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THE GLOBAL CRISIS OF ANTIMICROBIAL RESISTANCE: PUBLIC HEALTH IMPACTS AND CHALLENGES FOR THE FUTURE OF ANTIBIOTICS

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Luiz Filipe Santos Costa[1], Sasha Regina das Graças Saldanha[2], Elijalma Augusto Beserra[3], Maria Jaciane de Almeida Campelo[4], Jennyfer Souza Andrade[5], Marina da Silva Junqueira[6], Isabel Cristina Adão Schiavon[7], Júlia Lodigiani Rodrigues Bragança[8], André Luiz Baptista Galvão[9] and Ana Claudia Rodrigues da Silva[10].

ABSTRACT

Antimicrobial resistance (AMR) represents a serious global challenge, compromising the effectiveness of treatments against bacterial infections. Since the first cases of penicillin resistance, the inappropriate use of antimicrobials and the scarcity of new drugs have favored the increase of multidrug-resistant microorganisms. In Brazil, AMR is associated with thousands of deaths annually, highlighting the urgency of strategies to contain its

[1] Master in Biomedicine
State University of Santa Cruz UESC
luiz06filipe@gmail.com
https://orcid.org/0009-0000-7812-9064
[2] Oral Pathology Resident
João de Barros Barreto University Hospital
sashasaldanha98@gmail.com
https://orcid.org/0009-0000-3327-441X
[3] Doctorate student in Agroecology and Territorial Development
Federal University of the São Francisco Valley (UNIVASF)
elijalma@gmail.com
https://orcid.org/0000-0001-6445-347X
[4] Dr. in Plant Biology
Federal University of Pernambuco (UFPE)
jaciane.campelo@univasf.edu.br
https://orcid.org/0000-0003-2152-0948
[5] Medical Student
Universidade Nove de Julho - Guarulhos (UNINOVE)
andradesjennyfer@gmail.com
https://orcid.org/0009-0002-7614-293X
[6] Master in Professional and Technological Education
Federal Institute of Education, Science and Technology of Tocantins
marinajunqueirasdt@gmail.com
https://orcid.org/0000-0003-4070-3803
[7] Dr. in Nursing
Federal Institute of Education, Science and Technology of the Southeast of Minas Gerais - IFSUDESTEMG
isabel.schiavon@ifsudestemg.edu.br
https://orcid.org/0000-0003-1679-985X
[8] Undergraduate student in Nursing
Federal University of São João Del Rei, Dona Lindu Midwest Campus (UFSJ)
julia.lodigiani2@gmail.com
https://orcid.org/0009-0009-8772-5533
[9] Doctor of Veterinary Medicine
Federal University of Roraima UFRR
albg130182@gmail.com
https://orcid.org/0000-0002-8509-9809
[10] Post-Graduate in High Complexity Nursing and Intensive Care
Unemat
enf.anaclaudia@hotmail.com
https://orcid.org/0000-0002-2610-9325

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advance and ensure effective treatments. This article aims to explore the global crisis of antimicrobial resistance, analyzing its impacts on public health and the challenges faced to secure the future of antibiotics. This is a comprehensive integrative literature review, conducted in 2025, based on consultations with the LILACS, MEDLINE, and PubMed databases. Projections indicate that, by 2050, AMR could cause up to 10 million deaths annually, with a growing impact on the elderly, aggravated by the inadequate use of antimicrobials, self-medication, and structural factors such as poor sanitation. AMR hinders the treatment of diseases such as multidrug-resistant tuberculosis and gonorrhea, while hospital environments favor the emergence of nutritious microorganisms. Innovative strategies such as phage therapy, gene editing, and artificial intelligence add to educational campaigns and management programs to mitigate this challenge. The "One Health" approach, led by the WHO, reinforces integrated actions in human, animal and environmental health, highlighting the need for robust public policies, epidemiological surveillance and sustainable investments to control the spread of AMR and reduce its impacts. It is concluded that the mechanisms of AMR and the spread of resistant pathogens compromise treatments, increase costs, and aggravate morbidity and mortality, especially in low- and middle-income countries. In this context, health education, public policies for the rational use of antimicrobials, epidemiological surveillance, and innovative technologies are essential to mitigate the impacts of AMR. Health professionals play a strategic role in raising awareness and prevention, contributing to safer and more effective practices in facing this global problem.

Keywords: Drug Resistance. Antimicrobials. Public Health.

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INTRODUCTION

Antimicrobials have been instrumental since their discovery, making it possible to treat infections that were once fatal. The discovery of penicillin stood out as a revolutionary milestone due to its effectiveness in fighting several bacteria that caused infections that were previously untreatable, becoming a watershed in the history of medicine. However, only three years after the beginning of its use, penicillin-resistant bacterial strains emerged, representing 40% of the strains in 1950 and reaching 80% in the 1960s, evidencing the emergence of antimicrobial resistance (AMR) (Vieira; Freitas, 2021).

The emergence of antibiotics favored the rapid development of mutation mechanisms associated with bacteria. Microorganisms exposed to antibiotic agents naturally and randomly undergo changes in their genetic codes as a survival strategy against the action of these drugs. Such modifications, in turn, are genetically transmitted, resulting, over time, in the accumulation of adaptations that contribute to the emergence of antimicrobial resistance (Almeida et al., 2023).

A significant increase in the multi-resistance capacity of microorganisms has been observed, which has serious impacts on public health and generates losses in sectors of collective interest, such as security, education, and infrastructure. Such a scenario occurs because the resources that could be allocated to these segments are redirected to the acquisition of more potent antimicrobials and in greater quantities, compromising the development and well-being of society as a whole (Silva; Ortega, 2022).

The inappropriate use and overconsumption of antimicrobials have accelerated the development of multi-drug resistance. Consequently, antimicrobial resistance has become a global concern, as new resistance mechanisms are emerging and spreading worldwide. This reality compromises the effectiveness in the treatment of common infectious diseases, resulting in the prolongation of these diseases and, in more severe cases, leading to death (Lomazzi et al., 2019).

Thus, globally, it is noted that AMR has outlined two distinct eras: the first, characterized by the period before the development of antimicrobial agents; and the second, marked by the period after its introduction, now aggravated by the ineffectiveness of state-of-the-art antimicrobials in the treatment of infections caused by strains of Gram-positive and Gram-negative bacteria resistant to multiple drugs (Matar; Andremont; Bazzi, 2020).

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Studies indicate that more than 70% of pathogenic bacteria develop resistance to at least one antibiotic. This global spread of resistance, combined with the scarcity of new drugs, configures an alarming scenario for global public health. In addition, the approval rate of new antibiotics has fallen by 90% in the last three decades, highlighting the urgency of developing effective solutions to address this impasse and ensure adequate treatment of bacterial infections (Santos, 2004).

Annually, antimicrobial resistance is directly responsible for about 34 thousand deaths in Brazil, while another 138 thousand are associated with this condition. In addition, the country registers approximately 221 thousand deaths due to bacterial infections and 400 thousand cases of sepsis each year, evidencing the severity and magnitude of this public health problem (Brasil, 2021).

In short, AMR represents one of the greatest threats to global public health in the twenty-first century, compromising the effectiveness of infectious disease treatments and aggravating the morbidity and mortality associated with bacterial infections. The misuse and indiscriminate use of antibiotics, coupled with the scarcity of new antimicrobial agents, has accelerated the development of resistant strains, rendering conventional therapies ineffective. Given this scenario, understanding the impacts of AMR on public health and the challenges for innovation and sustainable use of antibiotics is essential to mitigate its consequences and preserve advances in modern medicine.

Therefore, this study aims to explore the global crisis of antimicrobial resistance, analyzing its impacts on public health and the challenges faced to ensure the future of antibiotics.

METHODOLOGY

This research consists of an integrative literature review, described as the most comprehensive review method. This format allows for the simultaneous inclusion of experimental and non-experimental studies, involving an in-depth understanding of an interest of interest. In addition, this approach makes it possible to combine data from the theoretical and empirical literature, covering a wide range of objectives, such as the definition of concepts, the review of theories and evidence, and the analysis of methodologies. (Whittemore; Knafl, 2005)

The elaboration of the central question of this article was based on the PICo strategy, which covers the elements Population, Interest and Context. Through this

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methodology, it was possible to formulate the following question: "What are the impacts of antimicrobial resistance on public health and the challenges faced to ensure the development and sustainable use of antibiotics in the global context?"

The articles used in this study were selected from searches carried out in the Latin American and Caribbean Literature on Health Sciences (LILACS), *Medical Literature Analysis and Retrieval System Online* (MEDLINE), and PubMed (PMC) databases. For the research, the descriptors "Drug Resistance" *AND* "Antimicrobials" *AND* "Public Health" were used. Data collection took place during the month of January 2025.

The inclusion criteria established for this study included: experience reports, case studies, and research of a quantitative, qualitative or mixed approach nature, as long as they were available in full; written in Portuguese, English or Spanish; published in national or international journals in the last five years from 2020 to 2025; and with summaries accessible in the selected databases.

On the other hand, the exclusion criteria considered articles whose full version was not available, publications prior to 2020, studies that did not directly address the central theme of the research, as well as course completion papers (TCCs), dissertations, theses, and content extracted from websites.

Thus, after applying the inclusion and exclusion criteria, 13,267 articles were identified. Among these, 49 were selected for full reading and 21 were selected for reading the titles and abstracts, resulting in the inclusion of 10 studies that fully met the previously defined criteria, composing the final sample. This process is detailed in the flowchart shown in **Figure 1**.

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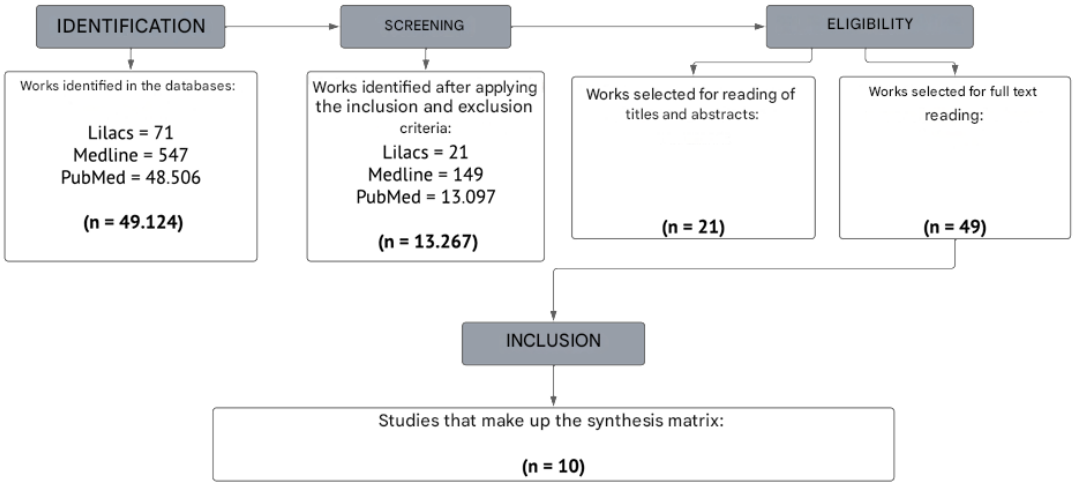
Figure 1 - Illustrative flowchart of the articles selected for the research in accordance with the proposed theme



Source: Prepared by the authors, 2024.

After the conclusion of the bibliometric analysis, the results were systematized in a synoptic table, highlighting the main findings. The selected articles underwent a careful reading and a detailed review, aiming at extracting more relevant information, which were later examined in depth.

RESULTS AND DISCUSSION

The results of this analysis are organized in tabular format, followed by a detailed analysis of the data obtained. To collect the information, an instrument was developed that covers the following variables: title of the article, authors, year of publication and conclusion, as shown in **Table 1**.

Table 1 – Synthesis of the articles analyzed

TITLE	AUTHOR/ YEAR/DATABASE	CONCLUSION
An analysis of existing national action plans for antimicrobial resistance-gaps and opportunities in strategies optimising antibiotic use in human populations.	(Charani et al., 2023) MEDLINE	Currently, AMR represents a substantially greater impact than several diseases of great relevance. Developing and maintaining an efficient global response to combat AMR faces significant challenges, including disparities in the distribution of resources, deficiencies in policy execution, and difficulties related to market forces in the development of new drugs and diagnostics.

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Antibiotic Resistance: One Health One World Outlook	(Aslam et al., 2021) PUBMED	Antimicrobial resistance requires a multidisciplinary, multisectoral, and coordinated approach to address the health threats emerging at the interface between humans, animals, and the environment. This challenge is largely addressed by the "*One Health*" concept, which recognizes the intrinsic and inseparable bond between humans, animals, and the environment, promoting integrated actions in favor of global health and the well-being of communities.
Antimicrobial resistance crisis: could artificial intelligence be the solution?	(Liu et al., 2024) PUBMED	Artificial intelligence (AI) technologies have revolutionized several areas, especially medicine, by accelerating the discovery and development of new drugs and the clinical research process. In addressing the AMR crisis, AI plays a central role, integrating with interdisciplinary efforts to promote innovative and effective solutions.
Environmental antimicrobial resistance and its drivers: a potential threat to public health	(Samreen et al., 2021) PUBMED	The overuse of antibiotics is widely recognized as one of the main causes of the development of AMR on a global scale. The indiscriminate commercialization of antibiotics without the obligation to prescribe, the inadequacy of sanitation systems and the release of unmetabolized antibiotics, as well as their residues, through human and animal excretions or industrial effluents into the environment, have significantly aggravated this problem.
Genomics for public health and international surveillance of antimicrobial resistance.	(Baker et al., 2023) MEDLINE	Genomic analyses, by providing a high-resolution view of bacterial populations and AMR determinants, have significantly expanded the ability to identify and monitor emerging AMR threats over time. This approach allows traceability by geographic location, in addition to its application in public health networks, laboratories, and patient communities.

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Microbial Resistance Movements: An Overview of Global Public Health Threats Posed by Antimicrobial Resistance, and How Best to Counter	(Dhingra et al., 2020) PUBMED	Awareness of the impacts of inappropriate prescriptions on the excessive use of antimicrobials and the increase in AMR has encouraged initiatives aimed at more rational and judicious prescription, considered an indicator of quality in health care. However, raising awareness among the population is crucial to address challenges such as self-medication with remaining antibiotics and the need for professional training on the optimal duration of prescriptions.
Recent Approaches for Downplaying Antibiotic Resistance: Molecular Mechanisms.	(Ahmed et al., 2023) MEDLINE	Effective long-term AMR screening requires ongoing efforts to raise awareness through education, persuasion, and advocacy initiatives. However, it is essential to recognize the existing limitations and work on identifying the core aspects that contribute to the worsening of AMR. To meet this challenge, it is essential to adopt innovative ideas, effective strategies, and advanced techniques capable of mitigating the conditions that favor the emergence and spread of AMR.
Antimicrobial resistance, a silent pandemic	(Simon; Labandera, 2023) LILACS	AMR is considered a silent pandemic, with the potential to cause millions of deaths, aggravate human suffering, and significantly increase health care costs. In addition, projections indicate that, without effective actions to address AMR, the world economy may have a loss with a more severe impact on low- and middle-income countries.
Shortage of essential antimicrobials: a major challenge to global health security	(Shafiq et al., 2021) PUBMED	The shortage of antimicrobials has repeatedly impacted access to effective therapies. This limitation represents a serious public health problem, resulting in high mortality rates, especially in low- and middle-income countries. The need to resort to alternative antimicrobials due to the unavailability of the most suitable agents compromises clinical results, often leading to suboptimal antibiotic use.

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Why Assuring the Quality of Antimicrobials Is a Global Imperative	(Cadvalade; Good; Ching, 2024) PUBMED	National regulatory authorities, public health bodies, and policymakers play a key role as global stakeholders, being responsible for ensuring equitable access to antibiotics of proven quality, especially for the most vulnerable populations. However, the proliferation of unauthorized sellers and the shortage of medicines pose significant challenges to achieving this goal.

Source: Prepared by the authors, 2024.

According to a global analysis published in *the journal The Lancet*, projections indicate that, by 2050, approximately 1.91 million deaths could be attributed to AMR, while 8.22 million deaths caused by this condition on a global scale. In this context, the increase in the number of deaths attributable to AMR will be particularly pronounced among individuals aged 70 years and over. (Naghavi et al., 2024)

AMR is a phenomenon inherent to natural microbial communities, existing even before the therapeutic use of antibiotics. This process occurs through mutations or horizontal gene transfer (GHT), which allows the acquisition of resistance markers. The global spread of resistant pathogens, coupled with the rise in healthcare-associated infections, has led to a significant impact. The challenges are largely associated with the incorporation of already existing determinants of resistance, facilitated by THG. (See also, 2023)

In this context, the biological mechanisms that confer resistance to antimicrobials are diverse and involve structural and functional changes in bacterial cells. An example is the inactivation of the antimicrobial, promoted by the overproduction of enzymes that degrade the substance. In addition, bacteria can restrict the entry of the drug due to the characteristics of its membranes or actively expel it through efflux pumps. Another relevant mechanism is the modification of drug target receptors, as a result of protein mutations, which reduces the binding affinity between the drug and the receptor. These processes make bacteria more tolerant, requiring higher concentrations of antimicrobials to be eliminated. (Guimarães; Momit; Pupo, 2010)

In parallel, since the discovery of antibiotics in the twentieth century, significant advances have been achieved in the treatment and cure of bacterial infections. However, several factors have contributed to the spread of AMR. The inappropriate and indiscriminate use of antimicrobials in different sectors, such as human, animal and

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agricultural, results in the ineffectiveness of treatments, degradation of water and soil quality, in addition to boosting the spread of resistant bacteria. In addition, structural issues, such as inadequate housing, lack of access to drinking water, basic sanitation, hygiene, vaccines, and other preventive means, aggravate the scenario. Self-medication, often motivated by the search for savings or speed in treatments, also plays a critical role in accelerating the spread of resistant bacteria. (Silva; Cardoso; Vieira, 2022; Silveira et al., 2023)

That said, many individuals, often without proper knowledge, have adopted the indiscriminate use of antibiotics as a preventive measure. However, this practice is widely recognized as one of the main factors responsible for the development of bacterial resistance, as already mentioned. In addition, the economic, social, and environmental impacts arising from the promotion of bacterial resistance are significant. (Caldas et al., 2024)

In low- and middle-income countries, infectious diseases are accompanied by high mortality rates. Factors such as limited access to effective medicines, disorderly distribution of antibiotics, scarcity of financial support, and the presence of high-quality pharmaceuticals are conditions contributing to the advancement of AMR in these countries. In addition, the lack of options leads part of the population to resort to harmful practices, such as the search for false professionals and medicines of inferior quality, expired or with subtherapeutic dosages. (Sharma et al., 2022)

In this context, it is essential that the population is properly informed about access and correct use of medicines. In addition, health professionals must have the necessary knowledge to prescribe and guide patients appropriately, while health managers have the responsibility to promote equitable access to quality medicines. For this, it is necessary to implement public policies that encourage and ensure the rational use of medicines, contributing to collective and individual health. (Brazil, 2024)

Subsequently, the severity of infections and multiple bacterial resistance have made it difficult to treat specific diseases, such as multidrug-resistant tuberculosis, which has become a public health problem due to the significant increase in cases in recent years. This scenario can be attributed, in part, to low adherence to treatment and reduced disease control, but also to the prolonged use of antimicrobial compounds over time, contributing to the emergence of resistance. (Are Leão et al., 2021; Soares, 2021)

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Multidrug resistance (MDR) represents a critical challenge in the fight against tuberculosis (TB). In 2019, it was estimated that there were 465,000 cases of rifampicin-resistant TB, of which 78% had simultaneous resistance to rifampicin and isoniazid, characterizing them as MDR-TB cases. Although TB treatment usually achieves an 85% success rate, this rate decreases to 57% in cases of rifampicin resistance and MDR-TB. Underdiagnosis and treatment failures aggravate this scenario, favoring the transmission of MDR-TB and increasing its complexity for health systems. (Earle et al., 2022)

Similarly, resistant sexually transmitted infections, such as gonorrhea, stand out for their significant ability to develop resistance to several classes of antibiotics. As a common infection, it is of critical relevance, requiring ongoing surveillance and laboratory monitoring for antimicrobial resistance. In addition to also posing a serious threat to public health, the disease is recognized by the World Health Organization (WHO) as a potential risk of becoming incurable. (Araújo et al., 2021)

Furthermore, despite advances in hospital infection control practices, these still persist, which is particularly alarming due to the involvement of antibiotic-resistant microorganisms. Hospitals, especially those with intensive care units (ICUs), concentrate a significant amount of resistant bacteria. This is due to the intensive use of antimicrobials, which increases the selective pressure in the environment and favors the survival of microorganisms that develop resistance mechanisms. (Santos, 2013)

In this context, the presence of resistant infectious agents in the hospital environment, both gram-positive and gram-negative, includes: *Enterococcus faecium* (associated with hospital infections in general), *Staphylococcus aureus* (causing skin and blood infections and pneumonia), *Helicobacter pylori* (related to gastric ulcers and cancer), *Campylobacter spp.* (responsible for diarrhea), *Salmonella* (also causing diarrhea) and *Neisseria gonorrhoeae* (gonorrhea). (Albuquerque et al., 2022)

Infections caused by resistant organisms are considered to generate higher morbidity and mortality, as well as higher treatment costs and prolonged hospital stays, imposing a significant burden on health systems. While global efforts are underway to curb the rise in AMR, the challenge remains critical to global health, with an annual death rate of 700,000 cases caused by resistant infections, a number that could reach 10 million deaths per year by 2050. (Maia et al., 2021)

In this regard, antibiotics have revolutionized the treatment of bacterial infections, significantly decreasing disease rates and mortality on a global scale. On the other hand,

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the increase in the number of resistant strains, driven by changes and self-protection mechanisms, has made treatments difficult and increased the costs associated with health. Despite the urgent need for continuous development of new antibiotics, their production is discouraged by economic factors, since these drugs are used for short periods and in smaller volumes, generating lower financial returns when compared to experimental drugs, which offer greater profitability for a pharmaceutical industry. (BRITO; TREVISAN, 2021)

Undeniably, adequate guidance is essential to prevent the inappropriate use of antimicrobials, such as early interruption of treatment or the use of incorrect doses, factors that favor the development of AMR. In this bias, the personalized performance of pharmacists during the dispensing of medicines ensures that patients understand the importance of correctly following medical prescriptions, ensuring the effectiveness of the treatment. In addition, pharmacists play a strategic role in awareness campaigns, educating the population about the risks of indiscriminate use of antimicrobials, promoting preventive practices such as vaccination, proper hygiene, balanced diet and physical exercise. Thus, they contribute to the dissemination of accessible information, the reduction of self-medication, and the adoption of responsible behaviors in favor of public health. (Britto; Silva; Modified, 2024)

In addition, Antimicrobial Stewardship Programs, also known as *Stewardship* Programs, have been implemented globally with the aim of improving antimicrobial prescribing in health services, ensuring the safety and efficacy of treatments, reducing the incidence of adverse events, and preventing the spread of AMR (Nava et al., 2022)

Similarly, with the aim of promoting awareness and understanding of AMR, as well as encouraging improved practices across sectors of the "One Health" approach to reduce the emergence and spread of resistant infections, WHO conducts an annual global campaign to address this serious public health problem. In 2024, the central theme of the campaign was "EDUCATE. COLLABORATE. DO IT NOW."**,** inviting the global community to educate stakeholders about AMR, advocate for ambitious commitments and take concrete and immediate action in response to this growing threat (National Health Surveillance Agency, 2024a)

The *One Health approach* is based on a holistic view that integrates the interactions between humans, animals, and the environment. Its objective is to promote the health and sustainable development of these sectors through multisectoral and interdisciplinary

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collaboration, spanning the local, national and global levels. (Rosa Meurer; Soares Coimbra, 2024)

In 2015, given the limited existence of national plans on AMR, the 68th World Health Assembly passed WHA Resolution 68.20, establishing the "Global Plan of Action to Combat Antimicrobial Resistance." Developed in partnership with the Food and Agriculture Organization of the United Nations (FAO) and the World Organization for Animal Health (OIE), the plan adopts the One Health approach and aims to expand knowledge about AMR, strengthen epidemiological surveillance, combat infections, promote the rational use of antimicrobials in humans and animals, and ensure sustainable investments for its implementation. (Olive tree; Pear tree; Zamberlam, 2020)

While surveillance is an essential tool for informing infection prevention and control policies and strategies, it is critical in assessing the spread of AMR and monitoring the impact of local, national, and global actions. Since its foundation, the National Health Surveillance Agency (ANVISA) has developed actions aimed at the prevention and control of AMR, actively participating in the WHO's global campaign with educational materials and specialized discussions. In 2015, WHO launched the Global Antimicrobial Use and Resistance Surveillance System (GLASS), a collaborative initiative to standardize AMR surveillance, support the Global Action Plan, and guide strategies to combat resistance at all levels. (National Health Surveillance Agency, 2024b; World Health Organization, 2020)

Similarly, emerging technologies such as alternative therapies have gained prominence in the fight against resistance to multiple antibiotics, with phage therapy being one of the most promising approaches. This technique uses bacteriophage viruses to eliminate bacterial infections, offering an innovative and effective strategy in the treatment of infections resistant to conventional antibiotics. Thus, phage therapy emerges as a potentially revolutionary solution for the control of resistant bacterial infections. (Santos et al., 2024)

Similarly, gene-editing approaches, such as the CRISPR-Cas system, are being investigated with the goal of modifying bacterial resistance genes and reestablishing antibiotic sensitivity. In addition, the application of artificial intelligence (AI) in functional genomics, especially in enhancing the use of CRISPR technology, stands out as a revolutionary innovation, taking advantage of a mechanism originally used by bacteria as a defense against viruses. (Matthias; Oak; Silveira, 2024; Prado et al., 2023)

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With the increase in the scale of biological big data, several AI-based methods have emerged for its analysis. These tools make it possible to prevent new antibiotic compounds, identify resistant bacteria through imaging, and speed up the tracking of promising compounds. In addition, AI uses genomic data to anticipate possible resistance sites and enzyme functions, contributing to the development of more effective antibiotics (Liu et al., 2024) .

In the field of microbiology, genomic analysis plays a fundamental role in enabling the identification and differentiation of microorganisms based on their DNA sequences. Through these tools, it is possible to identify variations in the genetic material of organisms of the same species, map genes associated with resistance mechanisms, and determine whether these genes are linked to mobile genetic elements or are part of the constitutional genome of the organism. (Menezes, 2021)

Unquestionably, strengthening health education is indispensable to face an AMR crisis. Clear information about the risks and benefits of medicines empowers the population to make conscious and safe choices. At the same time, educational programs demystify mistaken questions and encourage responsible behavior. To this end, it is necessary to implement campaigns aimed at the population and continuing education programs for health professionals, promoting safer and more effective practices. (Barbosa et al., 2024b)

In addition, public-private partnerships are the most visible manifestation of the power of collaboration to advance research and development in diseases that predominantly affect the most disadvantaged. The products developed through these partnerships almost always have clear and transparent strategies to ensure access to them. (Dias, 2022)

Still in the context of strategies to cope with an AMR crisis, continuous surveillance of resistance rates and pattern analysis are essential to guide infection control practices and therapeutic strategies. WHO emphasizes the importance of robust surveillance systems capable of rapidly identifying and responding to outbreaks of resistance. In Brazil, the Antimicrobial Resistance Monitoring Network, under the coordination of ANVISA, plays a key role in the collection and analysis of data related to this problem. (Cavalini et al., 2024)

In summary, public policies and the development of new therapies play a crucial role in mitigating AMR. Progress in public health requires continuous evolution, integrating technological innovations and practices based on scientific evidence. The future of this field

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requires a collective effort in which governments, health professionals, communities and individuals collaborate in an integrated way to foster a healthy and equitable environment, ensuring the integral well-being of the population (Barbosa et al., 2024a).

CONCLUSION

AMR has profound impacts on global public health, representing one of the greatest challenges faced by contemporary medicine. The projected increase in deaths attributable to AMR by 2050 is alarming, especially among older individuals, highlighting the need for immediate and coordinated action to mitigate its effects. Resistance mechanisms, such as bacterial structural and functional changes, added to the global spread of resistant pathogens, compromise the effectiveness of antimicrobial treatments, increasing costs and increasing morbidity and mortality associated with resistant infections.

The analysis of the results obtained reveals that the factors contributing to the spread of AMR, such as the inappropriate use of antibiotics, self-medication practices, lack of basic sanitation, and inadequate infection control, are structural issues that require urgent attention. Low- and middle-income countries face additional barriers, such as disorderly distribution of medicines and limited access to quality treatment, exacerbating inequality in tackling AMR. This disparity is reflected in the challenges faced in controlling diseases such as multidrug-resistant tuberculosis and resistant sexually transmitted infections.

For society, the findings highlight the importance of health education and the implementation of public policies that promote the rational use of antimicrobials. In addition, the strengthening of epidemiological surveillance and the development of new technologies, such as phage therapy, gene editing, and the application of artificial intelligence, offer promising tools to combat AMR. The role of health professionals, especially pharmacists, is essential in guiding the population on the correct use of antibiotics, contributing to the reduction of self-medication and the indiscriminate use of these drugs.

Thus, it is recommended that future studies deepen the analysis of new therapies and emerging technologies, aiming to expand therapeutic options and improve the diagnosis of resistant infections. In addition, investigations that evaluate the effectiveness of existing public policies and awareness campaigns are essential to adjust strategies and ensure more effective results.

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