentais, especialmente o fundo de seguridade social da China, influenciam o desempenho ESG das empresas.	Estudo quantitativo com dados de 4.251 empresas listadas entre 2009 e 2020, utilizando métodos de Propensity Score Matching (PSM) e diferenças em diferenças empilhadas (stacked DID).	Empresas em fundos governamentais melhoraram no desempenho ESG, especialmente as não estatais. Os fundos promovem reputação e acesso a financiamento sustentável de longo prazo.
(53)	Examinar como as iniciativas ambientais dos governos locais influenciam as práticas de divulgação e investimento ambiental das empresas na China.	Análise textual dos relatórios de trabalho dos governos provinciais chineses, utilizando frequência e variação de palavras-chave ambientais como indicadores de iniciativa governamental.	Iniciativas ambientais moldam a divulgação empresarial, mas pouco influenciam investimentos. O estudo alerta para práticas oportunistas e recomenda estratégias eficazes para estimular ações ambientais reais.
	Propor um modelo de relatório ESG para governos, especialmente no contexto de cidades inteligentes, e explorar como dados urbanos podem apoiar essa prática.	Utiliza abordagem qualitativa e exploratória, com exemplo prático de dados de mobilidade de Nova York para ilustrar como tecnologias urbanas podem apoiar práticas de sustentabilidade pública.	Tecnologias urbanas, como big data e sensores, ampliam a transparência e eficácia na gestão pública, permitindo monitoramento e divulgação avançada de indicadores ESG.

	Investigar se a implementação de compras públicas sustentáveis (SPP) na China influencia positivamente o desempenho ESG das empresas.	Estudo quantitativo com regressão linear e testes de robustez, cruzando dados de 42.369 projetos públicos e 20.125 empresas para avaliar desempenho ESG.	A SPP melhora o desempenho ESG corporativo, especialmente em regiões centrais da China e empresas maduras, com efeitos duradouros e papel estratégico do governo.
	Analisar a relação entre o desenvolvimento do governo eletrônico (e-government) e os fatores ESG (ambientais, sociais e econômicos) em 26 países europeus.	Estudo quantitativo com dados da Eurostat (2003–2020), utilizando TOPSIS, índice de Perkal e método de Hellwig para ordenação e seleção de preditores.	O EGDI correlaciona-se positivamente com indicadores ambientais, sociais e econômicos. Infraestrutura digital e serviços eletrônicos geram benefícios sustentáveis duradouros para a gestão pública.
(83)	Discutir como a Teoria Monetária Moderna (MMT) e as empresas públicas podem contribuir para a sustentabilidade econômica, especialmente no contexto da União Europeia.	Estudo conceitual com análise normativa da MMT e sua aplicação em políticas públicas voltadas à sustentabilidade financeira e ambiental.	A MMT fundamenta a atuação estatal direta via empresas públicas para promover sustentabilidade econômica, suprimindo falhas do setor privado em metas ambientais e sociais.
(20)	Investigar as tendências de pesquisa sobre infraestrutura verde (GI) na Coreia do Sul e internacionalmente, sob a ótica ESG, visando fortalecer políticas públicas sustentáveis.	Revisão sistemática de 98 artigos acadêmicos publicados nos últimos 10 anos, com análise de palavras-chave, temas e funções da infraestrutura verde em conexão com ESG.	A pesquisa aponta foco crescente em sustentabilidade e diversidade ecológica, recomendando ampliar estudos técnicos e sociais para fortalecer a gestão ESG via infraestrutura verde pública.
(11)	Analisar os desafios de governança dos conselhos locais na Austrália e os impactos da Lei de Governo Local de 2020 na gestão pública municipal.	Estudo qualitativo e exploratório com análise documental de relatórios do VAGO e revisão de literatura sobre ESG, ética, cultura organizacional e governança pública.	Conselhos locais enfrentam falhas éticas e de transparência. O estudo propõe práticas ESG e inclusão comunitária como pilares para governança pública sustentável e responsável.
(84)	Avaliar os benefícios de investimentos públicos em edifícios inteligentes voltados para instalações esportivas comunitárias, no contexto da sustentabilidade urbana.	Estudo de caso comparativo entre um centro esportivo inteligente e um tradicional em New Taipei City, Taiwan, medindo externalidades positivas por meio da disposição a pagar por residências próximas.	Instalações esportivas em edifícios inteligentes geram valorização imobiliária e acessibilidade, justificando investimentos públicos sustentáveis mesmo sob restrições orçamentárias, devido às externalidades positivas geradas.
(52)	Analisar o desenvolvimento do eixo urbano Bistrița–Beclean na Romênia, destacando sua conformação espacial como vetor de transição para a sustentabilidade urbana regional.	Estudo de caso comparativo com modelagem espacial urbana, análise histórica e uso de GIS, Vertical Mix e rede em estrela para diagnosticar e estruturar territórios sustentáveis.	A transformação urbana sustentável exige articulação entre infraestrutura verde, planejamento espacial e cultura local, com foco em qualidade de vida e integração cidade–subúrbio via eixo geográfico.
(51)	Avaliar o envolvimento da comunidade no desenvolvimento de infraestrutura pública em Yewa South, Ogun State, Nigéria.	Estudo transversal com amostragem aleatória e múltiplas etapas. Aplicou questionários a 195 moradores e analisou correlações entre participação comunitária e infraestrutura rural sustentável via SPSS.	A participação comunitária fortalece a sustentabilidade dos projetos, mobiliza recursos e garante continuidade. Recomenda-se ampliar orientação local e aprimorar a gestão para acelerar o desenvolvimento.

(59)	Investigar os padrões de apropriação do espaço em áreas verdes urbanas (UGSs) em Xangai, considerando seu papel na sustentabilidade e coesão social.	Estudo de métodos mistos com mapeamento comportamental, observações qualitativas e análise estatística em três parques urbanos, focando apropriação do espaço e padrões de uso.	Identificaram-se 60 atividades em parques urbanos de Xangai. A apropriação foi moderada, com vitalidade ligada à diversidade. Espaços verdes demandam melhor design e gestão.
	Investigar se os atrasos em projetos públicos de infraestrutura afetam negativamente o desenvolvimento sustentável das comunidades.	Estudo quantitativo com survey de 325 especialistas da construção no Paquistão, usando PLS-SEM para analisar seis fatores de atraso e impacto no desenvolvimento sustentável.	Atrasos em projetos públicos afetam educação, saúde e qualidade de vida. O modelo confirma impacto direto e recomenda planejamento estratégico focado em sustentabilidade comunitária.
(77)	Identificar medidas gerenciais críticas para mitigar riscos financeiros em projetos sustentáveis de Parcerias Público-Privadas (PPPs).	Revisão sistemática da literatura conforme protocolo PRISMA, com análise de 56 artigos acadêmicos relevantes.	Identificaram-se 41 medidas para mitigar riscos financeiros em PPPs sustentáveis. O estudo propõe modelo de maturidade e recomenda foco em riscos climáticos e sanitários.
(33)	Analisar como a gestão energética contribui para cidades verdes, integrando estratégias sustentáveis em diferentes domínios do planejamento urbano.	Revisão sistemática de literatura interdisciplinar entre 2000 e 2021, cobrindo sete áreas do planejamento urbano sustentável.	Gestão energética eficiente é essencial para descarbonização urbana, exigindo políticas integradas, planejamento estratégico e monitoramento contínuo.
	Analisar os efeitos da microrrenovação urbana em Wuhan, considerando o valor posicional dos bairros e seus impactos sociais e espaciais.	Estudo de caso com entrevistas, análise espacial, e aplicação dos métodos AHP e FCE para avaliar impactos urbanos e percepção comunitária.	Microrrenovações elevam valor posicional, promovem inclusão social e melhoram qualidade urbana quando adaptadas ao contexto local e às necessidades da comunidade.
	Revisar modelos de economia circular aplicados a infraestrutura em parcerias público-privadas (PPP), identificando fatores críticos para o sucesso sustentável desses projetos.	Revisão de literatura com análise temática de estudos sobre economia circular e PPPs, destacando práticas sustentáveis e critérios de desempenho.	Fatores como gestão eficaz, financiamento, materiais de baixo carbono, cadeia de suprimentos e estratégias de aquisição facilitam a implementação da economia circular em PPPs.
(85)	Propor uma estrutura integrada para melhorar sustentabilidade e resiliência de infraestrutura pública frente aos riscos das mudanças climáticas.	Revisão crítica das práticas atuais e proposta de um modelo que combina estratégias de mitigação e adaptação com métodos de pensamento de ciclo de vida: LCP, LCA, LCCA e S-LCA.	A estrutura combina mitigação e adaptação climática, apoiando decisões sustentáveis em projetos públicos com foco em segurança, equidade e conservação ambiental.
(50)	Analisar como governos locais da África Austral financiam infraestrutura pública e os impactos sobre sua sustentabilidade financeira.	Revisão de literatura e análise de dados financeiros, com foco em práticas de financiamento, gestão fiscal e implicações para governos locais.	Gestão eficaz, financiamento adequado e alinhamento com metas sustentáveis facilitam a sustentabilidade fiscal em projetos públicos de infraestrutura.
(65)	Investigar como o marketing social voltado ao anticonsumo pode apoiar políticas públicas na promoção dos Objetivos de Desenvolvimento Sustentável (ODS).	Revisão sistemática de 42 artigos científicos, com análise temática multinível sobre anticonsumo, políticas públicas e stakeholders envolvidos.	O anticonsumo promove mudanças comportamentais e sistêmicas, exigindo políticas participativas, transparência e articulação entre governos, mídia, empresas e cidadãos para alcançar metas sustentáveis.

(16)	Investigar práticas de coleta de dados ambientais em contextos urbanos por meio do urbanismo participativo, com foco na qualidade dos espaços públicos.	Análise de melhores práticas envolvendo sensores fixos e iniciativas participativas em cidades como Viena; estudo qualitativo com foco em redes densas de sensores e envolvimento cidadão.	Práticas participativas ampliam a coleta de dados ambientais, promovem transparência e fortalecem decisões municipais alinhadas à sustentabilidade e ao engajamento comunitário.
(49)	Propor uma plataforma cognitiva digital pública para apoiar decisões urbanas inteligentes, sustentáveis e resilientes em cidades de diferentes escalas, com estudo em Semarang.	Desenvolvimento de arquitetura digital com IA, análise de anomalias urbanas, integração de dados urbanos e avaliação empírica da plataforma em contexto municipal.	A plataforma melhora decisões públicas, detecta anomalias urbanas, promove engajamento cidadão e fortalece a resiliência e sustentabilidade urbana por meio de inteligência proativa.
(48)	Explorar os desafios e soluções para garantir a segurança da infraestrutura de Internet das Coisas (IoT) em cidades inteligentes.	Revisão técnica e conceitual sobre riscos cibernéticos em IoT urbano, com propostas de frameworks baseados em blockchain, machine learning e criptografia.	Infraestruturas seguras de IoT exigem colaboração entre governo, indústria e sociedade, além de adaptação contínua para enfrentar ameaças emergentes em ambientes urbanos inteligentes.
(86)	Avaliar a caminhabilidade dos bairros de Sofia, Bulgária, com base no conceito da cidade de 15 minutos, relacionando acessibilidade urbana com sustentabilidade.	Aplicação de um Índice de Acessibilidade baseado em 4000 Pontos de Interesse (POIs), com uso de métricas de diversidade (índices de Shannon e Simpson) e análise espacial via GIS.	Bairros planejados mostraram alta diversidade e acesso a serviços essenciais, enquanto áreas novas revelaram lacunas. O estudo destaca o papel do design urbano na mobilidade, saúde e coesão.
(14)	Examinar criticamente o papel das parcerias público-privadas (PPPs) no desenvolvimento sustentável de infraestrutura em Gana, propondo recomendações estratégicas.	Revisão sistemática da literatura sobre PPPs em infraestrutura ganesa, com análise de fatores críticos de sucesso, desafios e práticas sustentáveis.	Estudos concentram-se em temas dominantes, mas há lacunas críticas em clima, energia e finanças. Recomenda-se ampliar pesquisas e orientar gestores para sustentabilidade em PPPs.
(17)	Investigar a relação de longo prazo entre capital público, crescimento econômico e consumo de energia renovável e não renovável em 48 países.	Modelo econométrico PMG (grupo de média agrupada) aplicado a dados de painel, avaliando relações de longo prazo entre capital público, energia e crescimento.	Capital público impulsiona o crescimento, mas eleva o consumo de energia não renovável. Recomenda-se integrar políticas energéticas sustentáveis à gestão fiscal para mitigar impactos ambientais.
	Analisar como requisitos de aquisição pública podem ser projetados e aplicados para reduzir emissões de carbono em infraestrutura pública na Austrália, Suécia, Reino Unido, EUA e Países Baixos.	Estudo comparativo com análise documental e entrevistas sobre práticas de contratação pública sustentável em cinco países líderes em infraestrutura.	Requisitos eficazes incluem metas claras, métricas verificáveis e engajamento com fornecedores. Estratégias variam conforme contexto institucional, modelo de entrega e maturidade do mercado.
	Avaliar a eficácia do programa Portugal 2020 na melhoria da eficiência energética de infraestruturas públicas e seu alinhamento com o modelo Triple Bottom Line (TBL).	Análise documental e quantitativa das propostas submetidas por municípios portugueses, com foco em investimentos em energia renovável, iluminação pública e edifícios públicos.	Apenas 46% dos municípios aprovaram projetos; 4,2% dos recursos foram destinados a edifícios públicos. Falta equilíbrio entre dimensões ambiental, social e econômica.

	Propor um modelo adaptativo de infraestrutura inteligente que integre tecnologias digitais à gestão urbana, respeitando contextos locais e promovendo sustentabilidade econômica.	Estudo conceitual com revisão de iniciativas de cidades inteligentes e proposta de um modelo baseado em Master Data Management (MDM), integrando IoT, big data e plataformas em nuvem.	Infraestruturas inteligentes exigem adaptação institucional e cultural. O modelo MDM mostrou potencial para melhorar eficiência, segurança e resiliência urbana com base em dados integrados.
(28)	Investigar se a informação contábil melhora a compreensão e a tomada de decisão sobre ativos de infraestrutura pública nos governos locais da Nova Zelândia.	Estudo empírico com entrevistas e análise documental em conselhos locais, avaliando o uso da contabilidade patrimonial na gestão de ativos públicos.	A contabilidade pública aumenta a transparência, mas favorece ativos visíveis. Isso compromete ativos invisíveis, exigindo políticas que equilibrem visibilidade e relevância estrutural para sustentabilidade.
(47)	Propor um novo método para definir requisitos de proteção populacional no planejamento territorial, com foco na segurança urbana na República Tcheca.	Análise comparativa internacional, indução e dedução de dados normativos, seguida da proposição e aplicação de um novo método de ordenamento territorial voltado à proteção civil.	O novo método reduz ambiguidades normativas, define requisitos gerais e específicos por risco territorial, e fortalece segurança e sustentabilidade no planejamento urbano da República Tcheca.
	Investigar como a modernização da infraestrutura pública, aliada à hospitalidade urbana, pode impulsionar o desenvolvimento sustentável das cidades ucranianas.	Estudo de caso com análise documental e indicadores urbanos, focando políticas públicas de infraestrutura e práticas de hospitalidade em cidades da Ucrânia.	A modernização conjunta da infraestrutura e hospitalidade melhora sustentabilidade urbana. O estudo propõe PPPs e gestão integrada de recursos para implementar projetos sustentáveis com impacto social positivo.
(24)	Investigar como os espaços públicos contribuem para a sustentabilidade social em assentamentos tradicionais em Kuala Terengganu, Malásia.	Estratégia de métodos mistos: observação direta e aplicação de questionários a 400 residentes para identificar os elementos mais valorizados da infraestrutura pública.	Moradores valorizam comodidades adequadas, espaços públicos multifuncionais e acessíveis. Tais espaços fortalecem comunidade, preservam patrimônio cultural e promovem coesão social em assentamentos tradicionais.
(76)	Avaliar como os marcos constitucionais, legais e políticos do Zimbábue influenciam a adoção de PPPs por autoridades locais urbanas para alcançar o ODS 11.	Análise jurídica e institucional dos frameworks nacionais, com foco na capacidade das autoridades locais de implementar PPPs para infraestrutura urbana.	Apesar das restrições fiscais, PPPs têm alto potencial para sustentabilidade urbana. Requerem marcos legais mais específicos e cidades inclusivas, seguras e resilientes para serem eficazes.
(23)	Desenvolver um modelo conceitual que relacione infraestrutura social com qualidade de vida, como base para a sustentabilidade social no ambiente construído.	Pesquisa documental com revisão crítica multidisciplinar (sociologia urbana, políticas habitacionais, infraestrutura pública), categorização conceitual e construção de rede teórica sobre sustentabilidade social no ambiente construído.	O estudo propõe um modelo conceitual que conecta infraestrutura social à qualidade de vida, destacando vínculos entre ambiente construído, inclusão, saúde e bem-estar urbano.

(66)	Avaliar o impacto dos fatores de sustentabilidade na determinação dos gastos públicos em 26 países africanos.	Aplicação de múltiplos métodos econométricos robustos: Mean Group (MG), Feasible Generalised Least Squares (FGLS), Generalised Linear Mixed Effects Model (GLMM) e o inovador Method of Moments Quantile Regression (MMQREG), com dados de 1990 a 2022.	Fatores sociais ganham protagonismo nos gastos públicos, superando os ambientais e econômicos. O estudo recomenda abordagem abrangente de sustentabilidade, ajustada ao perfil fiscal de cada país.
	Comparar os impactos de CO ₂ , pegada ecológica e fator de capacidade de carga na Tailândia, testando a validade da hipótese do paraíso poluidor (PHH).	Aplicação do teste de causalidade quantilica de Fourier com dados trimestrais (1975–2018), considerando variáveis econômicas e ambientais como energia renovável e investimento estrangeiro direto.	A hipótese do paraíso poluidor é válida para CO ₂ e capacidade de carga, mas não para pegada ecológica. Energia renovável melhora a qualidade ambiental.
(25)	Propor estratégias ecológicas para promover a sustentabilidade de comunidades rurais na China, com base em estudos de caso e indicadores ambientais.	Pesquisa longitudinal na comunidade rural ecológica Yanhe, com sistema de avaliação ambiental baseado em indicadores criativos: RES, PES e NES.	O estudo propõe estratégias ecológicas focadas em água, resíduos e energia renovável. Recomenda otimizar sistemas limpos, melhorar ambientes hídricos e ampliar participação comunitária sustentável.
	Estimar a pegada ambiental da comunidade urbana de Bath e North East Somerset (BANES), Reino Unido, e avaliar sua sustentabilidade em relação à biocapacidade local.	Estudo de caso com análise de fluxos materiais, consumo energético e uso da terra, integrando dados locais e regionais com indicadores de sustentabilidade ecológica.	A pegada urbana excede a capacidade da biorregião. O estudo recomenda planejamento territorial regenerativo, redução de consumo e articulação entre escalas urbana e ecológica.
(37)	Desenvolver um sistema de apoio à decisão ambiental (EDSS-SSCI) para orientar e avaliar o desempenho das cidades inteligentes sustentáveis na Índia.	Análise documental das diretrizes da Missão Cidades Inteligentes do governo indiano, cruzada com critérios do World Bank Environment Development (WBED) e City Key Indicators.	O estudo valida 24 indicadores ambientais para o framework EDSS-SSCI, integrando parâmetros oficiais, literatura especializada e recomendações do MoUD, BIS e JICA.
(31)	Avaliar a sustentabilidade ambiental de Xangai por meio de um sistema de indicadores de co-benefícios, considerando sinergias entre políticas de redução de gases de efeito estufa e poluição atmosférica.	Aplicação do framework DPSIR (Driver-Pressure-State-Impact-Response) com 23 indicadores, análise de dados de 2005 a 2018 usando método de entropia e média ponderada para calcular o Co-benefit Index (CBI).	O estudo propõe quatro estratégias: transição energética, reestruturação industrial, investimentos ambientais e cooperação regional para mitigar chuva ácida. Aborda também aplicabilidade e agenda futura.
(32)	Criar e validar o indicador IPEEI para avaliar a sustentabilidade ecológica urbana de forma integrada, considerando água, solo e ar.	Desenvolvimento do IPEEI via modelo DPSIR e associação Domain–Theme–Element, com análise geoespacial baseada em entropia ponderada e classificação Jenks para dados urbanos.	O IPEEI mostrou consistência com o Índice Ecológico e planos locais, validando sua eficácia para orientar políticas públicas sustentáveis em cidades inteligentes.
	Investigar como políticas fiscais e inovação tecnológica podem impulsionar o desenvolvimento sustentável e fortalecer a ação climática em economias emergentes.	Análise de dados em painel de 16 países usando o método Fourier-based ARDL e o teste de causalidade Toda-Yamamoto com frequência única.	Impostos ambientais fortalecem a resiliência climática; proteção de recursos reduz emissões. Tecnologia verde tem efeito limitado. Políticas robustas apoiam os ODS 9 (infraestrutura) e 13 (clima).

(45)	Avaliar o grau de “inteligência urbana” de cidades europeias com base na norma ISO 37120, destacando lacunas nos indicadores ambientais.	Aplicação de métodos estatísticos multivariados (MSA) para analisar dados de cidades que adotaram o padrão ISO 37120, com foco em aspectos sociais, econômicos e ambientais.	Cidades inteligentes contribuem para a sustentabilidade urbana, mas carecem de indicadores ambientais. Estruturas atuais priorizam dimensões sociais e econômicas, revelando lacunas na avaliação ecológica.
	Avaliar como critérios ambientais estão sendo incorporados em licitações públicas de obras civis e identificar os principais fatores que influenciam essa inclusão.	Análise de 343 documentos de licitação de 11 países, usando estatísticas descritivas, técnicas não paramétricas e regressões logísticas para mapear 4.500 instâncias de critérios ambientais.	Nove critérios ambientais e 22 subcritérios foram identificados. Gestão ambiental é o único usado na seleção. Inclusão varia conforme obra, contrato e infraestrutura.
	Investigar como governos locais nos EUA estão avaliando e gerenciando o desempenho de suas iniciativas de sustentabilidade.	Estudo empírico com coleta de dados sobre sistemas de gestão de desempenho ambiental em municípios, análise institucional e categorização de indicadores utilizados.	Governos locais dos EUA adotam avaliações de sustentabilidade, mas enfrentam dificuldades com indicadores e suporte institucional. A maturidade dos sistemas varia, revelando potencial de aprimoramento.
(44)	Analisar a relação entre o PIB e os indicadores ambientais — gastos públicos com proteção ambiental e receitas fiscais verdes — nos países da União Europeia.	Aplicação de análise discriminante e regressão logística, comparando os indicadores espanhóis com os do Financial Trends Monitoring System (FTMS) da ICMA.	Os indicadores ICMA sobre receitas, despesas e dívida classificam corretamente a condição financeira dos municípios espanhóis, validando sua confiabilidade como ferramenta internacional.
(35)	Examinar como os gastos públicos com proteção ambiental e as receitas fiscais verdes influenciam o PIB per capita nos países da União Europeia.	Análise estatística descritiva e modelos de regressão com efeitos fixos, utilizando dados per capita do banco de dados Eurostat para todos os países da UE a partir de 2014.	Gastos ambientais promovem sustentabilidade e crescimento econômico. Já receitas fiscais verdes exigem cautela, pois podem refletir aumento de atividades prejudiciais ao meio ambiente.
(61)	Avaliar o desenvolvimento do setor de gestão de resíduos sólidos urbanos na Jordânia sob a perspectiva do crescimento verde, com foco na meta de redução de 33% até 2025 estabelecida pela Jordan Vision 2025.	Aplicação da ferramenta Sustainability Window para o período de 2010–2015, comparando três cenários: tratamento mecânico-biológico com digestão anaeróbica, tratamento mecânico-biológico com compostagem e incineração.	O modelo atual não atende aos critérios de sustentabilidade. Cenários com tratamento biológico mecânico são mais eficazes, sendo a compostagem a opção mais econômica para mitigação de GEE.
(43)	Avaliar o grau de coordenação entre crescimento econômico e proteção ambiental nas províncias chinesas, visando promover desenvolvimento sustentável regional entre 2013 e 2019.	Aplicação de modelo de acoplamento-coordenação com dados estatísticos provinciais sobre PIB e indicadores ambientais. Análise comparativa regional e temporal para medir equilíbrio entre economia e ecologia.	A coordenação entre economia e meio ambiente melhorou, mas permanece desigual. Regiões mais desenvolvidas apresentam maior equilíbrio; áreas menos desenvolvidas enfrentam desafios estruturais e ambientais.

(12)	Investigar os fatores de gestão pública que influenciam a eficiência no uso de recursos financeiros em municípios da área metropolitana de Monterrey, México.	Revisão de literatura atualizada e aplicação de questionário a 47 servidores públicos. Os dados foram analisados por meio de componentes principais e regressão fuzzy para identificar variáveis não correlacionadas que afetam a eficiência financeira.	Os fatores de controle interno e fiscalização mostraram relação positiva significativa com a eficiência no uso dos recursos financeiros. O estudo reforça a importância da transparência, ética e prestação de contas na administração pública municipal.
(42)	Investigar como gestores públicos lidam com os desafios de participação e restrições administrativas em projetos de regeneração urbana em Reggio Emilia, Itália.	Estudo qualitativo baseado na perspectiva de “estratégia como prática”, com análise de um projeto público de pequena escala em Reggio Emilia, Itália.	Gestores municipais atuam estrategicamente ao equilibrar participação cidadã e restrições institucionais, adotando práticas concretas que viabilizam projetos colaborativos de regeneração urbana.
	Identificar os fatores que limitam o desenho e a formulação de políticas públicas voltadas à conservação de recursos naturais nos governos locais da Amazônia peruana.	Estudo qualitativo com amostragem não probabilística, utilizando entrevistas não estruturadas, grupos focais e análise documental. A análise seguiu o modelo de saturação teórica da grounded theory.	A conservação ambiental é negligenciada por falta de vontade política. Conflitos, corrupção e baixa capacidade decisória comprometem a gestão. Recomenda-se governança participativa e articulação multiescalar.
(73)	Realizar uma revisão sistemática sobre micro-municípios e propor um framework em rede para sua administração eficaz.	Revisão sistemática da literatura sobre administração pública em micro-municípios, com abordagem de análise de redes para identificar os nós de influência, fluxos de autoridade e relações entre atores.	O estudo propõe um framework em rede com liderança responsiva, participação cidadã e articulação multinível, destacando a complexidade e necessidade de governança adaptativa local.
(13)	Avaliar os mecanismos utilizados para melhorar a participação comunitária no processo de Planejamento de Desenvolvimento Integrado (IDP) na África do Sul.	Estudo empírico com abordagem de métodos mistos, realizado na municipalidade de Tzaneen, província de Limpopo. Baseado na teoria da Nova Gestão Pública (NPM), com entrevistas, análise documental e observações.	Mecanismos tradicionais de participação tornaram-se obsoletos após a COVID-19. O estudo recomenda e-participação e tecnologias da 4ª Revolução Industrial para inclusão cidadã efetiva.
(62)	Apresentar múltiplos projetos aplicados em cidades com base no conceito original de Cidade Digital Estratégica (SDC), visando à gestão urbana sustentável.	Revisão sistemática da literatura sobre o modelo SDC, com destaque para 11 teses de doutorado e projetos de ação aplicada.	Os projetos originais aplicados em diversas cidades promovem avanços interdisciplinares em gestão urbana sustentável, fortalecendo inovação pública e estudos urbanos com foco democrático e estratégico.
	Investigar como governos locais integram os ODS em suas estratégias, destacando o papel da capacidade administrativa na implementação de políticas sustentáveis.	Abordagem configuracional com fsQCA aplicada a 44 municípios italianos, identificando combinações de fatores que favorecem a integração eficaz dos Objetivos de Desenvolvimento Sustentável.	Capacidade administrativa, estabilidade política e sistemas de desempenho são cruciais para localizar os ODS. Arranjos internos diversos geram caminhos alternativos para cidades mais sustentáveis.

	Investigar a aplicação de critérios ESG na gestão municipal, considerando os municípios como unidades sociais voltadas à promoção da sustentabilidade local.	Abordagem qualitativa com síntese, comparação e análise financeira. Critérios ESG foram adaptados e aplicados a municípios de Beskydy, agrupados por classificação ESG.	Critérios ESG funcionam como indicadores de sustentabilidade municipal. O estudo propõe melhorias na gestão local e sugere novas pesquisas sobre ESG no setor público.
	Identificar o papel de entidades públicas e autoridades locais na implementação de práticas sustentáveis e os indicadores utilizados para avaliar seu desempenho institucional.	Revisão bibliográfica com Proknow-C e construção de modelo avaliativo baseado na metodologia Multicritério de Apoio à Decisão Construtivista (MCDA-C).	A administração municipal prioriza a dimensão social da sustentabilidade. O modelo proposto é replicável, permitindo identificar padrões decisórios em diferentes contextos locais.

PEPPER FRUIT YIELD UNDER DIFFERENT FERTILIZER RATES IN REGIONS OF THE AMAZON

PRODUTIVIDADE DE FRUTOS DE PIMENTA SOB DIFERENTES DOSES DE FERTILIZANTES EM REGIÕES DA AMAZÔNIA

RENDIMIENTO DE FRUTOS DE PIMIENTO BAJO DIFERENTES DOSIS DE FERTILIZANTES EN REGIONES DE LA AMAZONÍA



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ABSTRACT

The municipality of Amajari is located in the northern region of Roraima, 156 km from the capital Boa Vista, and has 13,927 inhabitants. Rural producers use rudimentary techniques, do not receive training or incentives, and are not part of projects from public agencies. Thus, the adoption of public policies and technical support is essential to provide assistance to small-scale rural producers (MEGIDO, 2020). The objective was to evaluate pepper fruit yield under different fertilizer rates in regions of the Amazon. Under the studied conditions, it was observed that treatment A (300 kg/ha P_2O_5 and 240 kg/ha K_2O) provided the greatest increase in fresh and dry mass of pepper fruits, measured in grams.

Keywords: Family Farming. Capsicum. Vegetable Crop.

RESUMO

O município de Amajari, localiza-se ao norte de Roraima, a 156 km da capital Boa Vista possui 13.927 habitantes. Os produtores rurais usam técnicas rudimentares, não recebem capacitações, incentivos e nem fazem parte de projetos de órgãos públicos. Assim, é fundamental a adoção de políticas públicas e assessoria no sentido de fornecer assistência ao pequeno produtor rural (MEGIDO, 2020). Objetivou-se avaliar a produção de frutos de pimenta em diferentes doses de adubação regiões da Amazônia. Nas condições estudadas, observamos que o tratamento A (300 kg/ha P_2O_5 e 240 kg/ha K_2O) foi o que proporcionou maior incremento na massa da matéria fresca e seca de frutos de pimenta em gramas.

Palavras-chave: Agricultura Família. Capsicum. Hortaliça.

RESUMEN

El municipio de Amajari se ubica en el norte del estado de Roraima, a 156 km de la capital Boa Vista, y cuenta con 13.927 habitantes. Los productores rurales utilizan técnicas rudimentarias, no reciben capacitación ni incentivos, y no forman parte de proyectos de

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organismos públicos. Por lo tanto, es fundamental la adopción de políticas públicas y asesoría técnica para brindar apoyo al pequeño productor rural (MEGIDO, 2020). El objetivo fue evaluar el rendimiento de frutos de pimiento bajo diferentes dosis de fertilización en regiones de la Amazonía. En las condiciones estudiadas, se observó que el tratamiento A (300 kg/ha de P_2O_5 y 240 kg/ha de K_2O) fue el que proporcionó el mayor incremento en la masa fresca y seca de los frutos de pimiento, expresada en gramos.

Palabras clave: Agricultura Familiar. Capsicum. Hortaliza.

1 INTRODUCTION

In Brazil, according to data from the 2017 Agricultural Census (IBGE, 2017), chili pepper production totaled 28,270 tons and generated revenue of R\$ 98,561,000. Embrapa researchers dedicated exclusively to chili pepper research estimated total production at 280,000 tons (across an annual cultivated area of 13,000 hectares) and an annual market value of US\$ 80 million. In other words, much higher. However, it is believed that even these figures are underestimated, as there is great difficulty in obtaining reliable statistical data on chili peppers, given that production is extremely fragmented and, almost always, is not the primary activity of the agricultural establishment (RIBEIRO et al., 2017).

“Brazilian family farming plays a major role in the Brazilian economy and serves as the economic foundation for 90% of Brazilian municipalities with up to 20,000 inhabitants, providing income for 40% of the economically active population” (SANTOS, 2021, p. 7). Pepper cultivation in Brazil has been expanding in recent years due to growing demand from domestic and international markets, leading to an expansion of cultivated area in several Brazilian states, primarily through family farming (OLIVEIRA et al., 2019).

The municipality of Amajari is located in the northern region of the state, 156 km from the capital, Boa Vista, and has a population of 13,927 (IBGE, 2022). Rural producers use rudimentary techniques, receive no training or incentives, and are not involved in public agency projects. Thus, it is essential to adopt public policies and provide advisory services to assist small-scale rural farmers (MEGIDO, 2020). The objective was to evaluate chili pepper production under different fertilizer application rates in regions of the Amazon.

2 METHODOLOGIES

The experiment was conducted from September 2024 to September 2025 in the municipality of Amajari, Roraima (RR), at latitude 03°39'11" North, longitude 61°22'17" West, altitude 100 meters, Koppen-Geiger climate: Humid Equatorial (Af), on the grounds of the Federal Institute of Roraima – Amajari Campus.

The soil in the experimental area was a previously cultivated dystrophic Yellow Latosol (LAd), with a sandy texture and gentle topography. Chemical analysis of the soil sample from the area used, collected from a depth of 0–0.20 m, was performed at the soil laboratory of the IFRR Novo Paraíso Campus, with the following results: pH in H₂O 5.62; P and K (on Mehlich 1) 2.04 and 28 mg/dm³, respectively; Ca²⁺ + Mg²⁺ and Al³⁺ (in KCl) 2.3 and 4.05 Cmolc/dm³ respectively; H+Al (in calcium acetate) 2.06 Cmolc/dm³. The cultivated species was *Capsicum frutescens* – hot pepper, of the Solanaceae family.

The experiment, consisting of four treatments and five replicates, was as follows: A – 300 kg/ha (P_2O_5) and 240 kg/ha (K_2O); B – 300 kg/ha (P_2O_5) and 120 kg/ha (K_2O); C – 150 kg/ha (P_2O_5) and 240 kg/ha (K_2O); and D – 150 kg/ha (P_2O_5) and 120 kg/ha (K_2O), totaling 20 plots. Fifty kilograms per hectare of limestone filler were applied, with two plants grown per 5-kg pot. Harvesting took place eight months after planting, and the following were evaluated: fresh fruit mass (FFM), dry fruit mass (DFM), dry mass of the aerial part (DMA) and dry mass of the root (DMR), and the ratio of dry mass of the aerial part to dry mass of the root (DMA/DMR).

The experiment was set up using a completely randomized design, and the results were subjected to analysis of variance at the 1% significance level using the F-test; Tukey's test was applied at the 5% significance level in cases where the F-test indicated significant treatment effects. The statistical software R was used for data analysis.

3 RESULTS AND DISCUSSION

Table 1 shows that all variables analyzed—including fresh weight and dry weight of fruit, dry weight of the aboveground biomass, and dry weight of the roots—were influenced by fertilization at the 1% significance level according to the F-test. However, the ratio of dry weight of the aboveground biomass to dry weight of the roots did not show a significant effect according to the F-test.

Table 1

Summary of the analysis of variance for fresh fruit mass (FFM), dry fruit mass (DFM), dry mass of the aerial parts (DMA), and dry root mass (DRM) of chili peppers grown under 4 different fertilizer combinations (P_2O_5 and K_2O)

		FFM	DFM	DMA	DMR	DAM/DMR
	Gl	-----Medium square-----				
Treatment	3	725,12**	224,85**	249,92**	192,32**	0,1086 ^{NS}
Error	16	20,57	2,95	2,75	5,12	0,0382
c.v.(%)		13,81	11,64	8,84	16,71	13,47
General average		32,85	14,75	18,75	13,55	1,45

Source: FIDELIS and RAMOS (2025). ** Significant at the 1% probability level according to the F-test; NS: not significant.

Table 2 shows that fertilizer application rates of 300 kg/ha of P_2O_5 and 240 kg/ha of K_2O resulted in the greatest increases in fresh and dry fruit weight under the conditions studied. According to Embrapa (2008, cited in Alcântara and Ribeiro, p. 85), “Most bulletins do not include recommendations for chili pepper cultivation.” The authors “therefore suggest following the recommendations for bell pepper cultivation, which is similar to chili pepper

cultivation.” According to the study by the 5th Approximation (1999, cited in Casali and Fontes, p. 181), “for bell peppers, when there is low availability of phosphorus and potassium in the soil, doses of 300 and 240 kg/ha of P_2O_5 and K_2O ” respectively are recommended, corroborating the findings here.

Table 2

Mean fresh fruit mass (FFM), dry fruit mass (DFM), dry mass of the aerial parts (DMA), and dry root mass (DMR) of chili peppers in grams after 8 months of cultivation under different fertilization treatments

Treatment	FFM	DFM	DMA	DMR
A - 300 kg/ha P_2O_5 e 240 k/ha K_2O	48,40 a	23,60 a	26,80 a	20,80 a
B - 300 kg/ha P_2O_5 e 120 k/ha K_2O	32,00 b	15,60 b	22,40 b	16,60 b
C - 150 kg/ha P_2O_5 e 240 k/ha K_2O	32,00 b	12,00 b	14,20 c	9,60 c
D - 150 kg/ha P_2O_5 e 120 k/ha K_2O	19,00 c	7,80 c	11,60 c	7,20 c

Source: FIDELIS and RAMOS (2025). Means followed by the same letter in the columns do not differ from one another at the 5% significance level according to Tukey's test.

4 CONCLUSIONS

Under the conditions studied, we observed that treatment A (300 kg/ha P_2O_5 and 240 kg/ha K_2O) resulted in the greatest increase in the fresh and dry mass of chili pepper fruits in grams.

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ECOTOXICITY ASSESSMENT OF ALLIUM CEPA IN A WATER TREATMENT SYSTEM CONTAMINATED WITH BTEX

AVALIAÇÃO DE ECOTOXICIDADE EM ALLIUM CEPA EM SISTEMA DE TRATAMENTO DE ÁGUA CONTAMINADA COM BTEX

EVALUACIÓN DE LA ECOTOXICIDAD DE ALLIUM CEPA EN UN SISTEMA DE TRATAMIENTO DE AGUA CONTAMINADO CON BTEX



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ABSTRACT

This study investigated the removal of BTEX compounds from water using a compact device consisting of vacuum suction and an adsorption system with activated carbon and rice husk ash. These were followed by ecotoxicity tests that assessed the root length of *Allium cepa*, considering the raw sample at 100% (BTEX100) and the 50% (BTEX50) and 25% (BTEX25) dilutions. Samples were collected at the following points: A1 – suction well; A2 – vacuum system; A3 – adsorption filter. Three trials were conducted with a total duration of 240 minutes, with sampling at monitoring times of 0 minutes (T0), 120 minutes (T120), and 240 minutes (T240). The results showed removal efficiencies greater than 99% of the concentrations of the compounds studied using the compact device. This decrease is mainly attributed to the vacuum suction process. However, the ecotoxicity tests indicated the need for the adsorption step to reduce the toxicity of the treated water.

Keywords: Groundwater. BTEX. Toxicity. Adsorption. Rice Husk Ash. *Allium Cepa*.

RESUMO

Este trabalho estudou a remoção dos compostos BTEX em água, utilizando equipamento compacto composto por sucção à vácuo, aeração e sistema de adsorção com 50% de carvão ativado e 50% de cinza de casca de arroz. A concentração dos BTEX foi determinada por Cromatografia Gasosa. Os testes de ecotoxicidade avaliaram o comprimento da raiz da *Allium Cepa*, considerando a amostra bruta 100% (BTEX100) e as diluições de 50% (BTEX50) e de 25% (BTEX25). Executaram-se 03 ensaios com duração total de 240 minutos, com amostragens nos tempos de monitoramento de 0 minutos (T0), 120 minutos (T120) e 240 minutos (T240). Os resultados mostraram eficiências de remoção superiores a 99% das concentrações dos compostos BTEX estudados, o que está associado,

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principalmente, ao processo de sucção à vácuo. No entanto, os testes de ecotoxicidade indicaram a necessidade de incluir a etapa de adsorção ao tratamento, visando a redução da toxicidade da água tratada.

Palavras-chave: Água Subterrânea. BTEX. Toxicidade. Adsorção. Cinza da Casca de Arroz. Allium Cepa.

RESUMEN

Este estudio investigó la eliminación de compuestos BTEX del agua mediante un equipo compacto que consta de succión al vacío, aireación y un sistema de adsorción con 50 % de carbón activado y 50 % de ceniza de cáscara de arroz. La concentración de BTEX se determinó por cromatografía de gases. Se realizaron pruebas de ecotoxicidad para evaluar la longitud de la raíz de Allium cepa, considerando la muestra cruda al 100 % (BTEX100) y diluciones al 50 % (BTEX50) y al 25 % (BTEX25). Se llevaron a cabo tres pruebas con una duración total de 240 minutos, con muestreo a los 0 minutos (T0), 120 minutos (T120) y 240 minutos (T240). Los resultados mostraron eficiencias de eliminación superiores al 99 % de las concentraciones de los compuestos BTEX estudiados, lo cual se asocia principalmente al proceso de succión al vacío. Sin embargo, las pruebas de ecotoxicidad indicaron la necesidad de incluir una etapa de adsorción en el proceso de tratamiento, con el fin de reducir la toxicidad del agua tratada.

Palabras clave: Agua Subterránea. BTEX. Toxicidad. Adsorción. Ceniza de Cáscara de Arroz. Allium Cepa.

1 INTRODUCTION

With the increasing number of use, transportation, storage, and disposal of petroleum products, soil and water pollution has become a critical environmental factor resulting from accidents and human activities involving these products (Li et al., 2020).

Gasoline and diesel oil are made up of hydrocarbons derived from petroleum such as the compounds benzene, toluene, ethylbenzene and the isomers (o, m, p) xylenes, also known as BTEX. The presence of BTEX in groundwater comes from fuel leaks in underground storage tanks, located at gas stations, leaks in pipes and spills on surfaces. The severity of these contaminations occurs due to the toxicity of these products that can cause serious environmental and public health problems (Yang et al., 2020; Khudur et al., 2019; Batista, Barros, Bárbara, 2021; Poddar et al., 2022; Flores-Chaparro et al., 2021).

BTEX have a lower density than water, so they form a contamination plume in groundwater and migrate easily with the movement of groundwater and can reach large areas of contamination (Yang et al., 2020). In this way, physical, chemical, and biological remediation techniques are applied for the recovery of contaminated sites (Li et al., 2020).

There are numerous technologies for the remediation of hydrocarbon-contaminated areas. Some treatment methods, such as bioremediation, chemical oxidation, Air Stripping and adsorption have already been employed and have been successful in removing these contaminants in water (Chiu et al., 2017). Caetano et al. (2016) employed a compact groundwater treatment system contaminated with BTEX and Total Petroleum Hydrocarbons (TPH) using vacuum suction system, aerators and adsorption filters. The results showed efficiencies of more than 90% in the removal of compounds. Cardoso, Lodi and Barros (2017) also report efficiency in groundwater treatment using Pump And Treat, Air Sparging, Advanced Oxidation Processes (AOP) and Bioremediation.

The Pump and Treat technique consists of pumping groundwater to the surface and applying other treatment methods, widely applied to volatile organic compounds (VOCs) or semi-volatiles in water. Another frequently used technique is Air Stripping by introducing an air current into contaminated water, promoting the release and transport of these contaminants into the air.

In the adsorption process, the contaminant is transferred from the liquid medium to the surface of the adsorbent material. Activated carbon (CA) is the most widely used due to its sorption properties, hydrophobicity, high surface area, and microporous structure (Ossai et al., 2020). However, due to their high cost of obtainment, difficulty of regeneration and the negative environmental impacts generated in their production, alternative, renewable and

low-cost materials such as industrial and agricultural waste are studied for water and effluent treatment (Foo; Hameed, 2009).

In this scenario, rice husk ash (CCA) is an alternative, an industrial waste usually originated in boilers by use for thermal energy generation. This material has a traditional final destination for dispersion in agricultural soil or industrial landfills, being a source of pollution due to the silica and carbon content in its composition (Camargo et al., 2018; Foo; Hameed, 2009). However, these characteristics allow the recovery of the waste for use as a co-product (Camargo et al., 2018; Foletto et al., 2005).

The use of CCA as an adsorbent in the treatment of water and effluents has been studied. For Foo and Hameed (2009), it has been shown to be a potential alternative adsorbent for wastewater treatment in the removal of organic and inorganic compounds. Kieling, Mendes and Caetano (2018) showed removals between 43% and 100% for effluents contaminated by Chromium VI using CCA as an adsorbent. Schmitt, Kieling, and Caetano (2020) applied CCA for the removal of emerging contaminants in aqueous solution. The research by Gomes et al. (2016), Caetano et al. (2016) and Caetano et al. (2018) showed removals greater than 90% with the use of CCA in the treatment of groundwater contaminated by BTEX and TPH.

In Brazil, the main legislation applicable to contaminated waters and soils is CONAMA Resolution No. 420/2009 (Brasil, 2009). The discharge of effluent into water resources must meet the requirements of CONAMA Resolution No. 430/2011 (Brasil, 2011). In addition to the traditional physical, chemical and biological parameters, the latter addresses the need for ecotoxicity tests to evaluate the toxic action of contaminants. (García-Medina et al., 2020).

For the verification of toxicity in water and effluents, the use of bioindicators stands out as a methodology. *Allium Cepa* (onion) is widely used in this application because it is easily cultivated and costs are low (Caetano et al., 2018).

Fiskesjö (1985) studied the root growth of *Allium cepa* to evaluate the toxicity in effluents. According to the author, the lower the concentrations of contaminants in effluents, the longer the length of the roots. This technique was also adopted in the research of Mazzeo et al. (2010), Caetano et al. (2018), and Kieling, Mendel, and Caetano (2018).

In this context, this research studied the use of a pilot-scale treatment system for the removal of BTEX present in groundwater contaminated by gasoline and diesel oil. The system used was composed of vacuum suction, aeration and adsorption filter with a composition of 50% CA and 50% CCA. The efficiency of the system was evaluated by BTEX removal and by the ecotoxicity test with *Allium Cepa*.

2 METHODOLOGY

2.1 PRESENTATION OF THE PILOT EXPERIMENT

The tests were carried out on a pilot scale (Caetano, 2014), in a remediation system installed at the University of Vale do Rio dos Sinos (UNISINOS). The treatment equipment developed is subdivided into three systems: vacuum treatment, aerators and adsorption filter. Figure 1 shows the equipment used.

Figure 1

Treatment equipment used in the trials



Legend: 1 – Reservoir for mixing water and contaminants; 2 - Suction well; 3 – Booster pump; 4 – Vacuum suction system; 5 – Aerators; 6 – Adsorption Filter; 7 – Treated water reservoir.
Source: Authors (2026)

The description of the equipment components is as follows:

- 1 - 5,000L reservoir for storage of water contaminated with diesel and regular gasoline (R1): rainwater and a mixture of 2.5L of regular gasoline and 2.5L of regular diesel were used to make the contaminated water, simulating groundwater contaminated by leaks at gas stations. The mixture was carried out for 30 minutes through a submerged pump at room temperature.
- 2 – Suction Well (Collection Point A1): a simulation of the soil profile and a suction well installed were carried out. The soil profile was executed inside a 500 mm PVC pipe. It consisted of layers of synthetic soil with horizons A (thickness of 0.2 m), B (thickness of 1.7 m) and C (thickness of 0.1 m). In the middle of the soil profile, a suction well composed of a 50 mm diameter pipe was installed.
- 3, 4 – Suction system (Collection point A2): the pumping process was carried out by suction of the water using a venturi injector. The treatment occurred partly by volatilization of organic compounds by the negative pressure provided (-700 mm Hg) and partly by *Air Stripping*. The gas outlet occurred through the drain at the top of the

equipment and treated by powdered activated carbon adsorption filters. The water flow at this point was about 0.027 L/s.

- 5 – Aerators: diffuse air aeration process (aspiration aerators). The propeller immersed in the liquid created a subpressure by sucking atmospheric air from a groove located at the top. The air diffused into the liquid medium in small bubbles, oxygenating and mixing the liquid mass. The process of removing the VOCs, as well as the suction stage, was by *Air Stripping*, however, with only oxygen ingress. The exit of the gases occurred through the drain at the top of the equipment. The water flow rate in aerator 1 was 0.026 L/s and in aerator 2 was 0.40 L/s.
- 6 – Adsorption Filter (Collection Point A3): water flowed through the mixed column (adsorbents: 50% CA and 50% CCA). The contaminants were adsorbed by the column, treating the water progressively until the filter came out. An adsorbent mass of 33.1 kg of CCA and 29.6 kg of AC was used. Corresponding to an adsorbent volume of 0.034 m³. The water inlet flow was equal to 0.04 L/s and the percolation speed was 0.08 cm/s.
- 7 – 5,000L reservoir for treated water storage (R2): 5,000 liter reserve for treated water.

2.2 CHARACTERIZATION OF ADSORBENT MATERIALS

The characteristics of AC and OKC are presented in Table 1 below.

Table 1

Characteristics of activated carbon (AC) and rice husk ash (CCA)

Parameter	CA Granular	CA Fino	CCA	Characterization methodology
pH	7,10	2,85	8,0	Ng Chilton et al. (2002)
Conductivity (μS/cm)	866,5	1470	81,70	Ng Chilton et al. (2002)
Specific mass (g/cm ³)	1,5135	1,7043	19	ABNT NBR-6508/1984
Grain size (mm)	4,05 - 0,425	0,297 – 0,044	1,70 - 0,053	ASTM D850, 2002
Percentage of loss to fire (%)	86,23	67,49	7,20	ABIFA, 2003

Source: Authors (2026)

The CA used comes from the chemical activation of burnt coconut shells from the supplier in the State of Paraná, Brazil. CCA, on the other hand, is the result of combustion in a boiler of a food company in Rio Grande do Sul, Brazil, which uses rice husk as fuel. The rice husk is automatically fed in a continuous system, with a burning condition of 900°C for 9 minutes. CCA was used in its natural form, without chemical or thermal treatment and was

segregated to improve the uniformity of the material, removing undesirable particles, such as unburned rice husks. Segregation was performed by a sieve shaker (1.2 mm mesh) for 5 minutes.

The chemical analysis (Energy dispersive X-ray Fluorescence Spectrometer, brand EDX 720 HS - Shimadzu) indicates that the major component found in CCA is silicon (85%), showing traces of other elements such as iron, manganese, calcium, potassium and phosphorus. For CA, the inorganic fraction showed silicon, sulfur, iron, copper, calcium, potassium and phosphorus. A higher concentration of potassium was observed, which associated with the alkaline pH of the material, indicates a possible activation with potassium hydroxide.

In the XRD tests (Siemens D5000 diffractometer), it was observed that the gross CCA and the segregated CCA presented the amorphism halo, which corresponds to the deviation from the baseline between the angles of 15° and 30°, indicating the amorphity of the material. According to the peaks presented, the silica of this ash may be present in the form of cristobalite. The CA diffractogram, on the other hand, indicated that the material is amorphous.

An analysis of the microstructure of the CCA (SEM Equipment, Shimadzu SSX-550) demonstrated that the burning is not uniform, resulting in particles with different particle sizes due to temperature and residence time during the combustion process. It was observed that CCA particles are formed by two parts: an external one, formed by a denser structure; the other internal, more porous that indicates the potential of its use as an adsorbent.

The kinetic studies demonstrated that CCA and CA have high and similar adsorption capacities at equilibrium time of 120 minutes. In general, the removal took place in the following order: ethylbenzene > xylene > toluene > benzene. The pseudo-second-order kinetic model (Table 2) showed the best correlation for all trials.

Table 2

Constants for Pseudo-second order for monocompounds

Compound	C0 (mg/L)	CCA				CA			
		QE (mg/g)	K2 (g.min/mg)	H2 (mg/g.min)	R2	QE (mg/g)	K2 (g.min/mg)	H2 (mg/g.min)	R2
Benzene	1	0,0971	8,5804	0,0809	0,9999	0,0984	2,0758	0,0201	0,9989
	5	0,4914	1,0647	0,2571	0,9998	0,5106	0,2880	0,0751	0,9981
	10	0,9739	0,218	0,2068	0,9988	1,047	0,0418	0,0459	0,9804
	20	1,7658	0,1434	0,4473	0,9992	2,1083	0,0156	0,0693	0,9665
Toluene	1	0,0997	15,5431	0,1545	0,9999	0,1005	2,8415	0,0287	0,9994

	5	0,4919	0,9497	0,2298	0,9998	0,4989	0,2523	0,0628	0,9969
	10	0,9706	0,6154	0,5798	0,9999	1,0018	0,1157	0,1162	0,9967
	20	1,8814	0,2737	0,9688	0,9998	2,0759	0,0271	0,1168	0,987
Ethylbenzene	1	0,10005	48,8011	0,4885	0,9999	0,1015	0,1941	0,002	0,9987
	5	0,4967	18,9404	4,6728	0,9999	0,5031	0,4302	0,1089	0,999
	10	0,9964	1,8823	1,8688	0,9999	0,9989	0,2894	0,2888	0,9994
	20	1,9908	0,4864	1,9278	0,9999	2,012	0,1724	0,6979	0,9996
Xylene	1	0,10009	58,1652	0,5827	0,9999	0,1007	1,4989	0,0152	0,9979
	5	0,501	2,8581	0,7174	0,9999	0,5049	0,5962	0,152	0,9996
	10	0,9906	0,7963	0,7814	0,9999	1,0039	0,3043	0,3067	0,9996
	20	1,95	0,1811	0,6889	0,9996	1,9896	0,0776	0,3073	0,9975

Legend: k_2 is the constant of the adsorption velocity (g.min/mg); q_e is the amount adsorbed at equilibrium (mg/g); h is the initial adsorption rate (mg/g.min); R_2 is the correlation coefficient.

Source: Authors (2026)

The experimental isotherms obtained for the monocompounds characterize the adsorption on porous surfaces with monolayer formation. The adjustments to the theoretical models were not unanimous, and in some situations there was an adequate correlation for Langmuir and Freundlich (Table 3).

Table 3

Model parameters for monocompounds

Langmuir model								
Compounds	CCA				CA			
	Qo (mg/g)	KL (L/mg)	RL	R2	Qo (mg/g)	KL (L/mg)	RL	R2
Benzene	13,33	0,1643	0,8762	0,9505	13,51	0,2054	0,8504	0,7675
Toluene	0,7868	14,233	0,2863	0,9387	0,7636	11,299	0,2820	0,9291
Ethylbenzene	0,8795	63,16	0,3134	0,9604	15,97	0,2208	0,9615	0,988
Xylene	1,64	14,89	0,4927	0,9137	3,22	0,853	0,7822	0,9704
Freundlich Model								
Compounds	CCA			CA				
	n	KF (mg/g)(L/mg) ^{1/n}	R2	n	KF (mg/g)(L/mg) ^{1/n}	R2		
Benzene	1,6482	0,9669	0,9204	1,9094	0,9519	0,8458		
Toluene	1,6382	25,351	0,9591	1,569	1,2525	0,924		
Ethylbenzene	1,6866	3,619	0,9942	0,8309	6,1108	0,9616		
Xylene	2,47	1,8736	0,9589	1,2993	1,9023	0,9174		

Legend: Q_0 is the maximum adsorption capacity (mg/g); KL are the adsorbent-adsorbate interaction forces (L/mg); RL is an equilibrium parameter; KF is the distribution of the active adsorption sites (mg/g) (L/mg)^{1/n}; n is the adsorption capacity of the adsorbent.

Source: Authors (2026)

2.3 TESTS FOR EVALUATION OF VACUUM AND ADSORPTION TREATMENT

Before the start of the first sampling, a 1h30min recirculation was carried out in all the equipment to standardize the contaminated water. The supply of the system was continuous during all tests. There were three rehearsals lasting 240 minutes each. The contaminated

water was transferred from the 5,000L reservoir (1) to the suction well (2), as shown in Figure 1. Therefore, the initial BTEX concentration for the three assays and at the three monitored times were different from each other.

The collections were carried out at points A1 - suction well; A2 – vacuum system; A3 – adsorption filter. Sampling was carried out at monitoring times of 0 minutes (T0), 120 minutes (T120) and 240 minutes (T240). For this purpose, 1L amber flasks were used, which were refrigerated between 0°C and 6°C.

For the quantification of contaminants, the samples were transferred to vials with 5mL of saturated NaCl solution, to increase the ionic strength of the solution, enriching the gas phase by reducing the solubility of the hydrocarbons by altering the equilibrium between the phases (Nogueira, 2006).

The concentration of BTEX was determined using a Gas Chromatograph (GC) with Flame Ionization Detector (FID), DANI, with Master DHS Dynamic Headspace of the same brand. The column used was from the brand DANI DN-WAX with the following characteristics: 30 m in length, 0.25 mm in internal diameter, 0.25 µm in film thickness, 40°C lower temperature limit and 250 °C upper temperature limit.

The analysis method was adapted from the methodology proposed by the U.S. Environmental Protection Agency (EPA), method No. 8260C. The adaptation was necessary due to the conditions of the column used, promoting a better quality of the chromatogram.

The samples were automatically injected through a Headspace sampler with an oven temperature of 40°C, with no incubation time and no shaking. The operating conditions used in the CG were: Carrier gas – Nitrogen; flow rate – 0.7 mL/min for 6 minutes, 2mL/min to 1mL/min flow; injector temperature - 200°C; FID detector temperature - 280°C; Split ratio - 1:50; initial temperature of 40°C, isotherm of 1 min, 2°C/min up to 70 °C and 50°C/min up to 220°, for an injected volume of sample of 100 µL. The identification and quantification of substances (BTEX), obtained by the DHS CG-FID, as well as the management of the DHS and CG-FID, were performed with the software for the Windows Clarity™ computer system version 4.0.04.987.

2.4 ECECOTOXICITY TESTS

The ecotoxicity tests were carried out based on the method proposed by Fiskesjö (1985), whose macroscopic evaluative parameter and responsible for the conclusion regarding the toxicity of the effluent corresponds to the length of the root of *Allium Cepa* (common onion) at the end of the tests.

The units of *Allium Cepa* used in the trial were selected by looking for bulbs of small diameters (about 20 to 30mm), dry and with absence of leaves or roots. The outer layers and roots were removed, keeping intact the primordial ring, from which new roots develop. Test tubes were used for the test (ϕ : 2.50cm and h: 15.00cm).

Collection points A1, A2 and A3 were evaluated at the monitoring times T0, T120 and T240. Samples were analyzed with 25% (BTEX25), 50% (BTEX50) and 100% (BTEX100) BTEX solution, and dilutions were performed with drinking water. Five replicates were monitored for each dilution and assay time. Drinking water was used as a negative control sample.

The bulbs of *Allium Cepa* were arranged in contact with the dilutions and taken to the germination chamber at controlled room temperature (+20°C), protected from sunlight, with a photoperiod of 16 hours light and 8 hours dark, for a period of 96 hours.

The volume lost by evaporation or absorption by the bioindicator was replenished once a day with the respective dilutions, stored in a refrigerator at a temperature of +4°C. At the end of the period, five measurements were made referring to the five largest roots in length of each *Allium Cepa* using a common ruler.

Finally, the Relative Control Index (CIR), which relates the length of the roots of the solutions to the control sample, was calculated as presented in Equation 1 and the Inhibition Index (Ii), which represents the resistance to root growth, was calculated according to Equation 2. The normality test was applied to verify whether the data were normally distributed, and for analysis of variance, the ANOVA method and TUKEY analysis were used, considering a confidence level of 95% ($p \leq 0.05$).

$$ICR = \frac{Lm}{Lc} \quad (1)$$

$$Ii = 100 - \left(\frac{Lm}{Lc} \right) \quad (2)$$

Where:

ICR: Relative growth rate (%);

Ii: Inhibition Index (%)

Lm: Average length of the roots of the sample (cm);

Lc: Average length of control roots (drinking water) (cm).

3 RESULTS AND DISCUSSIONS

3.1 INITIAL CONCENTRATION OF BTEX (A1)

The initial concentration of BTEX at the entrance of the system through the suction well, called Sample A1, was evaluated. Table 4 shows the monitoring at times 0, 120 and 240 minutes, considering the means obtained in the three tests performed.

Table 4

Mean initial BTEX concentration (Sample A1) for the three assays performed

Parameter (mg/L)	T0	T120	T240	Average	Standard deviation	Research Level (CONAMA 420/2009)
Benzene	0,422	0,950	1,247	0,873	0,418	0,005
Toluene	1,572	3,894	4,695	3,387	1,622	0,700
Ethylbenzene	0,175	0,381	0,470	0,342	0,151	0,300
P-xylene	1,569	2,593	3,149	2,437	0,801	-
M-Xylene	2,388	4,210	4,993	3,864	1,337	-
O-xylene	3,550	6,197	7,232	5,660	1,899	-
Total Xylene	7,507	12,999	15,373	11,960	4,035	0,500

Source: Authors (2026)

The concentrations of BTEX used are based on studies that monitored the presence of these compounds in contaminated areas. According to the EPA (1997), in the United States, BTEX concentrations ranging from 6 to 24 mg/L are reported. (2000) showed concentrations between 0.024 and 198 mg/L, with monitoring in 49 contaminated areas.

Afferden et al. (2011), in Germany, found initial concentrations of benzene in the order of 13.046 – 18.625 mg/L, toluene between 0.0067 – 0.008 mg/L, ethylbenzene between 0.031 – 0.050 mg/L and xylene between 0.0637 – 0.0825 mg/L. In Austria, Wirthensohn et al. (2009) evaluated contaminated groundwater with BTEX concentrations between 0.295 – 0.806 mg/L. And in Taiwan, Chen et al. (2010) observed BTEX concentrations between 0.0039 – 2.838 mg/L. In Brazil, studies such as the one by Gomes et al. (2014) and Caetano et al. (2016) also cite significant contamination of groundwater by hydrocarbons.

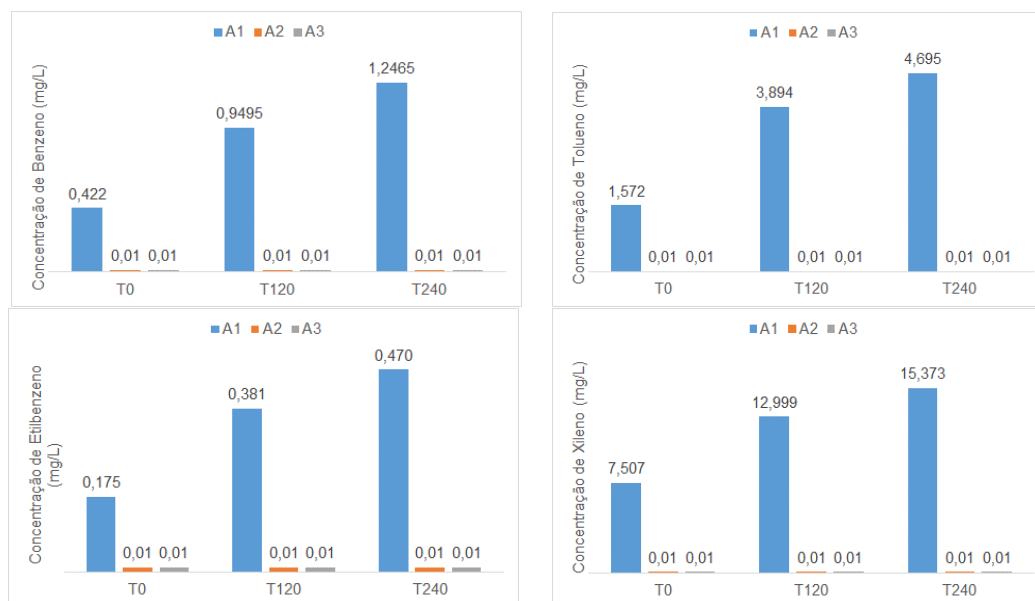
As shown in Table 4, the BTEX concentrations evaluated in the assays are higher than the levels of investigation required by national legislation, in this case, CONAMA Resolution No. 420/2009 (Brasil, 2009). These are values that represent the reality in contaminated areas, meeting the research proposal regarding the evaluation of an efficient treatment system for the removal of volatile hydrocarbons.

3.2 VACUUM SUCTION TREATMENT (A2) AND ADSORPTION (A3)

The mean results of the BTEX concentrations, considering the 3 assays performed, are shown in Figure 2. As the treatment was continuously supplied by contaminated water stored in the 5,000L Reservoir (Figure 1), the initial concentration of raw water was different for each monitored time.

Figure 2

Results of vacuum and adsorption treatment (average of the 03 assays performed) in BTEX



Legend: A1- suction well; A2 – vacuum system; A3 – adsorption filter.

Source: Authors (2026)

Figure 2 demonstrates the efficiency of vacuum suction treatment (A2) with a decrease in BTEX concentrations close to 100%. The results found are more effective compared to those presented by Caetano et al. (2016), in the order of 67.4% for Pilot Scale and 96.66% for Real Scale.

The use of *Air Stripping* or *Air Sparging* to reduce the concentration of VOCs are reported as efficient removal processes. Other studies that have used these technologies have shown levels of reduction in BTEX concentration in the order of 94.25% (EPA, 1997); 99.8%-99.9% (Khan; Husain; Hejazi, 2004), 30%-100% (Juneau Jr; Moyer; O'Connell, 2007), 95%–100% (Wirthensohna et al., 2009), 97%–100% (Afferden et al., 2011), and 100% (Franco; Chairez; Poznyaka; Poznyaka, 2012).

Regarding the treatment by adsorption, the removal of the compounds obtained is consistent with other similar studies, such as the research of Ayotamuno et al. (2006), Wirthensohn et al. (2009), Juneau et al. (2007), Caetano (2014), Gomes et al. (2014), Kieling (2016), and Caetano et al. (2016).

After the treatment performed, the reduction of the concentrations of toluene, ethylbenzene and xylene are sufficient to meet the Level of Investigation provided for by the National Legislation, CONAMA Resolution No. 420/2009 (Brasil, 2009). Regarding benzene, it is not possible to establish a precise conclusion due to the detection limit of the method being 0.01 mg/L and CONAMA 420/2009 reporting the investigation level for this parameter of 0.005 mg/L.

3.3 ECECOTOXICITY TESTS

Root growth was not uniform and, as a result, several units of *Allium Cepa* were used to obtain a more accurate result, as recommended by the methodology of Fiskesjö (1985). For the statistical analysis, all data from Trials 1, 2 and 3 were applied, since they were similar.

The results of root growth are shown in Table 5.

Table 5

Values of the root lengths of the Control (Drinking Water) and BTEX Samples

BTEX	Essay	Time (min.)	Root Growth (cm)					
			Average	A1 Standard Deviation	Average	A2 Standard Deviation	Average	A3 Standard Deviation
Control	1	-	5,3	1,3	5,3	1,3	5,3	1,3
	2	-	2,8	1,1	2,8	1,1	2,8	1,1
	3	-	3,7	1,1	3,7	1,1	3,7	1,1
BTEX25 %	1	0	2,9	1,3	4,3	1,6	2,9	1,4
		120	1,8	1,3	4,2	1,6	1,9	1,4
		240	2,0	1,2	4,0	1,4	2,1	1,6
		Average	2,2	1,3	4,2	1,5	2,4	1,4
	2	0	1,6	1,5	2,4	0,6	2,2	1,1
		120	1,2	0,5	1,2	1,0	3,0	0,5
		240	1,9	1,1	1,1	1,3	2,4	0,8
		Average	1,5	1,1	1,6	1,1	2,6	0,9
	3	0	1,0	1,4	4,2	1,3	3,5	1,3
		120	1,7	0,8	3,8	0,6	3,0	1,0
		240	1,6	1,0	3,7	1,2	3,5	1,0
		Average	1,5	1,1	3,9	1,2	3,5	1,1
BTEX50 %	1	0	2,0	0,9	4,0	1,4	5,0	1,2
		120	1,4	0,7	2,9	1,1	4,3	1,2
		240	1,4	0,9	3,2	0,9	4,0	1,0
		Average	1,6	0,9	3,3	1,1	4,3	1,2
	2	0	0,8	0,5	2,7	0,4	2,5	0,7
		120	0,4	0,2	0,7	0,7	1,6	1,2
		240	0,0	0,2	2,5	1,0	2,7	0,5
		Average	0,3	0,4	2,2	1,1	2,5	1,0
	3	0	1,0	1,1	4,1	1,6	4,3	0,4
		120	0,4	0,3	3,4	0,6	3,5	0,6
		240	0,7	0,3	3,1	0,8	3,6	0,3
		Average	0,7	0,7	3,5	1,1	3,9	0,6
BTEX10 0%	1	0	0,5	1,0	3,9	1,5	4,1	0,9
		120	0,1	0,9	3,3	1,4	4,0	0,7

	240	1,5	0,9	3,3	1,4	3,6	0,7
	Average	0,8	0,9	3,4	1,4	3,8	0,8
2	0	0,3	0,2	2,5	0,6	1,9	0,8
	120	0,2	0,2	2,5	0,9	1,8	0,7
	240	0,0	0,2	2,3	0,6	2,1	0,6
	Average	0,2	0,2	2,5	0,7	2,0	0,7
	0	0,3	0,3	4,3	0,8	4,2	1,3
3	120	0,0	0,2	3,0	0,7	4,8	0,7
	240	0,4	0,3	2,5	0,9	4,0	0,7
	Average	0,3	0,3	3,0	1,1	4,2	1,0

Source: Authors (2026)

The ANOVA and Tuckey tests showed significant differences ($p = 0.000$) between the root growth of the "Control" samples in relation to the BTEX25, BTEX50 and BTEX100 samples.

In the BTEX25 dilution, for the three assays performed and considering the T120 and T240 treatment times, the tests showed that there are no significant differences between the root growth for the A1 x A2 samples (T120 - $p = 0.275$; T240 - $p = 0.365$), A1 x A3 (T120 - $p = 0.210$; T240 - $p = 0.410$) and A2 x A3 (T120 - $p = 0.246$; T240 - $p = 0.294$). This is the same result for T0 comparing treatments A1 x A2 (T0 - $p = 0.882$) and A2 x A3 (T0 - $p = 0.620$). However, the statistical tests showed a significant difference comparing the T0 - A1 x A3 samples ($p = 0.012$) indicating the need for adsorption treatment to reduce ecotoxicity by BTEX, considering the 25% dilution. The efficiency of adsorption treatment using CCA and CA in reducing ecotoxicity (test with *Allium Cepa*) was also obtained by Caetano et al. (2018).

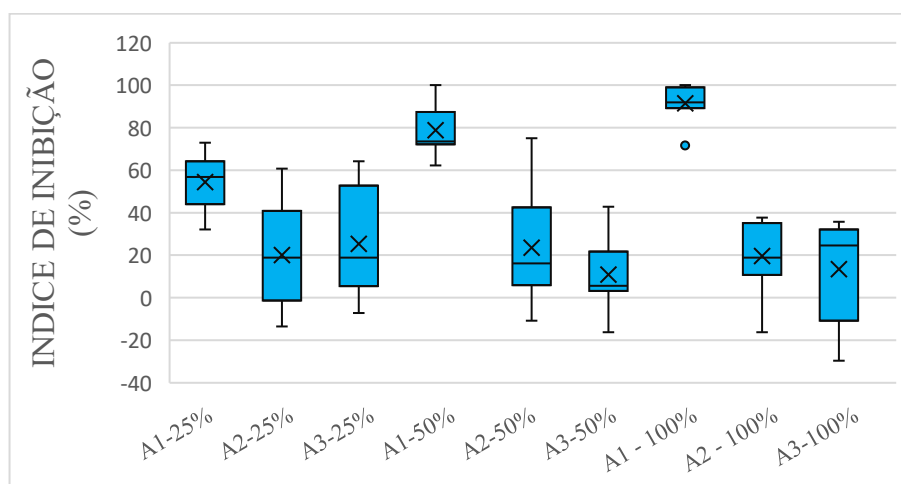
This statement is confirmed by analyzing the BTEX50 dilution. The ANOVA and Tuckey tests showed significant differences for samples A1 x A2 (T120 - $p = 0.000$); A1 x A3 (T120 - $p = 0.011$; T240 - $p = 0.000$); A2 x A3 (T0 - $p = 0.000$; T120 - $p = 0.000$).

Finally, for BTEX100, significant differences were obtained for T120 by comparing samples A1 x A2 ($p = 0.004$) and A2 x A3 ($p = 0.017$). Thus, with a higher concentration of volatiles, the use of vacuum treatment has a significant difference in treatment efficiency, a fact addressed by Caetano et al. (2016).

Figure 3 shows the results of the Mean Inhibition Index of the three toxicity assays, considering the BTEX concentration (25%, 50% and 100%) of the three samples studied (A1, A2 and A3).

Figure 3

Results of the inhibition index (%) in *Allium cepa* from vacuum and adsorption treatment



Source: Authors (2026)

The inhibition index (Ii) obtained indicates the resistance of the growth process that occurs in the roots of *Allium Cepa*. In this sense, the higher the value of Ii, the smaller the size of the roots. The results indicate the highest values of Ii for samples A1 (without treatment), with a decrease in Ii, as the dilution of the BTEX concentration occurs, with sample A1- 100% being the one with the highest inhibition index (91.51%). For the A2 samples (vacuum treatment), the means found for the values of Ii presented approximate values, being 20.01% for 25% of BTEX, 23.58% for 50% of BTEX and 19.59% for 100% of BTEX, indicating that the treatment applied contributes to the reduction of the inhibition index, considering the decrease in relation to the samples of the A1 set. In relation to the A3 samples (adsorption), the mean values for the inhibition index were 25.35% for 25% BTEX, 10.90% for 50% BTEX and 13.43% for 100% BTEX, indicating that the adsorption process can contribute to a greater growth of the roots, considering the decrease observed between the A2 and A3 samples in the concentration of 50% and 100% of BTEX.

In general, the assays contributed to evaluate the toxicity of BTEX in the germination and growth of *Allium Cepa* roots, since quantitative differences were observed in the number of roots and in their length, considering the concentrations of BTEX evaluated. In the work of Mazzeo et al. (2010) it was observed that with the biodegradation of BTEX present in water, there is a reduction in the genotoxic damage of *Allium cepa* cells. These results indicate that *Allium Cepa* is a good indicator of toxicity of water contaminated by BTEX, as well as an efficient means of evaluating the removal of these compounds in the system studied.

4 CONCLUSION

The compact equipment composed of vacuum suction, aeration and adsorption (AC and CCA) proved to be efficient, obtaining high performance for the removal of organic contaminants present in water. The rate of decrease in BTEX concentrations was around 99% in all assays. It was found that the treatment stage "Vacuum Suction" was the main responsible for such efficiency, being essential to meet the level of investigation provided for by the national legislation (CONAMA Resolution No. 420/2009).

Ecotoxicity tests, using *Allium Cepa* as a test organism, confirmed the reduction of the toxicity of contaminated water after suction (A2) and adsorption (A3). In addition, the statistical analyses (ANOVA and Tuckey) indicated the need for polishing the treatment after suction, using the adsorption filter composed of 50%-CCA and 50%-CA. Although most of the BTEX concentration was removed in the "Vacuum Suction" treatment, for the BTEX25 and BTEX50 dilutions, significant differences in toxicity were found comparing the A2 and A3 samples. Reinforcing the need for the adsorption process to reduce the toxicity of contaminated water.

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SELECTIVITY OF THE HERBICIDE DICAMBA (XTENDICAM) APPLIED AT THE TILLERING STAGE OF WHEAT

SELETIVIDADE DO HERBICIDA DICAMBA (XTENDICAM) APLICADO NO PERFILHAMENTO DA CULTURA DO TRIGO

SELECTIVIDAD DEL HERBICIDA DICAMBA (XTENDICAM) APLICADO DURANTE LA ETAPA DE AHIJAMIENTO DEL TRIGO



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ABSTRACT

The use of hormonal herbicides in wheat requires evaluation regarding selectivity, especially for molecules without registered recommendations for this crop. This study aimed to evaluate the effect of different doses of dicamba (Xtendicam) applied at the tillering stage of wheat on phytotoxicity and yield components. The experiment was conducted under field conditions in Verê, Paraná, Brazil, using a randomized complete block design with four replications and five treatments (0; 0.4; 0.6; 0.8; and 1 L ha⁻¹). The evaluated variables included phytotoxicity, plant height, number of tillers, number of grains per spike, thousand-grain weight, dry biomass, and yield. Increasing doses resulted in higher phytotoxicity, reaching 15.5% at 42 days after application at the highest dose, which was considered low and reversible. Reductions were observed in plant height, number of tillers, and number of grains per spike at higher doses. Grain yield was reduced at all doses, with a significant difference at 0.8 L ha⁻¹, showing a reduction of up to 34.9% compared to the control. The number of plants per linear meter, dry biomass, and thousand-grain weight were not affected. The results indicate that, although visual phytotoxicity was low, dicamba negatively affects wheat yield components. The dose of 0.4 L ha⁻¹ showed the lowest impact on the crop and was

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considered the safest under the evaluated conditions.

Keywords: Tillering. Phytotoxicity. Chemical Management. Weeds.

RESUMO

O uso de herbicidas hormonais na cultura do trigo requer avaliação quanto à seletividade, especialmente para moléculas sem recomendação registrada para a cultura. O presente estudo teve como objetivo avaliar o efeito de diferentes doses de dicamba (Xtendicam) aplicadas no perfilhamento do trigo sobre a fitotoxicidade e componentes de rendimento. O experimento foi conduzido a campo no município de Verê-PR, em delineamento de blocos casualizados, com quatro repetições e cinco tratamentos (0; 0,4; 0,6; 0,8 e 1 L ha⁻¹). Foram avaliadas fitotoxicidade, altura de plantas, número de perfilhos, número de grãos por espiga, peso de mil grãos, matéria seca e produtividade. O aumento das doses promoveu elevação da fitotoxicidade, atingindo 15,5% aos 42 dias após aplicação na maior dose, sendo considerada baixa e reversível. Houve redução na altura das plantas, número de perfilhos e número de grãos por espiga nas maiores doses. A produtividade foi reduzida em todas as doses, com diferença significativa na dose de 0,8 L ha⁻¹, apresentando redução de até 34,9% em relação à testemunha. O número de plantas por metro linear, matéria seca e peso de mil grãos não foram afetados. Os resultados indicam que, embora a fitotoxicidade visual seja baixa, o dicamba compromete componentes produtivos do trigo. A dose de 0,4 L ha⁻¹ apresentou menor impacto sobre a cultura, sendo considerada a mais segura nas condições avaliadas.

Palavras-chave: Perfilhamento. Fitotoxicidade. Manejo Químico. Daninhas.

RESUMEN

El uso de herbicidas hormonales en el cultivo de trigo requiere una evaluación de su selectividad, especialmente para moléculas sin recomendaciones registradas para este cultivo. Este estudio tuvo como objetivo evaluar el efecto de diferentes dosis de dicamba (Xtendicam) aplicadas durante el ahijamiento del trigo sobre la fitotoxicidad y los componentes del rendimiento. El experimento se realizó en campo en el municipio de Verê-PR, en un diseño de bloques aleatorizados, con cuatro repeticiones y cinco tratamientos (0; 0.4; 0.6; 0.8 y 1 L ha⁻¹). Se evaluaron la fitotoxicidad, la altura de la planta, el número de tallos, el número de granos por espiga, el peso de mil granos, la materia seca y la productividad. El aumento de las dosis promovió un incremento en la fitotoxicidad, alcanzando el 15.5% 42 días después de la aplicación con la dosis más alta, lo cual se consideró bajo y reversible. Se observó una reducción en la altura de la planta, el número de tallos y el número de granos por espiga con las dosis más altas. La productividad se redujo en todas las dosis, observándose una diferencia significativa con la dosis de 0,8 L ha⁻¹, que mostró una reducción de hasta el 34,9 % respecto al control. El número de plantas por metro lineal, la materia seca y el peso de mil granos no se vieron afectados. Los resultados indican que, si bien la fitotoxicidad visual es baja, el dicamba compromete los componentes productivos del trigo. La dosis de 0,4 L ha⁻¹ presentó el menor impacto en el cultivo, considerándose la más segura en las condiciones evaluadas.

Palabras clave: Ahijamiento. Fitotoxicidad. Manejo Químico. Malezas.

1 INTRODUCTION

According to data from the National Supply Company (2024), for the 2024/2025 harvest, the estimated wheat planted area in the world was 222.2 million hectares, representing a decrease of 0.27% compared to the 2023/2024 harvest.

Weeds represent an important factor of competition in wheat crops. According to Cunha and Caierão (2023), species such as oats (*Avena* spp.), picão-preto (*Bidens* spp.), parsley grass (*Bowlesia incana*), marmalade grass (*Brachiaria plantaginea*), crabgrass (*Digitaria horizontalis*), purpleflower (*Echium plantagineum*), false milkweed (*Emilia sonchifolia*), milkweed (*Sonchus oleraceus*), Viola Tree (*Ipomoea* spp.), ryegrass (*Lolium multiflorum*), turnip (*Raphanus* spp.), white poaia (*Richardia brasiliensis*), as well as volunteer plants of corn (*Zea mays*) and soybean (*Glycine max*). Horseweed (*Conyza* sp.) is *also noteworthy*, which has generated concern due to the difficulty of control with the herbicide 2,4-D.

Weed management involves cultural practices such as choosing the appropriate sowing time, crop rotation, reducing row spacing, and increasing plant density. Mechanical management, such as weeding and uprooting, is mainly used in small areas. However, the use of selective and non-selective herbicides is common. Among the main selective herbicides, the following stand out: 2,4-D (aryloxyalkanoic acid), applied in post-emergence and with an auxin-mimicking mechanism of action; metribuzin (triazinone), protox inhibitor; metsulfuron-methyl and iodosulfuron-methyl (sulfonylureas), ALS inhibitors; pyroxsulam (triazolopyrimidine sulfonamide), also an ALS inhibitor; bentazone (benzothiadiazinone), an FSII inhibitor; and pendimethalin (dinitroaniline), used in pre-emergence, acting on cell division. In addition, glyphosate, belonging to the group of substituted glycines, is widely used as a non-selective herbicide (EPSPS inhibitor) (CUNHA; CAIERÃO, 2023).

Among the herbicides used in weed management, dicamba also stands out, belonging to the chemical group of benzoic acids. This herbicide is absorbed by leaves, stems and roots, presenting systemic action and acting as an auxin mimimic. It is efficient in controlling dicotyledonous weeds and has recommendations similar to 2,4-D, promoting dysregulation of cell division and growth by acting as a plant hormone (SENSIX, 2022).

According to Brochado et al. (2021), the formulation with DGA (diglycolamine) salt has lower volatility compared to DMA (dimethylamine) salt, due to modifications in the formulation.

However, studies on the use of dicamba in wheat crops are still limited, with a lack of information in the literature. Thus, it becomes relevant to evaluate their behavior in this culture. Thus, the present study aimed to test different doses of dicamba, in order to evaluate

its selectivity for wheat. The experiment was conducted in the Southwest region of Paraná, in the municipality of Verê.

2 MATERIAL AND METHODS

2.1 PLACE OF REALIZATION

The experiment was carried out in the field on the property of Voldinei Luis Cagnini, located in the municipality of Verê, Paraná (approximate coordinates of $\phi = -25.87135$ and $\lambda = -52.87458$), in the community of União da Barra, belonging to the southwestern region of the state.

The climate of the region is classified, according to Köppen, as Cfa (humid subtropical), characterized by an average temperature of the coldest month between 18 and -3°C , well-distributed rainfall throughout the year and hot summers, with an average temperature of the hottest month above 22°C (ALVARES et al., 2013).

2.2 EXPERIMENTAL DESIGN

The experimental design was in randomized blocks, with four replications. Five treatments were evaluated (four different herbicide doses + control). The dicamba doses used were 0.4; 0.6; 0.8 and 1 L ha^{-1} of the commercial product Xtendicam, in addition to the control, as shown in Table 1.

The experiment consisted of 20 plots, with dimensions of $3 \times 1\text{ m}$, totaling 3 m^2 per plot and a total area of 60 m^2 .

2.3 IMPLEMENTATION AND CONDUCTION

Wheat sowing was carried out on June 23, using the Senna cultivar, which has a hyper-early cycle of approximately 100 days. This cultivar has a small size and weight of a thousand seeds of approximately 44 g (SEMENTEC AGRONEGÓCIOS, c2025).

Sowing was carried out with a Kuhn seeder of 21 rows, spaced at 0.17 m, regulated for seed deposition between 3 and 4 cm in depth and density of 430 plants m^{-2} .

2.4 CULTURAL MANAGEMENT

The cultural management was carried out according to the practices adopted by the producer, since the experiment was inserted in a commercial area. The insecticide Connect and the fungicides Fox and Nativo were used. In addition, fertilizer with a formulation of 30-00-20 was applied at the full tillering stage, at a dose of 205 kg ha^{-1} .

2.4.1 Application of dicamba (Xtendicam)

Considering reports in the literature about possible damage to the crop when the herbicide is applied in very early or late stages, the application was carried out at the tillering stage, considered the most appropriate.

As the objective of the study was to evaluate different doses, the Xtendicam recommendation for corn was adopted as a reference, also belonging to the grass group, since the product does not have a recommendation for wheat.

The doses were defined based on the product leaflet, which recommends 1 L ha⁻¹ for corn, with a volume of 200 L ha⁻¹. The recommendation of 2,4-D for wheat (0.4 to 0.7 L ha⁻¹) was also considered. Based on these parameters, doses of 0.4; 0.6; 0.8 and 1 L ha⁻¹ of Xtendicam.

The application was carried out on July 30, using a knapsack sprayer with a capacity of 20 L. The equipment was calibrated so that the flow rate of the AD-IA/D type spray tip (anti-drift, air induction, double fan) was 5 mL s⁻¹. The displacement speed was adjusted so that the application resulted in 40 mL per plot, corresponding to a spray volume of 133 L ha⁻¹.

For each treatment, a volume of 2 L spray was prepared. The application was carried out from the lowest to the highest dose, avoiding the need to wash the tank between treatments. The adjuvant XTEND PROTECT was used at a concentration of 1% v/v (20 mL for 2 L of mixture), with the objective of reducing evaporation and drift.

At the time of application, carried out in the morning, the wind speed was 7 km h⁻¹ and the temperature was 21 °C, with cloudy sky conditions, and these parameters were monitored with the aid of an anemometer.

2.5 PARAMETERS EVALUATED

Phytotoxicity in wheat was evaluated at 7, 14, 21, 28, 35 and 42 days after application (DAA), using the scale of the Brazilian Society of Weed Science (SBCPD, 1995).

The height of the plants was evaluated before application and at 42 DAA, by means of a ruler graduated in centimeters, and the values were compared with the control.

The number of tillers was determined at 42 DAA, based on the average of five plants per plot. The density of plants per linear meter was also evaluated, by counting in one meter of row in each plot.

To determine the dry matter of the shoot, after the evaluation of the other parameters, the plants were cut close to the ground in an area of 0.50 x 0.50 m. The ears were separated

from the stalks to evaluate the yield. After threshing the grains, the residues were gathered and packed in bags, which were later taken to the greenhouse for drying.

The number of grains per ear was determined by the average of five ears per plot. The weight of one thousand grains was obtained from four replicates of 100 seeds per plot, and the average values were multiplied by ten.

To determine the yield, the grain moisture content was adjusted to 13%, using the formula $PF = Pi \times (100 - iu) / (100 - 13)$. Subsequently, the values obtained were extrapolated to bags per hectare.

2.6 STATISTICAL ANALYSIS

The collected data were analyzed using The SAS System, version 9 (SAS Inst., Cary, United States, 2002), and submitted to analysis of variance at 5% probability. When significant, the means were compared using Tukey's test, followed by regression analysis in the Rbio application (BHERING, 2017).

3 RESULTS AND DISCUSSIONS

The increase in the doses of Xtendicam provided an increase in the levels of phytotoxicity in wheat, with a gradual increase over time, as observed in the evaluations carried out, reaching 15.5% at the highest dose (1 L ha^{-1}) at 42 days after application (DAA) (Table 1 and Figure 1). Although there was a statistical difference between the doses, even at the highest dose of Xtendicam the visual phytotoxicity was considered low, non-permanent and recoverable throughout the crop cycle. The coefficient of variation (CV) indicated moderate variation, conferring reliability to the averages obtained.

In a study conducted by Velloso and Dal'Piaz (1982), evaluating the application of dicamba and other chemical compounds at 30 days after emergence, at the tillering stage of wheat, barley and rye crops, phytotoxicity was analyzed at 15 days after application by means of the ALAM scale (1: total plant death; 2: very severe; 3: severe damage; 4: moderate damage; 5: slight damage; 6: absence of injury). The authors observed that dicamba, at a dose of 392 g ha^{-1} , was the compound that presented the greatest phytotoxic effect in the three crops, being classified as moderate damage (note 4) for wheat.

Considering the acid equivalent of Xtendicam (480 g L^{-1}), the dose of 392 g ha^{-1} corresponds to approximately 0.8 L ha^{-1} . At this dose, in the present study, symptoms classified as mild to moderate were observed, according to the phytotoxicity scale of the Brazilian Society of Weed Science (SBCPD, 1995), evidencing the presence of visual injuries

in the crop. Thus, the results obtained in this experiment are in agreement with those reported in the literature.

Table 1

Toxicity (%) of doses of Xtendicam applied to tillering of wheat over 42 days after application (DAA)

Xtendicam	7th DAA	14 DAA	21 DAA	28 DAA	35 DAA	42 DAA
0.4 L/ha	4.75 b	6.25 b	6.5 b	7.5 b	8 b	8 b
0.6L/ha	6 b	8.25 b	9.5 abs	10.75 abs	12 b	12 abs
0.8 L/ha	6 b	9.25 b	10 to	12.35 abs	13 abs	13.5 to
1 L/ha	9.25 to	14 to	12.75 to	14 to	15.25 to	15.5 to
0 L/ha	0 c	0 c	0 c	0 c	0 c	0 c
CV (%)	20,6	19,8	19	21,4	23,7	20,4

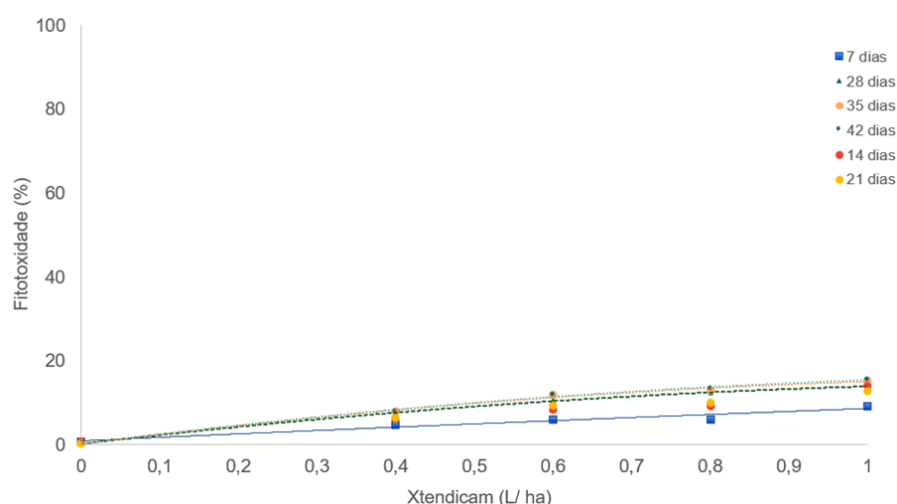
Means followed by the same letter, in the same column, do not differ from each other by Tukey's test at 5%.

CV= coefficient of variation

Source: Authors.

Figure 1

Phytotoxicity (%) of Xtendicam doses applied to wheat tillering over 42 days after application (DAA)



Source: Authors.

It can be observed that in the curves for the herbicide in all the evaluations carried out, the values of R^2 (coefficient of determination) were above 0.90, that is, they were significant (≥ 0.7) and explain in more than 90% the behavior of the data collected in the field evaluations (Table 2).

Table 2

Parameters of the quadratic polynomial equation and R^2 value for the phytotoxicity variable (%) of Xtendicam on wheat crop

DAA	Mediums	X	X ²	R ²
7	0,9422	8,42	0,7143	0,9397
14	0,9786	10,87	14,682	0,9687
21	0,3186	17,532	-54,483	0,9875
28	0,2323	21,862	-8,160	0,9982
35	0,2216	23,86	-8,988	0,9933
42	0,194	23,918	-8,652	0,9962

Polynomial quadratic equation $Y=X^2+X+Mean$.

Source: Authors.

In the present experiment, plant lodging was observed when in the presence of dicamba herbicide and when compared to the controls in the absence of dicamba, there was a delay in the emergence of ears or even no ears emission.

This was also reported by Oliveira and Greidanus (1991), who highlight the occurrence of lodging when 2,4-D and dicamba were applied in late stages of the crop, in addition to reducing the size of wheat, demonstrating that applications at the end of tillering had a more impactful effect on the crop, and also greater lodging, reporting that dicamba has greater aggressiveness.

As already mentioned by Roman et al. (2005), when the plant absorbs auxins they move with the flow of sugar and amino acids towards the growing points, thus, ruining the growth of the plants, which can cause epinasty, curling of branches, leaves and petioles, chlorosis and necrosis can also occur at the growing points. Also, Galon et al. (2010), report that symptoms such as the retention of ears in the stem after elongation, causing the ears to become crooked, also observed in this experiment, may occur.

Regarding plant height, before application (in tillering) there was no significant difference between the treatments, since the application was after the establishment of the crop, conferring uniformity in the plots that received the treatments (Table 3 and Figure 2). Regarding the height after herbicide application (evaluated at 42 DAA), only the height of 0.4 L/ha was not affected by dicamba, not differing significantly from the dose of 0 L/ha. The doses of 0.6, 0.8 and 1 L/ha were statistically lower than the dose of 0 L/ha, presenting an average reduction of 13% in plant height. Therefore, the herbicide reduced plant growth at

the highest doses when compared to the treatment in the absence of the herbicide. The low coefficient of variation indicates that a high accuracy of the results was obtained.

Table 3

Height of wheat plants (cm) before and after dicamba application

Xtendicam	Before application	After application
0.4 L/ha	34.25 to	67.6 abs
0.6 L/ha	34.2 to	62.8 b
0.8 L/ha	35, 28 to	63.1 b
1 L/ha	35.32 to	62.6 b
0 L/ha	34,325 to	71.8 to
CV (%)	5,12	5,25

Means followed by the same letter, in the same column, do not differ from each other by Tukey's test at 5%.

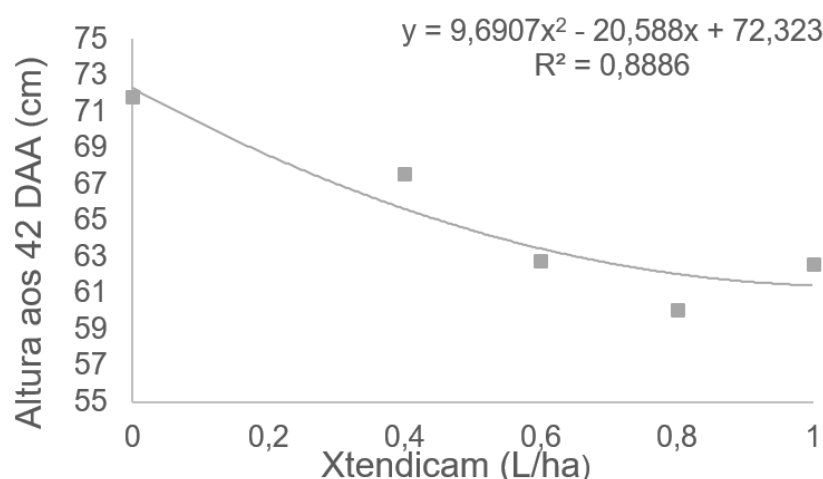
CV = coefficient of variation

Source: Authors.

According to Fleck et al. (1995), when hormonal herbicides are applied to wheat in the pre-tillering stage, they adversely affect crop height, being linked to a reduction in grain yield. Also as previously mentioned by Nunes et al. (2007), when applied high doses can cause complications to the wheat crop such as reduced seedling emergence, high degree of phytotoxicity and growth arrest.

Figure 2

Plant height 42 days after application of the herbicide Xtendicam on wheat crop during tillering



Source: Authors.

Regarding the number of tillers, the doses of 0.4 L/ha, 0.6 L/ha, 0.8 L/ha and 1 L/ha did not differ significantly from each other and were statistically lower than the number of tillers presented at the dose of 0 L/ha (1.3 tillers), negatively affecting this variable (Table 4).

The herbicide dicamba did not influence the number of plants per linear meter, as this variable had already been defined before its application. Similarly, dicamba doses did not significantly affect dry matter and the weight of one thousand grains.

The number of grains per ear was not negatively affected for the doses of 0.4 (28.9) and 0.8 L/ha (28.85), when compared to the dose of 0 L/ha (33.5), but at the doses of 0.6 (25.25) and 1 L/ha (27.85) there was a significant reduction, however, they were not different from the doses of 0.4 and 0.8 L/ha.

The wheat grain yield at the effective dicamba rates evaluated were lower than those observed at the 0 L/ha rate (85.86 bags/ha), however, there was only a significant difference between the 0.8 (55.87 bags/ha) and 0 L/ha rates.

Therefore, a significant reduction in grain yield can be observed in relation to the dose of 0 L/ha, being 15.2, 20.1, 34.9 and 30.8%, respectively, for the doses of 0.4, 0.6, 0.8 and 1 L/ha of Xtendicam. This represents about 13.0, 17.3, 30.0 and 26.5 bags/ha and considering the quotation of Coopertradição, Pato Branco-PR, on 01.07.2025 at 73 reais/bag, it is equivalent to 949, 1,262, 2,190 and 1,934 reais, respectively.

The coefficient of variation of 18.16% obtained for wheat grain yield is considered average, because according to Gomes (1990) for agricultural trials to evaluate grain yield the average CV class is represented by the CV interval of 10-20%, conferring average experimental precision, contributing to explain the considerable amplitude between the yield averages (possibly due to the influences of environmental factors) and the absence of significant difference between some effective doses and the control (0 L/ha). The VC for the other variables was less than 15%, showing that good precision and homogeneity of the results were obtained.

Table 4

Number of tillers per plant, plants per linear meter, dry matter, weight of one thousand grains, number of grains per ear and wheat yield

Dose Xtendicam	Number of tillers (Average of 5)	m/linear floor plans	MS (g)	Weight thousand grains (g)	No. of grains/cob	Productivity (sc/ha)
0.4 L/ha	0.95 b	58 to	156.88 to	39.2 to	28.9 ab	72.84 abs
0.6 L/ha	0.95 b	58 to	170.75 to	38.9 to	25.25 b	68.6 abs
0.8 L/ha	0.95 b	54 to	156.55 to	38.48 to	28.85 abs	55.87 b
1 L/ha	0.90 b	50 to	159.85 to	38.58 to	27.85 b	59.4 abs
0 L/ha	1.3 to	51 to	158.43 to	40.04 to	33.5 to	85.86 to
CV (%)	14,7	12,53	14,29	2,16	8,64	18,16

Means followed by the same letter, in the same column, do not differ from each other by Tukey's test at 5%.

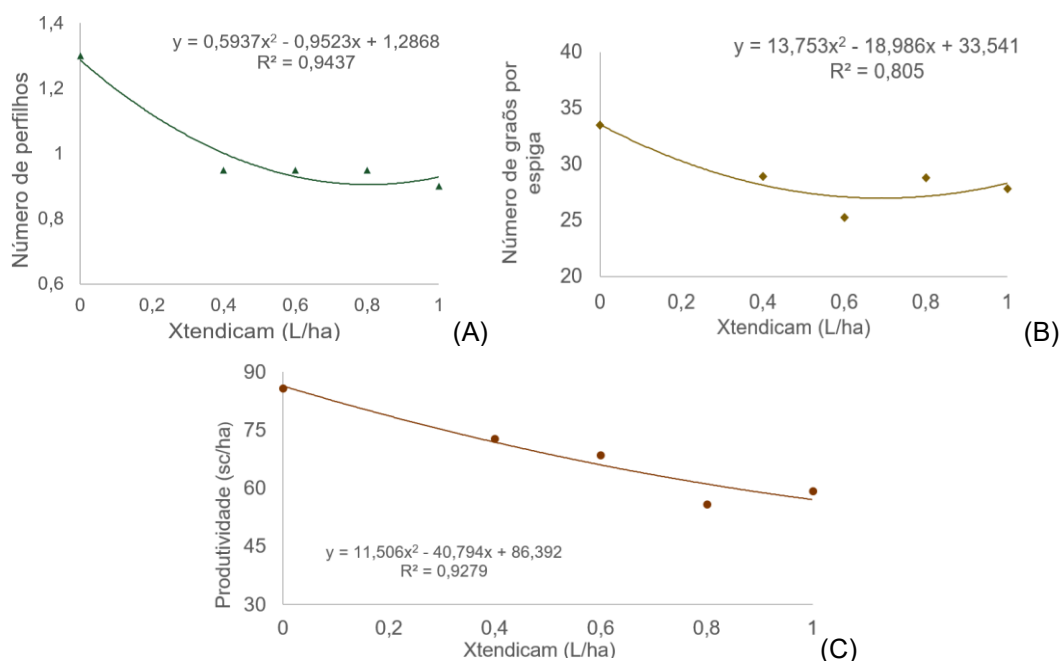
CV= coefficient of variation

Source: Authors.

The regressions indicate that the increase in Xtendicam doses reduced the number of tillers per plant, number of grains per ear and grain yield. In addition, it is possible to observe that the R^2 values were above 0.8, explaining in more than 80% the behavior of the data observed in the field (Figure 3).

Figure 3

Number of tillers (A), number of grains per ear (B) and yield (bags/ha) of wheat submitted to Xtendicam doses in tillering



Source: Authors.

According to Velloso et al. (1982), where diclofop, dicamba, 2,4 D + dicamba and the mixture diclofop + (2,4 D + dicamba) were analyzed, where the applications were carried out at 30 days after crop emergence, at the tillering stage, reported the absence of statistical differences between the treatments, for the variable reduction of the population of rye, wheat and barley plants. Thus, these herbicides did not affect the plant density of these crops, these same authors also report that dicamba caused a reduction in the grain yield of the three crops, showing little selective.

Rodrigues et al. (2006) did not observe effects in relation to the weight of a thousand grains when the hormonal herbicide dicamba was applied and its application reduced the number of full grains per ear, causing a loss of up to 60% in wheat grain yield when applied after the terminal spikelet period (end of tillering), and applications prior to the double-ring stage (beginning of tillering) can cause deformations in the ear and flag leaf.

Similarly, it was also verified by Fleck et al. (1995) that the greatest yield reductions, with applications of 2,4-D in wheat, occurred due to the reduction in the number of grains per

ear. Dicamba presents phytotoxicity to wheat causing foliar symptoms and a drop in grain yield. Also according to the same author, MCPA, 2,4-D (amine and ester) and 2,4-D amine + dicamba decreases the number of ears per area, for this reason having a decrease in grain yield. As already mentioned by Roman et al. (2006), the late application of hormones (after the beginning of elongation) causes a reduction in grain yield due to sporogenesis, causing sterility of the flowers and impairing ear formation if it is applied in late stages (Dercheid, 1951; Pinthus & Natowitz, 1967).

For these reasons, in order to have less negative impact of the crop on grain yield, the ideal would be to use the lowest dosage (0.4L/ha), which can take into account the lowest dosage of 2,4-D for wheat, in addition to applying where horseweed seedlings and other broad leaves are at an early stage to ensure a high level of control.

4 CONCLUSION

The application of dicamba herbicide in wheat crops, at the tillering stage, promoted an increase in phytotoxicity with the increase in doses, but the levels observed were low (<20%), non-permanent and with recovery capacity throughout the crop cycle.

Despite the low visual phytotoxicity, there was a negative impact on important yield components, such as number of tillers, number of grains per ear and plant height, especially at the highest doses. These effects directly reflected on grain yield, showing that the selectivity of dicamba for wheat is limited, especially at higher doses.

The variables number of plants per linear meter, shoot dry matter and weight per thousand grains were not influenced by the doses applied, indicating that the herbicide mainly affected the formation and development of the productive components, without compromising the quality of the grains.

The dose of 0.4 L ha⁻¹ of Xtendicam presented the lowest negative impact on the crop, being considered the safest under the conditions evaluated. However, even at this dose, a reduction in yield was observed in relation to the control, indicating the need for caution in the use of this herbicide in wheat crops.

The results obtained demonstrate the potential of dicamba for use in weed management in wheat, but reinforce the need for further studies to validate safe doses, efficiency in the control of target species and evaluation under different edaphoclimatic conditions, cultivars and management systems.

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ALLELOPATHIC EFFECT OF COVER CROP EXTRACTS ON GERMINATION AND INITIAL GROWTH OF WEEDS

EFEITO ALELOPÁTICO DE EXTRATOS DE PLANTAS DE COBERTURA SOBRE A GERMINAÇÃO E CRESCIMENTO INICIAL DE PLANTAS DANINHAS

EFFECTO ALELOPÁTICO DE EXTRACTOS DE PLANTAS DE COBERTURA SOBRE LA GERMINACIÓN Y EL CRECIMIENTO INICIAL DE PLANTAS INVASORAS



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ABSTRACT

The intensive use of herbicides has contributed to the selection of resistant weed populations, highlighting the need for alternative weed management strategies. In this context, allelopathy from cover crops may represent a complementary tool for weed suppression. This study aimed to evaluate the allelopathic potential of aqueous extracts from the shoot biomass of brachiaria (*Brachiaria ruziziensis*), sunn hemp (*Crotalaria ochroleuca*), and pearl millet (*Pennisetum glaucum*) on the germination and early development of Italian ryegrass (*Lolium multiflorum*), wild radish (*Raphanus sativus* L.), and beggarticks (*Bidens pilosa*). The experiment was conducted in a completely randomized design, using aqueous extracts at 10% (w/v). Germination percentage and speed, shoot and root length, and fresh and dry biomass accumulation were evaluated. Brachiaria and sunn hemp extracts significantly reduced all evaluated variables for the three weed species. Pearl millet extract showed a less pronounced allelopathic effect, with no significant interference on germination and dry biomass accumulation of wild radish. These results indicate that brachiaria and sunn hemp exhibit high allelopathic potential and may be used as complementary tools for sustainable weed management.

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Keywords Allelopathy. Resistance. *Bidens pilosa*. *Brachiaria ruziziensis*. *Crotalaria ochroleuca*.

RESUMO

O uso intensivo de herbicidas tem contribuído para a seleção de populações de plantas daninhas resistentes, evidenciando a necessidade de estratégias alternativas de manejo. Nesse contexto, a alelopatia de plantas de cobertura pode representar uma ferramenta complementar para a supressão de plantas daninhas. Este estudo teve como objetivo avaliar o potencial alelopático de extratos aquosos da biomassa da parte aérea de braquiária (*Brachiaria ruziziensis*), crotalária (*Crotalaria ochroleuca*) e milho (*Pennisetum glaucum*) sobre a germinação e o desenvolvimento inicial de azevém (*Lolium multiflorum*), nabo (*Raphanus sativus* L.) e picão-preto (*Bidens pilosa*). O experimento foi conduzido em delineamento inteiramente casualizado, utilizando extratos aquosos a 10% (m/v). Foram avaliados a porcentagem e a velocidade de germinação, o comprimento da parte aérea e da raiz, e o acúmulo de biomassa fresca e seca. Os extratos de braquiária e crotalária reduziram significativamente todas as variáveis avaliadas para as três espécies de plantas daninhas. O extrato de milho apresentou efeito alelopático menos pronunciado, sem interferência significativa na germinação e no acúmulo de biomassa seca do nabo. Esses resultados indicam que a braquiária e a crotalária apresentam alto potencial alelopático e podem ser utilizadas como ferramentas complementares no manejo sustentável de plantas daninhas.

Palavras-chave: Alelopatia. Resistencia. *Bidens pilosa*. *Brachiaria ruziziensis*. *Crotalaria ochroleuca*.

RESUMEN

El uso intensivo de herbicidas ha contribuido a la selección de poblaciones de malezas resistentes, evidenciando la necesidad de estrategias alternativas de manejo. En este contexto, la alelopatía de plantas de cobertura puede representar una herramienta complementaria para la supresión de malezas. Este estudio tuvo como objetivo evaluar el potencial alelopático de extractos acuosos de la biomasa de la parte aérea de braquiaria (*Brachiaria ruziziensis*), crotalaria (*Crotalaria ochroleuca*) y mijo perla (*Pennisetum glaucum*) sobre la germinación y el desarrollo inicial de raigrás (*Lolium multiflorum*), nabo (*Raphanus sativus* L.) y amor seco (*Bidens pilosa*). El experimento se realizó bajo un diseño completamente al azar, utilizando extractos acuosos al 10% (m/v). Se evaluaron el porcentaje y la velocidad de germinación, la longitud de la parte aérea y de la raíz, y la acumulación de biomasa fresca y seca. Los extractos de braquiaria y crotalaria redujeron significativamente todas las variables evaluadas para las tres especies de malezas. El extracto de mijo perla presentó un efecto alelopático menos pronunciado, sin interferencia significativa en la germinación ni en la acumulación de biomasa seca del nabo. Estos resultados indican que la braquiaria y la crotalaria presentan un alto potencial alelopático y pueden ser utilizadas como herramientas complementarias en el manejo sostenible de malezas.

Palabras clave: Alelopatía. Resistencia. *Bidens pilosa*. *Brachiaria ruziziensis*. *Crotalaria ochroleuca*.

1 INTRODUCTION

Annual crops play a central role in Brazilian agricultural systems, favored by edaphoclimatic conditions that allow the continuous expansion of cultivated areas. However, weed interference represents one of the main limiting factors for crop productivity due to competition for water, light, nutrients, and space, in addition to significantly increasing production costs associated with weed control.

Weed management in Brazilian agriculture is largely dependent on chemical control, which has led to escalating use of herbicides and contributed to resistant weed populations, posing economic, agronomic, and environmental challenges (Procópio et al. 2024). Moreover, the intensification of herbicide use is associated with environmental and human health risks, and Brazil is among the world's largest consumers of these products (Cassal et al. 2014).

Given this scenario, alternative and complementary strategies to chemical control have been widely discussed, particularly the use of cover crops in integrated weed management. Among the mechanisms associated with these species, allelopathy has received increasing attention, as certain plants are capable of releasing chemical compounds that interfere with the germination and early development of other species present in the same environment (Rice. 1984).

Allelopathy involves the release of primary and secondary metabolites that may act directly or indirectly on essential physiological processes, such as germination and early seedling growth. Studies have demonstrated that residues or aqueous extracts from cover crops can exert suppressive effects on other plant species, reducing seed germination and early seedling development. Fracasso et al. (2018) reported that residues of winter crops, such as wheat, ryegrass, and oats, significantly affected the germination and initial growth of corn and soybean under controlled conditions, indicating the potential of cover crops to interfere with plant establishment and reduce dependence on synthetic herbicides.

In this context, cover crops such as brachiaria (*Brachiaria ruziziensis*), crotalaria (*Crotalaria ochroleuca*), and millet (*Pennisetum glaucum*) present allelopathic potential that is still poorly explored against important agricultural weed species, such as ryegrass (*Lolium multiflorum*), forage radish (*Raphanus sativus* L.), and beggarticks (*Bidens pilosa*).

Thus, the objective of this study was to evaluate the allelopathic potential of aqueous extracts from the shoot biomass of cover crops (brachiaria, crotalaria, and millet) on the germination and early development of ryegrass, forage radish, and beggarticks.

2 MATERIALS AND METHODS

The experiment was conducted at the Federal University of Technology – Paraná (UTFPR), Dois Vizinhos campus, Brazil. The cover crops used were brachiaria (*Brachiaria ruziziensis*), crotalaria (*Crotalaria ochroleuca*), and millet (*Pennisetum glaucum*). The species were broadcast-sown in 1.5 × 1.5 m plots and allowed to grow for 60 days, corresponding to the period commonly observed in agricultural areas during the off-season.

After this period, the plants were cut close to the soil surface, and only the shoot biomass was used. The plant material was dried in a forced-air oven at approximately 31 °C for four days and subsequently ground in a knife mill until a fine powder was obtained for the preparation of aqueous extracts.

The weed species evaluated were ryegrass (*Lolium multiflorum*), forage radish (*Raphanus sativus* L.), and beggarticks (*Bidens pilosa*). Seeds were obtained from the cold storage chamber of the UTFPR seed laboratory, Dois Vizinhos campus.

For the preparation of aqueous extracts, 100 g of dried and ground material from each cover crop were mixed with 1,000 mL of distilled water, establishing a 10% (w/v) proportion. The suspensions were kept at rest for 24 hours at room temperature and subsequently filtered using filter paper, yielding the liquid extracts used in the treatments. The pH of the extracts was measured at the beginning of the experiment to verify possible interference with the results.

The experiment was arranged in a completely randomized design, in a factorial scheme consisting of four treatments (control, brachiaria extract, crotalaria extract, and millet extract) and three weed species, with four replicates. The germination test was carried out in plastic germination boxes (gerbox), using four sheets of germination paper per experimental unit. The volume of extract applied to each gerbox was 8 mL, corresponding to 2.5 times the dry mass of the paper, following standard procedures for seed germination tests.

In each experimental unit, 36 seeds of each weed species were distributed separately. The boxes were placed in a germination chamber at 25 °C for seven days. Evaluations were performed daily, and seeds were considered germinated when radicle protrusion exceeded 2 mm.

Germination percentage (%G) and germination speed index (GSI) were evaluated. Germination percentage was calculated as the ratio between the number of germinated seeds and the total number of seeds sown, expressed as a percentage. The GSI was determined by summing the number of germinated seeds each day and dividing by the corresponding time elapsed.

At the end of the germination test, shoot length, root length, and fresh mass of the seedlings were measured. Subsequently, the material was dried in an oven at 100 °C for 24 hours to determine dry mass.

The data were subjected to analysis of variance (F test), and means were compared using Tukey's test at a 5% probability level. Statistical analyses were performed using SAS software (Analytics Software & Solutions).

3 RESULTS AND DISCUSSION

3.1 HYDROGEN POTENTIAL (pH)

The pH values of the cover crop extracts ranged from 6.0 to 7.0 (Table 1), falling within the neutral to slightly acidic range.

Table 1

pH values of the control and aqueous extracts of cover crop shoots

Treatments	pH
Control	7,0
Brachiaria Extract	7,0
Crotalaria Extract	6,5
Millet Extract	6,0

The observed pH variations do not represent physiological limitations to the germination process or the initial development of the evaluated cultivars. Literature regarding the isolated influence of pH in allelopathy bioassays is scarce; however, studies with *Isocoma drummondii* indicate that germination reductions occur only under extreme acidity levels (pH = 2.0), while solutions in the 3.0 to 11.0 range do not promote significant alterations (MAYEUX; SCIFRES, 1978).

3.2 SEED GERMINATION AND GERMINATION SPEED INDEX (GSI)

There was a significant effect of the aqueous extracts on both germination percentage (%G) and germination speed index (GSI) of the evaluated weeds (Tables 2 and 3). *Brachiaria* sp. and *Crotalaria* sp. extracts promoted the most pronounced reductions in both variables, surpassing the inhibition caused by the pearl millet (*Pennisetum glaucum*) extract.

Table 2

Mean germination percentage (%G) and coefficient of variation (CV%) of weed seeds under different treatments

Germination percentage (%)

	Control	Brachiaria Extract	Crotalaria Extract	Millet Extract	CV
Ryegrass	95a	16,4c	22,1c	43,6b	20,9
Forage radish	59,3a	22,1b	23,5b	52,1a	14,4
Beggarticks	87,8a	5,0c	0,73c	39,3b	43,8

Means followed by the same letter in the row do not differ from each other according to Tukey's test ($p < 0.05$).

The allelopathic potential of *Brachiaria* was evidenced by a reduction exceeding 80% in ryegrass germination and 90% in beggarticks. Similar results were reported by Rotta and Coelho (2016), who observed inhibition of beggarticks germination using *B. ruziziensis* extracts. However, the allelopathic response is species-dependent; Fagioli et al. (2000) found no inhibitory effects of *B. brizantha* and *B. decumbens* extracts on pigeon pea seeds, suggesting selectivity of the involved allelochemicals. Regarding *Crotalaria*, %G inhibition approached 100% for beggarticks. Although Araújo et al. (2008) observed no allelopathic effect of *C. juncea* on this weed at low concentrations, Teixeira et al. (2003) confirmed the susceptibility of beggarticks to extracts of this legume, corroborating the present data.

Table 3

Mean germination speed index (GSI) of weed seeds under different treatments and coefficient of variation (CV%)

	Germination speed index				CV
	Control	Brachiaria Extract	Crotalaria Extract	Millet Extract	
Ryegrass	40,1a	0,97c	3,05c	11,5b	15,5
Forage radish	27,5a	6,5c	9,59c	18,9b	19,9
Beggarticks	39,3a	0,70c	0,075c	10,9b	31,4

Means followed by the same letter in the row do not differ from each other according to Tukey's test ($p < 0.05$).

The GSI showed a homologous behavior to germination, with severe reductions under the influence of *Brachiaria* and *Crotalaria* (Table 3). The reduction in germination speed is an indicator of physiological stress, resulting in seedlings that are less competitive for light and nutrient resources (SILVEIRA, 2010).

3.3 SHOOT AND ROOT LENGTH

Initial seedling growth was severely compromised by exposure to the aqueous extracts (Tables 4 and 5). For all three weed species, a drastic reduction in shoot length (SL) and root length (RL) was observed, particularly for beggarticks and wild radish, which showed zero or near-zero growth under the influence of *Brachiaria* and *Crotalaria*

Table 4

Mean shoot length of germinated weed seeds under different treatments and coefficient of variation (CV%).

	Shoot length (cm)				CV
	Control	Brachiaria Extract	Crotalaria Extract	Millet Extract	
Ryegrass	6,24a	0,29b	0,31b	0,27b	14,4
Forage radish	3,6a	0,03c	0,00c	0,34b	45,6
Beggarticks	4,01a	0,00b	0,00b	0,00b	19,8

Means followed by the same letter in the row do not differ from each other according to Tukey's test ($p < 0.05$).

Table 5

Mean root length of germinated weed seeds under different treatments and coefficient of variation (CV%)

	Root length (cm)				CV
	Control	Brachiaria Extract	Crotalaria Extract	Millet Extract	
Ryegrass	5,0a	0,0b	0,0b	0,24b	13,2
Forage radish	3,05a	0,45b	0,46b	0,81b	47,4
Beggarticks	2,88a	0,13c	0,02c	0,79b	24

Means followed by the same letter in the row do not differ from each other according to Tukey's test ($p < 0.05$).

The root system was the most sensitive structure to the action of allelochemicals (Table 5). Direct contact of the roots with the aqueous solutions enhances the absorption of phytotoxins, resulting in root atrophy. This root suppression is ecologically relevant, as it limits soil exploration and nutrient uptake, increasing weed vulnerability to water stress and competition with the main crop.

3.4 FRESH AND DRY SEEDLING MASS

The reductions in fresh mass (FM) and dry mass (DM) reflected the inhibitory effect observed in initial growth (Tables 6 and 7).

Table 6

Mean fresh mass of germinated weed seedlings under different treatments and coefficient of variation (CV%)

	Fresh matter				CV
	Control	Brachiaria Extract	Crotalaria Extract	Millet Extract	
Ryegrass	0,27a	0,01c	0,02bc	0,04b	13
Forage radish	1,02a	0,16c	0,18c	0,50b	22,4
Beggarticks	0,375a	0,008b	0,001b	0,060b	25,4

Means followed by the same letter in the row do not differ from each other according to Tukey's test ($p < 0.05$).

Table 7

Mean dry mass of germinated weed seedlings under different treatments and coefficient of variation (CV%)

	Dry matter				CV
	Control	Brachiaria Extract	Crotalaria Extract	Millet Extract	
Ryegrass	0,052a	0,007c	0,015c	0,027b	20,3
Forage radish	0,21a	0,08b	0,08b	0,19a	15,9
Beggarticks	0,0527a	0,0042c	0,005c	0,00b	49,5

Means followed by the same letter in the row do not differ from each other according to Tukey's test ($p < 0.05$).

DM reduction was most pronounced in beggarticks, reaching total suppression under pearl millet and Crotalaria extracts. The discrepancy between the observed effects highlights the selectivity of secondary metabolites, reinforcing the use of cover crops as a strategic tool in integrated weed management.

4 CONCLUSION

The aqueous extracts of the evaluated cover crops exhibited significant allelopathic potential on the germination and early development of the studied weed species. Extracts from brachiaria (*Brachiaria ruziziensis*) and crotalaria (*Crotalaria ochroleuca*) were the most effective, consistently suppressing germination, vigor, and initial growth of ryegrass (*Lolium multiflorum*), wild radish (*Raphanus raphanistrum*), and beggarticks (*Bidens pilosa*).

Conversely, pearl millet (*Pennisetum glaucum*) extract showed a selective allelopathic effect, with limited interference on the germination and biomass accumulation of wild radish. Overall, these results indicate that incorporating cover crops with high allelopathic potential—particularly brachiaria and crotalaria—serves as a viable complementary strategy for sustainable weed management, potentially reducing the reliance on chemical control.

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PRACTICAL EXPERIENCE IN MELON CULTIVATION: A SUPERVISED INTERNSHIP REPORT

VIVÊNCIA PRÁTICA NA CULTURA DO MELÃO: RELATO DE ESTÁGIO SUPERVISIONADO

EXPERIENCIA PRÁCTICA EN EL CULTIVO DEL MELÓN: RELATO DE PASANTÍA SUPERVISADA



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ABSTRACT

This report presents the activities developed in melon cultivation during the mandatory supervised internship at the Mata Fresca Apodi Branch, located at Sítio Boa Esperança, in the rural area of Apodi, Rio Grande do Norte, Brazil. The importance of the internship in consolidating theoretical knowledge and developing the practical skills of the Agricultural Technician is highlighted, focusing on cultivation techniques, management, pest control, harvesting and the marketing of melons. Cultivation takes place in a semi-arid climate, using drip irrigation to ensure water efficiency and production quality. Seedling planting is carried out with rigorous care, respecting adequate spacing. Management involves fertilisation based on soil analysis, chemical and mechanical weed control, constant pest monitoring with traps, and the application of chemical pesticides. Harvesting occurs 62 days after transplanting, and planting is done with maximum care to avoid damage to the plant and thus ensure fruits that meet rigorous standards of size, colour and firmness, which are essential for the domestic and international markets, especially the European market. Preparation for commercialisation includes selection, classification and appropriate packaging to preserve the integrity of the fruit during transport, as well as market strategies involving demand analysis, channel diversification and logistical planning to maximise profitability. The internship highlighted integrated management and sustainability practices, emphasising the importance of the

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proper use of natural resources and compliance with global quality standards, consolidating a solid foundation for professional work in the agricultural sector.

Keywords: *Cucumis melo* L. Pest Control. Drip Irrigation.

RESUMO

Esse relatório apresenta as atividades desenvolvidas no cultivo do melão, durante o estágio supervisionado obrigatório na Empresa Mata-Fresca Filial Apodi, no Sítio Boa Esperança, Zona Rural de Apodi, RN. Destaca-se a importância do estágio na consolidação do conhecimento teórico e no desenvolvimento prático do Técnico em Agropecuária, com foco em técnicas de cultivo, manejo, controle de pragas, colheita e comercialização do melão. O cultivo ocorre em clima semiárido, utilizando irrigação por gotejamento para garantir a eficiência hídrica e a qualidade da produção. A implantação das mudas é realizada com cuidados rigorosos, respeitando espaçamentos adequados, o manejo envolve adubação baseada em análises de solo, controle químico e mecânico de plantas daninhas, monitoramento constante de pragas com armadilhas e aplicação de defensivos químicos. A colheita ocorre aos 62 dias após o transplante, e o plantio é feito com máximo cuidado para evitar danos a planta e, assim, garantir frutos que atendam a padrões rigorosos de tamanho, cor e firmeza, que são essenciais para mercados internos e externos, principalmente o europeu. A preparação para comercialização inclui seleção, classificação e embalagem apropriada para preservar a integridade dos frutos durante o transporte, assim como estratégias de mercado que envolvem análise de demanda, diversificação de canais e planejamento logístico para maximizar a rentabilidade. O estágio evidenciou práticas de manejo integrado e sustentabilidade, ressaltando a importância do uso adequado dos recursos naturais e do atendimento aos padrões globais de qualidade, consolidando uma base sólida para a atuação profissional no setor agrícola.

Palavras-chave: *Cucumis melo* L. Controle de Pragas. Irrigação por Gotejamento.

RESUMEN

Este informe presenta las actividades desarrolladas en el cultivo del melón durante la pasantía supervisada obligatoria en la Empresa Mata-Fresca, Sucursal Apodi, en el Sítio Boa Esperança, Zona Rural de Apodi, RN. Se destaca la importancia de la pasantía en la consolidación del conocimiento teórico y en el desarrollo práctico del Técnico en Agropecuaria, con énfasis en técnicas de cultivo, manejo, control de plagas, cosecha y comercialización del melón. El cultivo se realiza en clima semiárido, utilizando riego por goteo para garantizar la eficiencia hídrica y la calidad de la producción. La implantación de las plántulas se efectúa con cuidados rigurosos, respetando espaciamentos adecuados; el manejo involucra fertilización basada en análisis de suelo, control químico y mecánico de malezas, monitoreo constante de plagas con trampas y aplicación de productos fitosanitarios. La cosecha ocurre a los 62 días después del trasplante, y la siembra se realiza con el máximo cuidado para evitar daños a la planta y, así, garantizar frutos que cumplan con rigurosos estándares de tamaño, color y firmeza, que son esenciales para los mercados internos y externos, principalmente el europeo. La preparación para la comercialización incluye selección, clasificación y embalaje apropiado para preservar la integridad de los frutos durante el transporte, así como estrategias de mercado que involucran análisis de la demanda, diversificación de canales y planificación logística para maximizar la rentabilidad. La pasantía evidenció prácticas de manejo integrado y sostenibilidad, resaltando la importancia del uso adecuado de los recursos naturales y del cumplimiento de los estándares globales de calidad, consolidando una base sólida para el desempeño profesional en el sector agrícola.

Palabras clave: *Cucumis melo* L. Control de Plagas. Riego por Goteo.

1 INTRODUCTION

The supervised internship represents a fundamental stage in the training of the Agricultural Technician, as it enables practical experience of the knowledge acquired throughout the course and contributes to the development of essential skills for professional practice in the field. Through this experience, the student has the opportunity to observe, participate in and understand the different stages that make up the agricultural production process, identifying challenges, solutions and techniques applied in the daily routine of rural properties.

Brazilian agriculture is one of the largest and most diversified in the world, with significant participation in the international market. Among the various crops grown in the country, melon stands out owing to its high economic value and wide acceptance in both external and domestic markets, especially in the North-east, which offers the ideal climatic conditions for its cultivation (Yuri, 2025). In addition, melon is of great nutritional importance, given its contribution to a healthy diet, being rich in essential nutrients such as vitamins and minerals (Morais *et al.*, 2025). Its cultivation requires specific technical management, involving the appropriate choice of soil, efficient irrigation practices and rigorous control of pests and diseases. According to Rocha *et al.* (2021), the adoption of different plant arrangements can directly influence the productivity and quality of melon, factors that are essential to the success of the crop. Irrigation management and nutrient control are crucial to optimising the use of natural resources, especially in semi-arid regions such as the backlands (Sertão) of Paraíba.

The supervised internship carried out at Sítio Boa Esperança, located in the rural area of Apodi, Rio Grande do Norte, focused on monitoring the melon production cycle, with activities ranging from the preparation of the planting area through to the harvesting and marketing of the fruit. According to Pereira *et al.* (2021), practices such as the control of drip irrigation and the choice of cultivars are decisive in obtaining superior-quality fruit, which is essential to meeting the demands of the national and international markets. Melon production plays an important role within the regional agricultural sector, especially in the North-east, where irrigated fruit growing is one of the main economic activities, generating employment, income and high-quality products destined both for the domestic market and for export.

In view of this, the objective of this report was to present the activities developed during the mandatory supervised internship at the Mata Branch in Apodi, concerning melon production, with emphasis on the activities of planting, management, pest control, harvesting and packaging.

2 DEVELOPMENT

2.1 GENERAL ASPECTS OF THE MELON CROP

Melon (*Cucumis melo* L.) is one of the most important fruits in Brazil, especially in the North-east, owing to the hot, dry climate that favours its cultivation. The melon crop is widely grown in semi-arid regions, such as those of the north-eastern backlands, standing out for its high productivity and economic relevance. According to Yuri (2025), melon production requires special attention to soil management and irrigation control, since the plant is sensitive both to excess water and to water scarcity. Furthermore, melon adapts well to drip irrigation systems, which allow efficient water use.

Melon cultivation involves several technical aspects, such as the choice of suitable cultivars, soil preparation, the control of pests and diseases, as well as efficient management of irrigation and fertilisation. The production system must also consider commercialisation, which requires high-quality fruit with good presentation in order to meet the demanding national and international markets (Rocha *et al.*, 2021). Appropriate management of the melon crop is fundamental to the success of production, since it ranges from soil preparation through to harvesting, including practices such as weed control, the management of pests and diseases, and irrigation. Soil preparation is one of the first stages, in which it is necessary to carry out pH correction and nutrient control, generally through the application of lime and fertilisers specific to the crop.

Irrigation is one of the most critical factors in melon cultivation, especially in regions with water scarcity. According to Pereira *et al.* (2021), drip irrigation is the most recommended technique, as it ensures efficient water distribution, avoiding waste and promoting better control over soil moisture. In addition, the control of pests and diseases is essential, since melon can be attacked by various pests, such as fruit flies, aphids and mites, which compromise fruit quality and crop productivity (Morais *et al.*, 2025).

Melon production is an important economic activity for several regions of Brazil, especially the North-east, which stands out as one of the largest producers. In recent years, melon has had a significant impact on the local and national economy, with a large part of production destined for export. Moreover, melon is a fruit widely consumed both fresh (*in natura*) and processed, offering several health benefits. From a nutritional standpoint, melon is an excellent source of vitamins A and C and of minerals such as potassium and magnesium, and it has a low calorie content, making it a healthy option for a balanced diet. Its culinary versatility, which includes juices, desserts and salads, contributes to its popularity in the market (Basílio *et al.*, 2024). The melon crop is of great importance in combating food

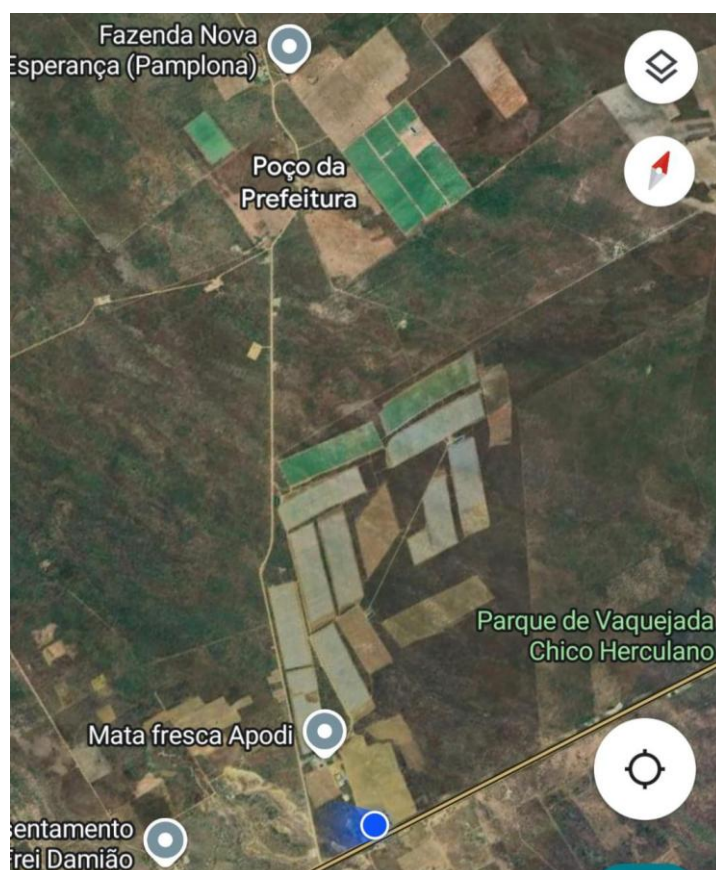
insecurity, as it contributes to dietary diversification by providing essential nutrients for human health.

2.2 CHARACTERISATION OF THE INTERNSHIP SITE

The internship was carried out at the melon-producing company Mata Fresca, Apodi Branch, located at Sítio Boa Esperança, in the Northern Sector of the rural area of Apodi, in Rio Grande do Norte, approximately 60 km from the urban area (Figure 1). The region has a semi-arid climate, characterised by long periods of drought, which makes the use of irrigation techniques such as drip irrigation fundamental to melon cultivation. The terrain of the area is flat, which facilitates the installation of irrigation systems and agricultural management.

Figure 1

Location of Mata Fresca LTDA, Apodi Branch, Sítio Boa Esperança, Apodi, Rio Grande do Norte.



Source: Google Maps (2025).

The facilities of Mata Fresca LTDA, at Sítio Boa Esperança in Apodi, include sheds for the storage of inputs and equipment, as well as a specific area for the packing and marketing of the fruit (*packing house*). This site offers a suitable environment for the internship, allowing

the application of efficient agricultural practices and the monitoring of melon cultivation and management activities, under the supervision of experienced and qualified professionals.

2.3 ACTIVITIES DEVELOPED

2.3.1 Seedling establishment and transplanting

The establishment of seedlings at Mata Fresca LTDA followed a rigorous protocol in order to guarantee a standard of fruit quality. The seedlings were initially produced in greenhouses, where they received appropriate care until they reached the ideal size for transplanting, which is carried out with the utmost care, respecting the spacing between plants — fundamental to avoiding competition for nutrients, water and light. According to Rocha *et al.* (2021), the choice of appropriate spacing and the correct management of planting density are decisive for the good development of the plants and for the final quality of production.

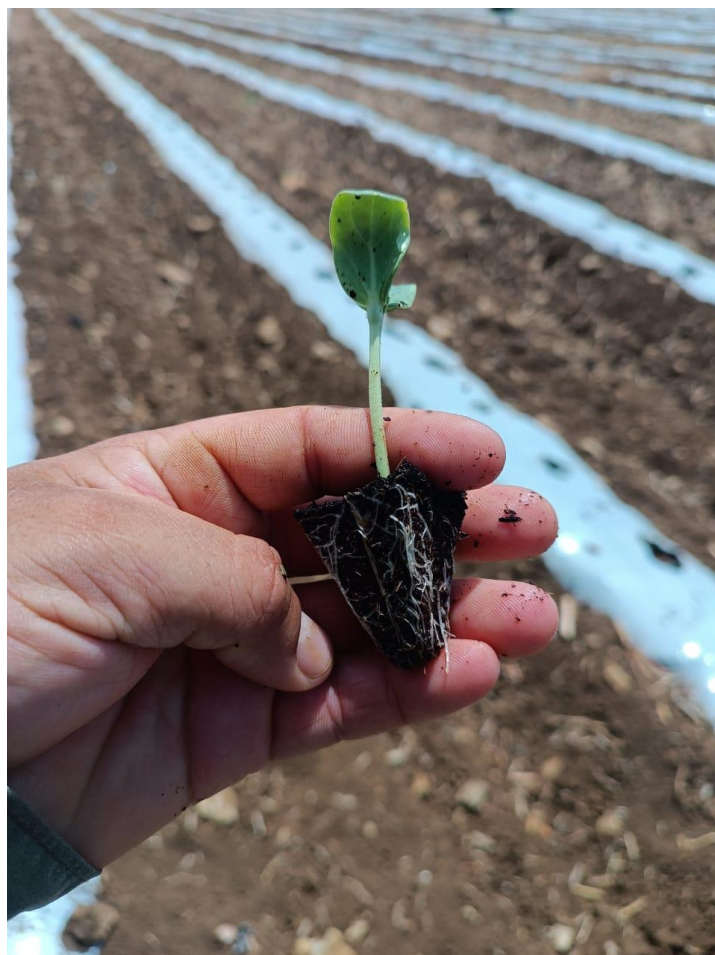
The transplanting of the seedlings took place at the beginning of the rainy season, taking advantage of the natural moisture of the soil, which facilitates their rooting. Prior to transplanting, the area was covered with *mulching* using a harrow (Figure 2A); subsequently, over the *mulching*, the planting holes were opened for transplanting (Figure 2B). The technique adopted was furrow planting, as recommended by Pereira *et al.* (2021), a practice that contributes to better drainage and irrigation control, favouring the healthy growth of the plants. The use of the drip irrigation system, as suggested by Basílio *et al.* (2024), was fundamental, as it ensures efficient water distribution, avoiding excess and promoting efficiency in the use of water resources.

The appropriate establishment and transplanting of the seedlings directly influence the quality of the harvest, as emphasised by Morais *et al.* (2025), who highlight the importance of these stages for success in melon cultivation. Proper management of these phases ensures that the plants grow healthily and, consequently, produce high-quality fruit. Figure 2 shows a melon seedling produced in a greenhouse being transplanted to the field, 8 days after sowing (DAS), the ideal phase for this practice.

Figure 2

Yellow melon production: harrow extending the mulching over the planting area (A), opening of holes over the mulching (B), and a melon seedling produced in a greenhouse, 8 days after sowing, being transplanted to the field (C), at Mata Fresca LTDA, Apodi, Rio Grande do Norte.





Source: prepared by the author (2025).

This transplanting process is a critical stage in cultivation, as it ensures that the plants begin their growth in the soil appropriately. The seedling must be well transplanted, with intact roots and the minimum of stress, so that it develops fully and produces good-quality fruit.

2.3.2 Crop management and care during growth

During the supervised internship in melon cultivation, crop management and care during plant growth were essential activities to ensure the success of production. Irrigation, carried out via a drip system, was the main technique adopted, as it ensures efficient water distribution, avoiding waste and maintaining constant soil moisture — essential for the development of the plants in a semi-arid region such as the backlands of Paraíba (Basílio *et al.*, 2024).

In addition, nutritional control was carried out on the basis of soil analyses, adjusting fertilisation according to the needs of the crop. The use of specific fertilisers contributed to the healthy growth of the plants, favouring root development and the formation of quality fruit. Appropriate fertilisation is crucial to the production of high-value melons, as highlighted by Rocha *et al.* (2021).

Weed control was also an important practice, carried out manually and mechanically in order to avoid the excessive use of herbicides. This reduced competition for nutrients and space, allowing the healthy growth of the plants. The monitoring of pests and diseases is fundamental and was therefore carried out every three days, using traps (Figure 3). The presence of pests such as fruit flies and aphids was controlled using the chemical method — that is, the use of plant-protection products — since the company does not use biological agents, although biological control is a method that is growing ever more widespread and demonstrating that it will be the future of agriculture. Maintaining constant vigilance and integrated pest control are essential to preserving the quality and productivity of the crop, as indicated by Morais *et al.* (2025).

Therefore, management of the melon crop during growth was carried out using practices that ensured the efficient use of resources and the production of quality fruit, respecting the local climatic and environmental conditions.

Figure 3

Yellow melon production: trap for monitoring and controlling pests in the field, at Mata Fresca LTDA, Apodi, Rio Grande do Norte.



Source: prepared by the author (2025).

This trap is used to capture pests such as whitefly, leafminer fly, aphids and other pests that may compromise the quality of production. These traps are essential in integrated pest management, allowing the early detection of infestations and the application of corrective measures, such as the use of insecticides or biological control, in a more efficient and targeted manner. The use of traps also minimises environmental impact, reducing the need for chemical pesticides.

Figure 4 shows a melon flower with a pest very common in watermelon, known as thrips (*Frankliniella schultzei*). This insect is a major disseminator of viruses and bacteria, depositing its eggs both on the flower and on the fruit. In addition, this pest also prevents bees from carrying out pollination in the crop.

Figure 4

Yellow melon production: melon flower with the presence of thrips (Frankliniella schultzei), at Mata Fresca LTDA, Apodi, Rio Grande do Norte.



Source: prepared by the author (2025).

2.3.3 Harvesting and assessment of fruit quality

The melon harvest was carried out 62 days after transplanting (DAT), the period in which the fruits reach the appropriate size, colour and firmness — factors essential to guaranteeing product quality. To determine the harvest point, criteria such as skin colouration and the Brix degree were observed, in accordance with the guidance of Rocha *et al.* (2021). Choosing the right moment for harvesting is crucial, as early or late harvesting may compromise the quality and shelf life of the melon.

After harvesting, the melons were transported to the *packing house*, where they underwent a selection process, being classified according to size, shape and the absence of visible defects. The best-quality fruits were destined for commercialisation, especially for demanding markets such as the European one, which seeks melons with specific standards of colour and size. Quality assessment also included tests of sweetness, acidity and flesh consistency — fundamental parameters for the acceptance of the product in the market, as highlighted by Basílio *et al.* (2024).

Handling of the fruit during the harvesting process was carried out with care to avoid damage to the skin, which could compromise the durability of the melon during transport and storage. Packaging was carried out using appropriate materials that ensured the protection of the fruit and facilitated distribution, maintaining its integrity until reaching its destination.

Therefore, the processes of harvesting and quality assessment were essential to ensuring that the fruit produced meets the standards demanded by consumers, ensuring its competitiveness in the national and international markets.

The melons were harvested in a semi-mechanised manner (Figure 5B); this method helps to improve working conditions, providing greater comfort for the workers and higher productivity, thereby preventing the fruit from suffering damage. Melon cultivation requires specific care during harvesting, such as the delicate handling of the fruit, in order to avoid injuries that could compromise its quality for commercialisation.

Figure 5

Yellow melon production: semi-mechanised harvesting (B) of melon, at Mata Fresca LTDA, Apodi, Rio Grande do Norte.



Source: prepared by the author (2025).

Figure 6 shows a melon at the ideal point for the first cut, displaying the size and colouration ideal for export. The appearance of the fruit indicates that it is at the ideal point of maturation, with a rounded shape and a vibrantly coloured skin, which is an indicator of good quality for the market. The harvesting of fruit such as this, presenting consistent sizes and characteristics, is essential to meeting the quality requirements of the market, both in Brazil and for export.

Figure 6

Yellow melon production: fruit with colouration and size ideal for harvesting, at Mata Fresca LTDA, Apodi, Rio Grande do Norte.



Source: prepared by the author (2025).

2.3.4 Preparation for commercialisation and market strategies

Preparation for the commercialisation of the melon involved several stages, from the selection and classification of the fruit through to the logistical organisation for transport. After harvesting, the melons were carefully inspected, separating the fruit according to size, colour and firmness. The best-quality melons, which meet the standards demanded by the domestic and external markets, were packaged with appropriate materials to ensure their protection during transport and storage, as recommended by Andrade *et al.* (2025).

Packaging was carried out so as to minimise physical damage, using boxes and packaging specific to fruit, which preserve its integrity and prolong its post-harvest shelf life. This process is crucial to ensuring that the product reaches its destination with good appearance and quality, especially when destined for international markets, which have rigorous standards of quality and presentation (Rocha *et al.*, 2021).

In addition to packaging, market strategies were adopted that involved the study of consumption trends and the demand for melons in different regions. The diversification of commercialisation channels was also considered, including local markets, fairs and export. The identification of potential markets, such as the European one, was essential to maximising the profitability of production. Logistical planning was also a key point, ensuring that the fruit was transported efficiently, reducing costs and maintaining product quality.

Market analysis allowed production to be strategically directed to meet demand, in both the domestic and international markets. This approach was fundamental to improving the competitiveness of the region's melon production, promoting an increase in sales and consolidating the presence of the crop in the global market.

3 FINAL CONSIDERATIONS

During the supervised internship at Mata Fresca LTDA, melon production was monitored from planting through to harvesting, with special attention to the management practices adopted. The efficient use of the drip irrigation system and appropriate fertilisation were decisive for the healthy growth of the plants and the development of high-quality fruit. Satisfactory productivity was observed, with melons of uniform size and colour that met the standards demanded by the domestic and external markets. The integrated control of pests and diseases, through traps and constant monitoring, contributed to preserving fruit quality. Harvesting was carried out at the ideal point of maturation, ensuring that the fruit reached the market with good appearance and flavour. The continuous monitoring of growth and productivity variables allowed rapid adjustments to management practices, which resulted in efficient, quality production.

Melon production requires constant attention to climatic conditions, especially regarding the sustainable use of water, a vital resource in the region. The drip irrigation system adopted during the internship was one of the main practices responsible for the high productivity and quality of the fruit, in addition to minimising water waste. Integrated pest management, with the use of traps and biological control, is also essential to maintaining plant health and ensuring the quality of production.

The supervised internship was an enriching experience that provided practical exposure to the agricultural techniques and practices applied to melon cultivation. The opportunity to follow all the stages, from planting to commercialisation, was essential to a deep understanding of the production process and the challenges faced by producers. Direct contact with the professionals and technicians in the field allowed valuable learning about the appropriate management of crops, pest control, irrigation and post-harvest care. In addition,

the internship made it possible to apply the theoretical knowledge acquired during the course, promoting the development of practical skills and the capacity to act efficiently in the labour market. The activities carried out and the observations made throughout the internship reinforced the importance of integrated management and sustainability in cultivation — factors that are essential to achieving high-quality, profitable production in the agricultural sector.

The internship also made it possible to understand the demands of the market, both domestic and external, and the importance of meeting the standards required to ensure the competitiveness of production in the global market. The experience also highlighted the need for strategic planning for commercialisation, ranging from harvesting through to the distribution of the fruit, ensuring its integrity and prolonging its shelf life.

In short, the internship was fundamental to consolidating the knowledge acquired throughout the course and to broadening understanding of sustainable agricultural practices in melon cultivation. The experience provided a solid foundation for working in the labour market and highlighted the importance of innovation and adaptation to the needs of the agricultural sector for success in cultivating high-quality melons.

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STUDY OF SOME BIOACTIVE COMPOUNDS OF WHITE- AND RED-FLESHED PITAYAS (CEREUS UNDATUS, SYNONYMY: HYLOCEREUS GUATEMALENSIS, H. UNDATUS)

ESTUDO DE ALGUNS COMPOSTOS BIOATIVOS DAS PITAYAS DE POLPAS BRANCA E VERMELHA (CEREUS UNDATUS, SINONÍMIA: HYLOCEREUS GUATEMALENSIS, H. UNDATUS)

ESTUDIO DE ALGUNOS COMPUESTOS BIOACTIVOS DE LAS PITAYAS DE PULPA BLANCA Y ROJA (CEREUS UNDATUS, SINONIMIA: HYLOCEREUS GUATEMALENSIS, H. UNDATUS)



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ABSTRACT

The pitaya (*Cereus undatus*, synonymy: *Hylocereus guatemalensis*, *H. undatus*) is an exotic fruit whose consumption is slightly increasing in our country. The functional properties commonly attributed to this fruit prompt the study of its physical, chemical and microbiological characteristics. It should be emphasised that fruits are primary sources of several vitamins and other bioactive compounds, such as antioxidants, vitamins and sugars. The intake of these compounds enhances individuals' immunity, leading to better health levels and improving their physical and mental performance. The reference values for pitaya are still unknown to the general public, since it is a fruit consumed by a wealthy class, as its price is excessively high by Brazilian standards. Food matrices are very complex, given their natural characteristics. In view of this, several techniques are used for the analytical determination of bioactive compounds, among them High-Performance Liquid Chromatography (HPLC) and ultraviolet–visible spectrophotometry. The aim of this work is to study the presence of vitamin C and sugars in white- and red-fleshed pitayas by HPLC, as well as to determine the antioxidant activity content by the 2,2'-azinobis(3-ethylbenzothiazoline-6-sulfonic acid – ABTS) radical scavenging method, soluble solids content (°Brix), in addition to acidity and pH.

Keywords: White And Red Pitayas. Bioactive Compounds. Analyses.

RESUMO

A pitaya (*Cereus undatus*, sinonímia: *Hylocereus guatemalensis*, *H.undatus*) é uma fruta exótica e de consumo ligeiramente crescente no nosso país. As atribuições funcionais dadas a essa fruta, pelo senso comum, incita ao estudo das suas características físicas, químicas e microbiológicas. Deve-se ressaltar que as frutas são fontes primárias de várias vitaminas e outros compostos bioativos, como por exemplo, os antioxidantes, vitaminas e açúcares. A ingestão desses compostos aumenta a imunidade dos indivíduos, induzindo a melhores níveis de saúde e melhorando o seu rendimento físico e mental. Os valores de referência

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para a pitaya, ainda, são desconhecidos do grande público, por ser esta uma fruta de consumo de uma classe abastada, por seu preço ser demasiadamente alto para os nossos padrões brasileiros. As matrizes em alimentos são muito complexas, dadas as suas características naturais. Diante disso, várias são as técnicas utilizadas para determinações analíticas de compostos bioativos, dentre elas, têm-se a Cromatografia Líquida de Alta Eficiência (CLAE) e espectrofotometria U.V visível. O objetivo deste trabalho é estudar a presença de vitamina C e açúcares nas pitayas de polpas branca e vermelha por CLAE, bem como, determinar, ainda, o teor de atividade antioxidante pelo método de captura do radical 2,2'-azinobis (3- etilbenzenotiazolina-6-ácido sulfônico – ABTS), teores de sólidos solúveis (°Brix), além da acidez e pH.

Palavras-chave: Pitayas Branca e Vermelha. Compostos Bioativos. Análises.

RESUMEN

La pitaya (*Cereus undatus*, sinonimia: *Hylocereus guatemalensis*, *H. undatus*) es una fruta exótica y de consumo ligeramente creciente en nuestro país. Las atribuciones funcionales dadas a esta fruta, por el sentido común, incitan al estudio de sus características físicas, químicas y microbiológicas. Cabe destacar que las frutas son fuentes primarias de varias vitaminas y otros compuestos bioactivos, como por ejemplo los antioxidantes, vitaminas y azúcares. La ingesta de estos compuestos aumenta la inmunidad de los individuos, induciendo a mejores niveles de salud y mejorando su rendimiento físico y mental. Los valores de referencia para la pitaya aún son desconocidos para el gran público, por ser esta una fruta de consumo de una clase acomodada, ya que su precio es demasiado alto para nuestros patrones brasileños. Las matrizes en alimentos son muy complejas, dadas sus características naturales. Ante esto, son varias las técnicas utilizadas para determinaciones analíticas de compuestos bioactivos, entre ellas se tienen la Cromatografía Líquida de Alta Eficiencia (CLAE) y la espectrofotometría U.V visible. El objetivo de este trabajo es estudiar la presencia de vitamina C y azúcares en las pitayas de pulpa blanca y roja por CLAE, así como determinar el contenido de actividad antioxidante por el método de captura del radical 2,2'-azinobis(3-etilbencenotiazolina-6-ácido sulfónico – ABTS), contenidos de sólidos solubles (°Brix), además de la acidez y el pH.

Palabras clave: Pitayas Blanca y Roja. Compuestos Bioactivos. Análisis.

1 INTRODUCTION

The pitaya (*Cereus undatus*, synonymy: *Hylocereus guatemalensis*, *H. undatus*) is an exotic fruit whose consumption is slightly increasing in our country. The functional properties commonly attributed to this fruit prompt the study of its physical, chemical and microbiological characteristics. Several techniques are used for such determinations; among them, we shall address the study of some bioactive compounds, such as vitamin C, anthocyanins and sugars, by High-Performance Liquid Chromatography (HPLC), and the antioxidant activity by means of ultraviolet absorption spectrophotometry, in addition to characteristics such as soluble solids content (°Brix), acidity and pH. The use of pitaya is primarily as food, being consumed fresh or in refreshing beverages. There is also medicinal use, in the treatment of gastritis, as a laxative, fortifier, among others. The increase in the consumption of this fruit arouses interest in the food industry, also as a raw material for food colourants used in low-pH foods and for its antioxidant action. There are few studies on these columnar cacti regarding their nutritional values. It should be recalled that a colourful food whets the palate, after all we eat first with our eyes, and anthocyanins are particularly enhanced with colours ranging from ruby red to purple, as well as blue and its nuances. Anthocyanins are water-soluble, facilitating their incorporation into so-called aqueous systems; there are wide variations in nature, they do not cause diseases—qualities that favour them as excellent natural colourants. Interest in anthocyanins, sugars and vitamin C in fruits is very pressing in recent years, since several scientific studies have shown that there is great antioxidant potential in these foods. The pitaya (*Cereus undatus*, synonymy: *Hylocereus guatemalensis*, *H. undatus*) is a fruit of high vitamin and nutritional value that presents a content of phenolic compounds, mainly anthocyanin pigments that produce a colour ranging from primary red to purple in foods. It should be emphasised that the functional property of a food involves several factors, such as: benefits in metabolism, combating free radicals, development and maintenance of organisms, among other factors. The toxicological aspects of antioxidants have been one of the most controversial areas in debates on the safety of food additives. Results of long-term studies conducted in recent years have shown that compounds such as BHA and BHT, which are synthetic antioxidants, can produce tumours in experimental animals. This increases the demand for natural products, such as the action of vitamin C (BIANCHI; ANTUNES, 1999). The High-Performance Liquid Chromatography (HPLC) technique is one of the most promising analytical methods, both qualitatively and quantitatively. The reasons for this are simple: its adaptability for quantitative determinations with good sensitivity and the possibility of separating non-volatile and thermally unstable species. Ultraviolet–visible spectrophotometry is used as another technique for the

determination of antioxidant activity, using the 2,2'-azinobis(3-ethylbenzothiazoline-6-sulfonic acid – ABTS) radical scavenging method. The aim of this work is to study the presence of some bioactive compounds, such as anthocyanins, vitamin C and sugars in white- and red-fleshed pitayas by High-Performance Liquid Chromatography (HPLC), as well as to determine the soluble solids content ($^{\circ}$ Brix), total titratable acidity and pH.

2 MATERIALS AND METHODS

The samples of white- and red-fleshed pitayas (Figure 1) were purchased at a market in the City of Rio de Janeiro. The fruits were selected, washed and frozen, and then the pulp of the fruits (edible part) was collected for subsequent analyses by HPLC (High-Performance Liquid Chromatography), Waters 2695 brand, ALLIANCE model, with a Waters 2996 photodiode array detector, for the determination of vitamin C, sugars and anthocyanins. The total titratable acidity and pH were determined using the Metrohm® automatic titrator, model 785 DMP - Titrino, with sodium hydroxide reagent standardised with sodium biphthalate. Acidity values were expressed in g of citric acid per 100 g of sample. Analyses were performed in triplicate, and the soluble solids content (SS) was determined in a digital refractometer, model Refractometer PAL-1 POCKET, ATAGO brand. The samples of white- and red-fleshed pitayas were placed in a fine mesh, and a few drops were squeezed onto the refractometer, and the filtrate was read in the equipment. All analyses were carried out at the Liquid Chromatography Laboratory of Embrapa Agroindústria de Alimentos, located in Guaratiba – RJ. The antioxidant activity was determined by the TEAC assay following the procedure proposed by Re *et al.* (1999) using the ABTS•+ radical cation. The ABTS•+ stock solution (7 mM) was prepared with K₂S₂O₈ as the oxidising agent. The ABTS•+ working solution was obtained by diluting the stock solution in ethanol to give an absorbance of 0.70 ± 0.02 at a wavelength of 734 nm. The extraction of the antioxidants was carried out in triplicate and in two stages, as follows: the first extraction with methanol (50%) and the second with acetone (70%). This combination is important, as extraction cycles with solvents of different polarities maximise the extraction of antioxidant compounds with different polarities (Pérez-Jiménez *et al.*, 2008).

Figure 1*Fresh white- and red-fleshed pitayas*

Source: rocha, 2012.

3 RESULTS AND DISCUSSION

Sugar contents were found in the white-fleshed pitaya, corresponding to: fructose equal to 3.71 g/100 g and glucose 7.39 g/100 g; sucrose was not detected. In the samples of red-fleshed pitaya, these contents were: fructose equal to 4.25 g/100 g; glucose equal to 6.77 g/100 g; and sucrose continued to be undetected. The vitamin C concentration found in the red-fleshed pitaya samples was 1.81 mg/100 g; considering that the recommended daily intake (RDI) of this vitamin for adults is 45 mg, the value found is considerably low (BRASIL, 2005). The contents found are still insufficient to assess an adequate antioxidant activity in the analysed pitaya samples (*Hylocereus undatus* Haw), since according to Yu *et al.* (2002), there may be effects of other compounds that are important for the antioxidant capacity, in addition to vitamin C. The freezing of the samples may have contributed to the low concentration found of this vitamin. The analysis in an ion-exchange column contributes to certain actions, such as the non-elevation of temperature and the use of solvents with greater carrying potential, since this could degrade this nutrient. The pH of the white- and red-fleshed pitaya samples was 5.25 and 4.81, respectively. Faleiro *et al.* (2010) detected, in studies with pitayas of the species *Hylocereus undatus*, that the mean pH was 4.87. As for the total titratable acidity content, 1.56% and 2.76% of citric acid were found, respectively for the white- and red-fleshed pitayas. The values found may confirm that the red pitaya samples have higher sugar contents than the white-fleshed ones. Studies found Brix values between 13% and 16%, with sweetness equivalent to apple and banana, increasing as the fruit peel acquires a redder colour (NERD *et al.*, 1999). No considerable amounts of anthocyanins were

found in the white- and red-fleshed pitaya samples. However, there was a presence of this colourant in the halo of the red-fleshed pitaya (the region between the peel and the pulp, Figure 2), this being Cyanidin-3-glucoside (BOBBIO; BOBBIO, 1995), as shown in Figure 3. The analysis of the Trolox Equivalent Antioxidant Capacity (TEAC), using the ABTS•+ radical scavenging, showed greater activity in the red-fleshed pitaya samples, with an average result of 2.9 μmol Trolox/g, whereas in the white-fleshed samples the average was 1.44 μmol Trolox/g, which signified a low index of antioxidant activity by the method used. With this method, no significant levels of antioxidant activity were found in the analysed pitayas.

Figure 2

Identification of the halos in the red- and white-fleshed pitayas, respectively. (Halo, Halo, Halo, Halo)



Source: rocha, 2012.

Figure 3

Chromatogram of the halo of the red-fleshed pitaya (peaks: 212.1; 516.5; 279.5; 329.5; AU axis from 0.000 to 0.030; Minutes axis from 0.00 to 45.00)



Source: rocha, 2012.

6 CONCLUSIONS

The values found for the pitayas regarding the contents of vitamin C, pH and total titratable acidity (g of citric acid/100 g of fruit), since it is an exotic fruit and of recent consumption in our country, still need to be monitored and analysed, possibly under controlled cultivation conditions of this food. As for the anthocyanin results, since it is a colourant that degrades rapidly, its presence proved to be negligible, requiring further analyses and standardisation under more specific monitoring conditions.

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