# SCIENTIFIC STRENGTHENING ACTIONS AS A MEANS OF CONTROLLING ANTIMICROBIAL RESISTANCE IN THE CONTEXT OF SDG 12.A

# AÇÕES DE FORTALECIMENTO CIENTÍFICO COMO MEIOS DE CONTROLE DA RESISTÊNCIA MICROBIANA NO CONTEXTO DO ODS 12.A

# ACCIONES DE FORTALECIMIENTO CIENTÍFICO COMO MEDIO PARA CONTROLAR LA RESISTENCIA A LOS ANTIMICROBIANOS EN EL CONTEXTO DEL ODS 12.A

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**Vinicius Cavalcante Morais[1], Brena Freire de Oliveira Claudino[2], Ana Beatriz Rodrigues dos Santos[3], Ana Beatriz Batista Maia Macedo[4], Cleyton de Sousa Gomes[5], Roosewelt Andriel Barbosa da Silva[6], Mateus Mendes Vieira[7], Kaíque Yago Gervazio de Lima[8], Ulrich Vasconcelos[9]**

## ABSTRACT

Microbial resistance to conventional therapy antibiotics (RAM) is one of the two biggest challenges of the 21st century. From different years, the beginning of the present series marks a definition of an important agenda for human development. Two 17 objectives, the one that deals with development brings together a series of goals that converge as the theme “microbial resistance”. Goal 12.4 deals with technological development, strengthened by scientific promotion and partnership between nations. This text presents an analysis of the topic, pointing out the intimate relations between the technical-scientific development with the crisis of two antibiotics, proposing a discussion on how this scenario can contribute to the reduction of deaths due to microbial infections. The text was produced by Master and Doctorate students of two Post-Graduation programs, as part of the final exercise of the discipline that deals with this topic.

**Keywords:** Sustainable Development Goals. Antimicrobial Resistance. Industry and

[1] Biotechnologist. Universidade Federal da Paraíba (UFPB). E-mail: viniciusc.morais@live.com
Orcid: https://orcid.org/0009-0001-2835-1174 Lattes: http://lattes.cnpq.br/1723556599359483
[2] Pharmaceutical. Universidade Federal da Paraíba (UFPB). E-mail: brenafreireclaudino@gmail.com
Orcid: https://orcid.org/0009-0006-5195-2660 Lattes: http://lattes.cnpq.br/6909118065460463
[3] Biomedical. Universidade Federal da Paraíba (UFPB). E-mail: biarodriguessds@gmail.com
Orcid: https://orcid.org/0009-0001-3451-7927 Lattes: http://lattes.cnpq.br/7108437590038456
[4] Biotechnologist. Universidade Federal da Paraíba (UFPB). E-mail: beatrizbmacedo@outlook.com
Orcid: https://orcid.org/0000-0003-0065-5974 Lattes: http://lattes.cnpq.br/5510583958519277
[5] Biologist.Universidade Federal da Paraíba (UFPB). E-mail: cleytong777@gmail.com
Orcid: https://orcid.org/0009-0007-7962-7875 Lattes: http://lattes.cnpq.br/8126196903040038
[6] Pharmacist.Universidade Federal da Paraíba (UFPB). E-mail: roosewelt.farma@gmail.com
Orcid: https://orcid.org/0009-0007-2561-0461 Lattes:http://lattes.cnpq.br/6759820008159118
[7] Biotechnology. Universidade Federal da Paraíba (UFPB). E-mail: mateusvieira@ltf.ufpb.br
Orcid: https://orcid.org/0009-0007-9785-393X Lattes: http://lattes.cnpq.br/6920061926178546
[8] Master in Biotechnology. Universidade Federal da Paraíba (UFPB).
E-mail: kaique.gervazio@gmail.com Orcid: https://orcid.org/0000-0002-4050-2246
Lattes: http://lattes.cnpq.br/6069890892351176
[9] Dr. in Chemical and Biochemical Process Engineering. Universidade Federal da Paraíba (UFPB). Pernambuco, Brazil. E-mail: vasconcelos@cbiotec.ufpb.br Orcid: https://orcid.org/0000-0001-8289-2230
Lattes: http://lattes.cnpq.br/7714123072132679

Technology.

**RESUMO**
A resistência microbiana aos antibióticos da terapia convencional (RAM) é um dos maiores desafios do século XXI. A partir de diferentes ações, o início do presente século marcou uma definição de agenda importante para o desenvolvimento humano. Dos 17 objetivos, aquele que trata do desenvolvimento reúne uma série de metas que convergem com o tema “resistência microbiana”. A meta 12.4 trata do desenvolvimento tecnológico, fortalecido pelo fomento científico e parceria entre as nações. Este texto faz uma análise do tema, apontando as relações íntimas entre o desenvolvimento técnico-científico com a crise dos antibióticos, propondo uma discussão sobre como este cenário pode contribuir com a redução das mortes por infecções microbianas. O texto foi produzido por discentes de Mestrado e Doutorado de dois programas de Pós-Graduação, como parte do exercício final da disciplina que trata deste tema.

**Palavras-chave:** Objetivos de Desenvolvimento Sustentável. Resistência Microbiana. Indústria e Tecnologia.

**RESUMEN**
La resistencia antimicrobiana a la terapia antibiótica convencional (RAM) es uno de los mayores desafíos del siglo XXI. A través de diversas iniciativas, el inicio de este siglo marcó un hito importante en la agenda de desarrollo humano. De los 17 objetivos, el de desarrollo reúne una serie de metas que convergen en el tema de la "resistencia a los antimicrobianos". La Meta 12.4 aborda el desarrollo tecnológico, fortalecido por el desarrollo científico y las alianzas entre naciones. Este texto analiza el tema, destacando la estrecha relación entre el desarrollo técnico y científico y la crisis de los antibióticos, y propone un debate sobre cómo este escenario puede contribuir a la reducción de las muertes por infecciones microbianas. El texto fue elaborado por estudiantes de maestría y doctorado de dos programas de posgrado como parte del ejercicio final del curso sobre este tema.

**Palabras clave:** Objetivos de Desarrollo Sostenible. Resistencia a los Antimicrobianos. Industria y Tecnología.

## 1 INTRODUCTION

Microbial antibiotic resistance (AMR) represents one of the greatest threats to public health in the context of infection prevention and treatment. It occurs when microorganisms undergo changes when exposed to antimicrobials, becoming resistant and, as a result, the drugs lose their effectiveness, infections persist and spread. As a growing global public health problem, coordinated action by all government and society sectors is needed (PAHO, 2025). This health crisis is intrinsically linked to human activities and presents particular challenges for developing countries, where limited scientific and technological infrastructure increases population vulnerability. Sustainable Development Goal 12.a (SDG 12.a) aims to support developing countries in strengthening their scientific and technological capacities for more sustainable patterns of production and consumption (BRASIL, 2015; UN BRAZIL, 2015). The convergence between human activities, the emergence of resistant microorganisms and the need for sustainable technological innovation configures a field that needs multidisciplinary analysis and coordinated strategies to safeguard both therapeutic efficacy, in the context of human disorders, and environmental sustainability.

## 2 HUMAN ACTIVITIES AS DRIVERS OF ANTIMICROBIAL RESISTANCE

In 2021, AMR was listed as one of the top 10 threats to global public health (WHO, 2021), with human activities being identified as the main driver of the evolution and spread of AMR through multiple interconnected mechanisms, such as the irrational use of antibiotics (WHO, 2019). Projections for the future put the total number of deaths from drug-resistant diseases close to 10 million by 2050 if action is never taken to curb AMR (Tangcharoensathien *et al.*, 2021). This irrational use by the general public and health professionals emerges from a low level of knowledge and awareness about antibiotic use and microbial resistance (WHO, 2019). Thus, AMR arises as a result of mutations in pathogens and selection pressure from antibiotic use, which generates a competitive advantage for altered lineages (Esmaeili-khoshmardan *et al.,* 2024).

Allel *et al.* (2023) observed high rates of microbial resistance in several regions of the world, even in places where antimicrobial use is relatively low. This suggests that the incorrect use of antibiotics may represent only one of the risk elements, and not necessarily the most determinant, so effective strategies to cope with AMR must transcend the simple reduction of this misuse. Thus, integrated policies should be incorporated that involve the strengthening of sanitary and epidemiological surveillance, and basic sanitation.

Climate change alters the environment, facilitating the persistence and spread of resistant bacteria, especially due to increased temperature, changes in rainfall patterns, which impairs sanitation and increases the transmission of pathogens. Industrialization intensifies the problem by releasing pollutants such as pharmaceutical residues and heavy metals, contaminating ecosystems and creating selective pressures for bacterial resistance (Oyelayo *et al*., 2025).

Heavy metals are important environmental contaminants that favor co-resistance between these compounds and antibiotics through shared genetic mechanisms, facilitating the spread of resistant genes in the environment and potentially in clinical settings. Polluted ecosystems act as reservoirs of resistance, increasing AMR and impacting global public health (Ezeonuegbu *et al*., 2024). Inadequate hospitals, pharmaceutical industries, and wastewater treatment systems also release significant concentrations of antimicrobials into the environment, creating so-called "selection zones" where microorganisms develop resistance (Esmaeili-khoshmardan *et al*., 2024).

## 2.1 TECHNOLOGICAL CAPACITY AND FOOD SAFETY

According to the Food and Agriculture Organization of the United Nations (FAO), the term food security designates a condition when everyone, at all times, has physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and dietary preferences to enjoy an active and healthy life (FAO, 2024). Achieving this feat is a duty of each country and reinforced by international objectives, as evidenced by the 1996 World Food Conference (WCF). The CMA presents the agreement of the participating countries to reduce the number of people facing hunger by using integrative actions between the environment, politics, production and trade.

The boost in the agricultural sector is evidenced by the increase in its production scale over the years, however, problems related to access to food and its quality reveal inconsistencies in achieving the desired goals (EMBRAPA, 2018; Marchioni *et al*., 2025). Countries in Latin America and the Caribbean are still one of the most affected by hunger in the world (FAO, 2024). In the national context, Brazil has public programs to combat hunger, in addition to programs that work on the redistribution of income that, as a consequence, improve access to safe food, but which, due to economic and sociopolitical changes, do not achieve their goal of eradicating hunger (Cabral *et al*., 2014; Lins; Baptist; Espinoza, 2023).

Technological development can be a key to improving the quality of the food that reaches the population. Technologies such as whole-genome sequencing can be used to ensure the quality of the production chain and combat the spread of resistant microorganisms (FAO, 2018). However, developing countries face difficulties in ensuring technological development, as technological fragility for significant innovations is still one of the main obstacles to faster economic growth and better development indices (Leal; Figueiredo, 2021).

The indiscriminate use of antimicrobials in animal production, a common practice since the 1940s, has contributed significantly to the worsening of AMR worldwide, especially in developing countries. In these contexts, surveillance systems are fragile and regulation is deficient. In addition, the use of antibiotics as growth promoters or in subtherapeutic doses is a frequent practice, intensifying the selection of these microorganisms (Ansari *et al*., 2020; EMBRAPA, 2021).

AMR poses a threat to global public health as different pathogens, such as *Escherichia coli* ESBL, *Salmonella* spp. and *Staphylococcus aureus* MRSA can be found in foods of animal origin, and can be transmitted to humans through meat, vegetables irrigated with contaminated water, and inadequate food hygiene practices (CFS, 2024; Founou *et al*., 2016). The problem is even worse when sanitary inspection is insufficient. In addition, developing countries face challenges such as intensive production systems and scarce investments in biosafety, favoring the spread of AMR. FAO (2017) highlights that the food chain is an important vector of resistance, and that exposure to antimicrobials in livestock, agriculture and aquaculture contributes to the problem. Agricultural practice is also an aggravating factor, as the frequent and preventive use of antibiotics against phytopathogens, especially bacteriosis, has accelerated the selection of resistant strains (Machado; Luna, 2025).

The economic impact of AMR is significant: resistant infections, such as multidrug-resistant Salmonella, generate annual costs in excess of 365 million dollars in the US alone. If these numbers and the problem are extrapolated to countries with less health infrastructure, they can have even more serious consequences (Food Safety Brazil, 2024). In view of this, coordinated global actions are urgent, but especially in developing countries, it is essential to strengthen public policies, technical training, promotion of sustainable practices and the implementation of alternatives to the use of antimicrobials

## 2.2 SCIENTIFIC AND TECHNOLOGICAL STRENGTHENING IN THE CONTEXT OF SDG 12.A

Technical-scientific training has been shown to be a limitation and challenge faced by low- and middle-developed countries in coping with AMR (Kajumbula *et al.*, 2024). The lack of qualified professionals in areas such as microbiology, epidemiology, pharmacology, and health surveillance compromises everything from the collection and analysis of clinical samples to the interpretation of epidemiological and genomic data. This deficit is aggravated by inadequate laboratory infrastructure, absence of quality systems, shortage of reagents, and disarticulation between the technical and political levels (Okolie *et al.*, 2025).

Kajumbula *et al.* (2024) discussed in their study that only 1.3% of laboratories in 14 African countries perform basic microbiological tests, while the average compliance with quality standards is less than 50%. Additionally, in the Americas, it was observed that even in countries with active academic centers, such as Colombia and Jamaica, the dependence on external partnerships for specialized training is still high, evidencing the fragility of autonomous research networks (Kilmarx *et al.*, 2024).

In the Brazilian context, the development of public policies aimed at the prevention and control of antimicrobial resistance has played a central role in tackling this problem, structuring actions ranging from the promotion of the rational use of drugs to the implementation of microbiological surveillance systems (Aguiar *et al.*, 2023). Through historical programs such as the National Immunization Program and the control of hospital infections, to more recent strategies, such as the National Action Plan for the Prevention and Control of Antimicrobial Resistance (PAN-BR) (Brasil, 2022), the country has consolidated initiatives that aim to integrate efforts in the human, animal, and environmental sectors (Aguiar *et al.*, 2023).

With technological and scientific advances, many solutions for monitoring, prevention, diagnosis, and treatment have been proposed to combat bacterial resistance. Brown *et al.*, (2020) developed an automated, compact and low-cost system for microbial susceptibility testing, based on an optical system and machine learning. This system is particularly suitable for use in developing regions. From another perspective, the Oswaldo Cruz Foundation coordinates the structuring of a national network for genomic surveillance of multidrug-resistant bacteria. The institution trains professionals in genetic sequencing techniques for these bacteria. In addition, the use of nanoparticles, monoclonal antibodies, bacteriophages, and vaccines is being studied as a promising therapeutic approach in the fight against AMR (Elbehiry *et al.*, 2022).

## 2.3 TECHNOLOGICAL INNOVATION FOR SUSTAINABLE PRODUCTION AND CONSUMPTION

The adoption of sustainable consumption and production patterns is crucial to mitigate environmental risks that compromise public health and environmental integrity. However, the implementation of these practices faces challenges, notably in developing countries. In these contexts, economic growth is often prioritized as the main vector for improving the population's living conditions, which can result in the adoption of measures with an adverse impact on sustainability. Urbanization and the expansion of urban centers is an example. By attracting large companies and the acceleration of industrialization, there is an increase in job search, *per* capita income and improvements in essential services such as health and education. In view of the above, the search for economic growth often overlaps with the adoption of a more sustainable development model.

On the other hand, developing nations have tools conducive to the implementation of an economic model capable of reconciling financial progress with sustainability. This is particularly relevant in the context of bacterial resistance, often aggravated by the improper disposal of industrial, hospital and agricultural waste into the environment. The adoption of the circular economy emerges as a promising solution to mitigate improper disposal. This concept, formalized in 1989 by British economists David W. Pearce and R. Kerry Turner, aims to extend the useful life of consumer goods and reduce the generation of waste from the conception of products. In the environmental context and the mitigation of AMR, this economic paradigm proves to be more advantageous than the current linear model (extraction, production, consumption and disposal), as it contributes to the reduction of waste that contaminates soils, rivers and lakes, favoring the regeneration of ecosystems. (Pearce, Turner, 1989).

Environmental management alternatives play a crucial role in mitigating bacterial resistance. Effluents from hospitals, slaughterhouses, and agricultural centers represent significant foci of Antibiotic Resistant Bacteria (ARB) and Antibiotic Resistance Genes (ARG) (Harth, 2025). This issue is particularly acute in least developed countries (LMICs), where the discharge of hospital effluents and other sources occurs directly into the environment, without adequate prior treatment. Given this scenario, it is imperative to implement accessible technologies aimed at reducing this problem (Hounmanou, *et al.* 2025). Advanced technologies, such as Advanced Oxidation Processes (AOPs), have shown great potential in wastewater treatment. These processes are based on the generation of free radicals, especially hydroxyl (-OH·), which have high oxidizing power and, consequently, high pollutant degrading properties (Divyapriya *et al.,* 2022).

## 3 STRENGTHENING COOPERATION AND TECHNOLOGY TRANSFER

As previously mentioned, AMR predominantly affects less developed countries, due to limited access to health services, inappropriate use of antimicrobials, and reduced focus on environmental issues, points related to the scarcity of resources. In view of this scenario, the collaboration of developed or high-income nations is imperative to control the spread of AMR, since it transcends the local scope, configuring itself as a global problem. Technology Transfer initiatives are fundamental for supporting poorer nations, establishing a model of cooperation between them and developed countries. This process enables access to high-cost and complex technologies, making them more accessible to countries with limited resources, as well as adapting their use to local specificities, independent of external support, but fostering self-sufficiency, as well as the development of scientific reasoning and the ability to overcome AMR (Harris; Tanner, 2000).

The diversity of technologies available to help combat bacterial resistance covers several sectors of research and development, including the design of rapid and more specific tests with molecular scope. Such tests can contribute to reducing the detection time of resistant bacterial species, thus speeding up the start of treatment (IDSA, 2011). The development of new antimicrobials with innovative mechanisms of action, such as metal-based compounds, is also crucial in this context, given that the speed of discovery of new antimicrobials is inversely proportional to the speed of emergence of new resistant strains. (Baker, *et al.* 2018) Low- and middle-income countries often have a vast biodiversity, and the support and cooperation of more developed countries in capacity building and technologies can be considered an incentive.

## 4 CONCLUSION

AMR represents a complex crisis, directly related to the unsustainable patterns of production and consumption addressed by SDG 12. The inadequate management of pharmaceutical waste and heavy metals highlights the need for environmentally safe practices. In addition, in addition, the 12th proposes to strengthen scientific and technological capacities, especially in developing countries. These actions are essential to generate sustainable production systems. The "One Health" approach aligns with the systemic vision of SDG 12. Tackling AMR requires profound changes in global production and consumption patterns. Only with this transition can it be possible to avoid alarming projections of deaths from infections caused by resistant pathogens and meet the commitments of SDG 12. This perspective is essential to understand that antimicrobial resistance is not a phenomenon isolated to the clinical use of antibiotics, but the result of complex interactions between environmental, socioeconomic, and governance factors.


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