

## Scenario and trends in nanotechnology: a literature review

### ABSTRACT

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Nanotechnology is an area of knowledge that operates on a nanoscopic scale, producing new materials from atoms. The aim of the research is to present and analyze the applications and trends of nanotechnology in the various areas of knowledge, based on the scientific production available, while also verifying the possible risks arising from the use of this technology. Articles were selected on the Portal Periódicos CAPES and the abstracts were analysed through software Iramuteq. The results obtained are significant for understanding the current scenario of nanotechnology, which has numerous applications, helping to facilitate human actions and avoid future problems, especially in the health area with the help of nanotechnology equipment, and which produces potential benefits in other areas such as education, industry and agriculture. With regard to risks, the papers analyzed highlight the need for more ongoing and in-depth research to ensure the well-being of society. Nanotechnology is an area of knowledge that has been updated over the years and has broad applications and must take cultural and social differences into account. The certainty is that the future will rely even more on the contributive effects of nanotechnology on society.

**KEYWORDS:** Nanotechnology. Nanoscience. Nanomedicine. Welfare of society. Bibliographical research.

## INTRODUCTION

Nanotechnology is an area of knowledge that operates on a nanometric scale in matter, producing new materials from atoms. Some of the areas in which nanotechnology is applied are: nanomedicine, nanoelectronics, flexible and wearable devices, the internet of things, food, computer science, physics, chemistry, biology, materials engineering and nanobiotechnology, which is widely used to help cure diseases (Leopoldo; Vecchio, 2020).

Martins and Siqueira (2007) carried out a bibliographic survey of nanomaterial construction techniques and presented the applications of nanotechnology in the restoration of traumatized peripheral nerves and even in the manipulation of axons, as also indicated by the authors Giri, Maddahi and Zareinia (2021).

In their bibliometric study, the authors Renzcherchen et al. (2022) state that the scientific papers in the databases on the subject of nanotechnology and sustainability are related to waste management and wastewater treatment, and also report that there are gaps in the literature on nanotoxins in the human body and the environment.

In a broader context, nanotechnology can be understood as a social technology. This occurs when it takes inclusion, sustainability and community participation into account, as it can promote the development of a community and contribute to society itself (Alvear et al., 2024) and according to the authors Antunes Filho and Backx (2020), it encompasses complex processes at both the technological and scientific levels with impact on society.

In the area of nanopharmaceuticals, Pereira et al. (2022) state that with the COVID-19 pandemic, nanotechnology could be used to make textile fibers with silver nanoparticles due to their antibacterial and antiviral characteristics. Other uses of nanotechnology extend to cross-cutting areas, such as biotechnology, and this integration between different fields, combined with the Sustainable Development Goals (SDGs) of the United Nations 2030 Agenda, reinforces the prominent social and environmental dimensions of the area, in addition to highlighting the broad potential for application of this technology (Robusti; Farina, 2025).

In this way, the broad spectrum of application of nanotechnology in the various sectors of activity and in health becomes clear. As an enabling technology of importance to Brazil and the national industry, it is timely to present its applications and trends in the various areas of knowledge. Professionals and academics, as well as society, can benefit and learn about this technology and contribute to its development. Therefore, the research problem of this study is: what are the applications and trends of nanotechnology, in the various areas of knowledge, based on available scientific production?

Thus, the aim of this research is to present and analyze the applications and trends of Nanotechnology in the various areas of knowledge, based on available scientific production. The justification for this work is to present the applications and trends of Nanotechnology, in the various areas in which this technology is present, such as: nanomaterials, nanointermediaries, and products enabled by Nanotechnology, as well as analyzing the possible risks and advantages arising from the use of this technology and, with this, it seeks to fill the gap observed in

the review work carried out by Antunes Filho and Backx (2020), since the authors stress the need for more studies in this area.

### THEORETICAL REFERENCIAL

The idea of manipulating atoms and molecules was seen by Richard Feynman as a breakthrough in science. However, for this breakthrough to become a fact, it was necessary to create equipment capable of recording images on a nanometric scale and, in 1986, the scanning electron microprobe microscope appeared (Sanfelice; Pavinatto; Correa, 2022).

Nanotechnology seems to be a topic that is far removed from people's daily lives and there is a need for students to become scientifically literate and for people to be informed so that there is a greater understanding of the subject. The authors Clebsch and Watanabe (2017) made several hypermedia materials published on a blog about the subject for primary school students and concluded that nanotechnology sparked in-depth study and discussion, contributing to their learning.

Díaz-Marcos and Mendoza González (2025) analyze the role of education in the popularization of nanotechnology, emphasizing its importance in scientific training from the earliest school levels. Among the various pedagogical initiatives presented, the authors mention the NanoInventum project, which promotes creativity, critical thinking and inclusion, in addition to addressing ethical and social aspects of nanotechnology, proposing an interdisciplinary and responsible approach to its teaching and dissemination. In this project, the authors also highlight the emphasis on the role of girls who are underrepresented in the disciplines of science, technology, engineering and mathematics. The authors conclude that integrating nanotechnology into education requires a broad approach to prepare new generations.

Oliveira, Arusievicz and Barcello (2025) also address this issue in the research they carried out regarding the existing barriers that hinder women's participation in the areas of Information Technology, indicating that gender issues harm women's trajectory in the technological field since childhood. Due to its broad scope, nanotechnology must be researched and presented to society taking into account the relationship between science, technology and society and deepening the analysis of technology with gender relations, technology and education, in addition to other topics.

Regarding social transformations Silva Júnior et al. (2020) carried out a systematic review of the literature on the subject of "Nanoscience and Nanotechnology - N&N integrated into education" and concluded that the approach is still scarce in Brazil. However, given the importance of the topic, it is considered that more studies should be carried out to broaden scientific dissemination and deepen understanding of the Nanotechnology scenario and trends. This can offer opportunities for entrepreneurship, especially entrepreneurs who try new opportunities based on technology, according to Koch, Machado and Lazzarotti (2024), which can create value for certain regions and for society in general.

According to Fernandes and Filgueiras (2008), Chemistry is related to Nanotechnology since it deals with the composition and structure of matter, both

at the molecular and atomic levels, and Nanosciences and Nanotechnologies (N&N) represent manipulation, production and assembly at these levels. After analyzing Nanotechnology in Brazil, the authors point out that there is a direction of innovation in this area where companies from various sectors and researchers are making partnerships and there are policies to support these initiatives.

Junges et al. (2022) emphasize that the development of nanotechnology in the food industry aims to avoid waste, optimize the production chain with a consequent reduction in cost and also increase the shelf life of ingredients. It is important to emphasize that there are benefits for society and no dangers to people or the environment (Gomes et al. 2015). Resch and Farina (2015) identified four trends in the mapping of nanotechnology knowledge in the agri-food sector: the use of biosensors to detect contamination, the use of active packaging, the delivery of encapsulated nutrients, and issues related to regulation, risks and benefits.

Teixeira et al. (2018) emphasize the importance of graphene in civil construction since it can be included in production to increase the strength of materials as well as not containing toxic substances and therefore contributing to sustainability, which is corroborated by Correa Neto et al. (2020).

Pinto and Invernizzi (2020) evaluated the influence of the National System of Nanotechnology Laboratories (SisNANO) at the Federal University of Paraná and found that the results obtained indicate that the laboratory has contributed to the formation of interdisciplinary research networks.

Pinto, Hupffer and Quevedo (2021) carried out a bibliometric study from 2007 to 2019 and found that the increase in scientific production was 624.93% in relation to the period from 1991 to 2006, focusing on the Web of Science database and this result indicates the crucial role that Nanotechnology has been playing.

Hupffer and Lazzaretti (2019) point out that the characteristics of nanomaterials are important and contribute to improving life and society, as highlighted by Drewes et al. (2016) in the treatment of skin cancer, however, their regulation is a major challenge to be debated between governments, companies and sectors of activity as well as society due to the risks associated with these products for health. Ferreira, Cemlyn-Jones and Cordeiro (2013) warn of respiratory effects such as multifocal granulomas, inflammation of the bronchi, among others, due to the characteristics of nanoparticles.

Santos and Matos (2022) also highlighted the risks that the development of nanoproducts in different segments can cause for society. Due to the fact that these materials have only been available on the market for a short time, it is important that information is analyzed regarding the risks that the environment may be subjected to and the negative effects on human health.

The authors also highlight the importance of creating an effective inventory of all available nanoproducts. The most current inventory, "The Nanodatabase", still lacks information, such as the labeling on the packaging of products indicating that they are nanotechnological. This lack of information can make it difficult for consumers to understand the material they are purchasing (Santos; Matos, 2022), a concern already highlighted by Batista and Pepe (2014).

Ferreira, Villalobos and Moura (2015) highlight the importance of e-science (data-intensive science) for researchers working in collaboration, forming a

network in the area of Nanotechnology of the National Institutes of Science and Technology (INCT) in a study carried out between 2008 and 2014. The authors conclude that the large supply of data demands more collaborative relationships in the scientific community, which can contribute to scientific knowledge and a better society.

Silva et al. (2025) highlight the importance of nanomaterials in agriculture, superior to the agrochemical products used, with more productivity and less waste. The economic and environmental advantages must be added. According to the authors, nanotechnology transforms the sector by boosting more research.

In this way, the joint work of researchers in the many areas of Nanotechnology research with indications of trends in the various fields of activity can help to leverage more knowledge on the subject of Nanotechnology and ensure society's understanding of its applications.

Nanotechnology generates innovative solutions in areas such as health, agriculture, education and the environment and, when applied with a focus on improving people's lives, inclusion, sustainability and community participation, it comes closer to the concept of social technology. In this way, nanotechnology is a tool that contributes to human and territorial development.

## **METHODOLOGY**

This study is an automated content analysis survey of the papers selected in the Portal Periódicos CAPES with the expressions "Nanotechnology" and "scenarios" and "tendencies" and "risks", in the period from 2014 to 2022 for scientific articles, which resulted, after analysis and selection, in 82 works consistent with the research objective. The collection, identification, selection and analysis of scientific articles that deal with a particular topic and its applications, scenarios and trends contributes to knowledge, and is the specific type of bibliographical research, according to Marconi and Lakatos (2021).

In order to facilitate content analysis based on the abstracts of the selected articles, Iramuteq software was used, observing the results of groupings using the Descending Hierarchical Classification (DHC) and the active words with the highest number of citations. The Iramuteq software is based on the Python and R programming languages to carry out statistical analyses based on textual corpuses and lexical analysis, which helps in studies in the Humanities and Social Sciences by allowing a large volume of texts to be analyzed (Camargo; Justo, 2018). The work presents the applications of Nanotechnology: in sustainability, education, food production, the discovery of new treatments and medicines in order to contribute to raising awareness in society and motivating more studies in general.

## **RESULTS AND DISCUSSION**

With regard to word frequency, using the Iramuteq software, the term "nanotechnology" is the most prominent, used 182 times within the abstracts, the adverb "as" (158) appears in second place and in the abstracts it appears in expressions of the following form: "This work aimed to analyze the dynamics of [...] in human beings" (Giuriatti et al., 2020). "The use of nanomaterials as

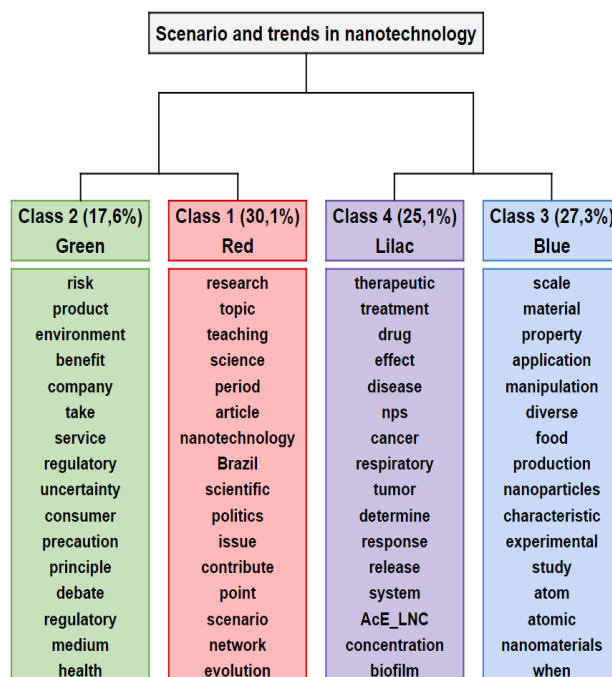
treatment enhancers holds great promise [...]" (Guerra, 2021); "nanotechnology stands out as a promising alternative in the current context of Brazilian technological innovation [...]" (Laniski et al., 2022). Followed by the terms application (66), research (60), nanoparticles (51), new (50), area (46), science (44), material (43), study (42). This indicates that nanotechnology is always linked to another area of general knowledge and is presented in applications for the benefit of various fields in society, as highlighted by Silva et al. (2025) about the importance of nanotechnology.

With regard to the word "application", it is used in two distinct moments, both to indicate general applications "[...] have properties with a specific function, which allows them to be applied in various areas [...]" (Santos et al., 2019); and to indicate the application of nanotechnology in the specific development of something "[...] involving nanotechnology with application to the development of medicines for use in humans [...]" (Giuriatti et al., 2020).

While the word "research" essentially reflects the results obtained in the articles or what is being researched, as seen in: "The research points out that there is no specific regulation for nanotechnologies in Brazil [...]" (Lazzaretti; Hupffer, 2019), although already indicated by Resch and Farina (2015). In turn, the word nanotechnology appears at several different times due to the fact that it is the main object of research in the papers analyzed.

The Iramuteq software was used to apply the Reinert method to obtain the Descending Hierarchical Classification (DHC) and the textual classes that take into account lexical proximity and similarities in the text segments in order to include in each class the words most associated with each other (Salviati, 2017). In Figure 1, the subjects were grouped into 4 classes, with the aim of separating all the topics covered by the selected abstracts in an organized way.

Figure 1 - Dendrogram of the 4 lexical clusters classified by Iramuteq.



Source: Prepared by the authors using Iramuteq software.

The first class (colored red), which accounts for 30.1% of all text segments, presents nanotechnology in studies and terms linked to general research such as: Research; Theme; Science; Scenario; Evolution; Analyze and to Point. It represents articles on nanotechnology applied to an environment of study and analysis. These studies could, for example, be linked to nanotechnology applied to the food or agri-food industry.

As an example of a study environment, the authors Resch and Farina (2015) deal with the agri-food sector in which nanotechnology is widely used and one of its possibilities is to detect pesticides or invaders using nanosensors, as well as leveraging crop protection with the nanoformulation of pesticides and fertilizers.

Another example is biosensors, which are essential for food protection, as they detect the appearance of pathogens (host disease organisms) and preserve production. The nanosensors connected to the biosensors deliver a positive result, because the detection surface of the nanosensors is small, the results delivered can be analyzed more carefully (Resch; Farina, 2015). This class can be nominated as Scientific Production in Nanotechnology: Contributions, Themes and Policies.

The second class (green) delivers words linked to nanotechnology and human beings, because in this class there are words such as: Risk; Product; Uncertainties; Environment; Benefit; Services; Precaution and Consumer. It can be seen that a total of 17.06% of this analysis focuses on nanotechnology and its positive and negative impacts on the environment and human beings. The first word in this class is risk and this problem is alerted by Santos and Matos (2022) about the consequences to human beings and society.

These studies are presented, for example, in the application of nanotechnology in the fashion industry. The authors Britto, Kitazawa and Pepece (2019) present nanotechnology applied to the fabric threads that make up a garment, which can help protect pregnant women from contact with mosquitoes. Some species can cause serious risks to children, such as microcephaly, and because of this, the company Megadose has created garments with repellent properties applied to the textile threads. In this case, the substances that form the repellent are micro-encapsulated and impregnated directly onto the fabric, significantly protecting (especially pregnant women) from mosquito bites.

Nanotechnology is linked to medicines, mainly in controlling the release of drugs. Drugs are the substances that make up any medicine, and with nanotechnology it is possible for nanostructured systems to help release these drugs into the body, making the effect of the medication or treatment more assertive and also minimizing side effects (Batista; Pepe, 2014). This class is nominated as Risks, Benefits and Socio-Environmental Regulation in the Nanotechnology field.

In the third class (blue), the main subjects are the variations of nanotechnology in its forms of use, such as: Nanoparticles; Nanometrics; Properties; Application; Manipulation; Nanomaterials; Scale and Material. It can be seen that within the subject studied, there is a range of variations in the ways in which it is used.

For example, chitosan nanoparticles can contribute to technological advances in the food industry. Some animals, especially exoskeletons, need a protective and supportive base in their bodies to facilitate their development in their environment

of origin and this protective base is called chitin. Alkaline deacetylation of chitin (changing the natural formula) results in chitosan, which is an excellent natural biopolymer that can be modified. This polymer of chitosan nanoparticles provides benefits in the field of biomedicine and is used in the release of drugs, delivering some therapeutic effects to humans and animals, and is also used to strengthen vaccines, strengthen joints and even regenerate cartilage tissues. Chitosan nanoparticles, when linked to nanoparticles that can be manipulated in magnetic fields, contribute to water treatment (Toledo; Soares, 2016).

Nanotechnology in water treatment can be used for many benefits, and in different functionalities that are divided into three stages. The first stage is called "Treatment and Remediation", where in this stage nanotechnology contributes to the healthy prolongation of water, in the process of rehabilitating non-potable water and in desalination, which is the removal of salts from salt water. The second stage is called "Sensing and Detection" and aims to help nanotechnology detect biological contaminants using sensors and also facilitate the creation of low-cost equipment capable of carrying out water analysis. The last stage is "Pollution Control", which has the possibility of using nanomaterials to treat polluted wastewater (Santos et al., 2019).

The author Fuenmayor (2017) presents an application of nanotechnology in agriculture. A deficiency was detected in the traditional application of agrochemicals, because in some cases and with climate interference, insecticides, herbicides, among others, end up not being able to perform their function for a long time and, with this, the study of encapsulating agrochemicals in nanoparticles was developed, so that their functionality lasts longer and the damage to the environment decreases since there will be less use. This class can be nominated as Characterization and Applicability of Nanoparticles in Technological and Food Processes. All these applications contribute to life and society (Hupffer and Lazzaretti, 2019).

Finally, in the fourth class (lilac color), the graph shows the areas in which nanotechnology can be applied: Therapeutic; Treatment; Drug; Disease; Cancer; Tumor; System and NPS (nanoparticles). This class shows that there are many studies on the application of nanotechnology in the health area, with a percentage of the total text of 25.1%, what confirms nanotechnology as a social technology (Alvear et al. 2024)

This class shows a large number of studies focused on nanotechnology in the health area, such as the contribution of nanotechnology to the treatment and discovery of brain cancer. This contribution is due to the fact that, due to the small size of the nanoparticles, between 10 and 100 nanometers (nm), it is possible for them to enter the genetic mutation system within the tumor. This is due to the EPR effect - Enhanced Permeability and Retention of tumors, which, due to this effect, allows the tumor to accumulate hydrophilic nanoparticles in its environment. It is important that the nanoparticles that enter the tumor mutation use hydrophilic polymers, such as polyethylene glycol (PEG), which leaves the nanoparticles surrounded by proteins, increasing their half-life and consequently allowing them to reach more distant tumor cells (Pereira, 2014).

Skin cancer caused by heavy exposure to ultraviolet rays, or from genetic factors, known as malignant melanoma, is highly dangerous, causing the death of many patients and nanotechnology is a contributor to its treatment. Only one type

of treatment has been tested in some patients, which is based on the encapsulation of albumin (protein) in nanoparticles containing anti-cancer cell medication, which, due to their size, target this medication more effectively to the center of the tumor mass, as highlighted by the authors Drewes et al. (2016).

The authors Ratija et al. (2021) show that these treatments, both for tumor cancer and skin cancer, can be applied to other types of cancer, such as breast cancer, ovarian cancer and brain cancer, bringing greater degradation of tumors in smaller amounts of medication and contributing to greater effectiveness of common treatments such as chemotherapy, radiotherapy and surgery. This class can be nominated as applications and therapeutics of nanotechnology in diseases. The expression nps means nanoparticles and the expression AcE LNC means AcE-LNC: Aceclofenac-loaded Lipid-core Nanocapsules.

The analysis segmented by the Iramuteq software shows the trends and applications of nanotechnology, highlighting its importance and potential in various sectors, from agriculture to medicine, presented in different classes. These classes show an interconnection between general studies of nanotechnology (class 1) and concerns about its risks and benefits (class 2). At the same time, they indicate how the properties of nanotechnology (class 3) are applied in specific fields such as disease treatment and drug development (class 4). This highlights the far-reaching impact of nanotechnology on new technologies and treatments, as well as on improving industrial and environmental processes.

Nanotechnology can boost the creation of new ventures based on innovation and is related to the theme of technological entrepreneurship, through scientific production and practical applications of knowledge (Koch; Machado; Lazzarotti, 2024). In this context, nanotechnology represents not only a technical advance, but also a strategic opportunity for the development of innovative businesses.

## RISKS OF NANOTECHNOLOGY

The second class identified in the CHD (Figure 1), whose main topic is "Risk", highlights the importance of understanding the possible risks that nanotechnology poses to society. In the area of health, nanotechnology is widely explored, but the use of nanomedicines and equipment can bring significant risks. Batista and Pepe (2014) point out that although nanotechnology can improve the release of drugs, it can also make medicines toxic at certain stages, increase their costs, harming the lower social classes, and allow nanoparticles to reach other organs.

In Brazil, the verification and release of medicines containing nanotechnology is carried out by the Agência Nacional de Vigilância Sanitária (ANVISA). This is in accordance with Law No. 5.076 of 2005, which created the Comissão Técnica Nacional de Nanosseguurança (CTNano) and set up the Fundo de Desenvolvimento de Nanotecnologia (FDNano). These institutions ensure the safe commercialization of nanotechnology products and promote research into their risks, as well as requiring the proper labelling of medicines (Batista; Pepe, 2014).

The authors Santos and Matos (2022) note that nanotechnology is being applied in various sectors, requiring an understanding of the risks to the environment and human health. Certain nanomaterials, such as carbon nanotubes and zinc oxide (ZnO) nanoparticles, can release toxic substances into the environment. Consales (2022) points out that nanoparticles can enter the

bloodstream through breathing or the gastrointestinal system, being distributed to organs such as the spleen and liver, which intensifies the risks due to the small size of the particles.

Despite the relevance of the risks, there are few articles available on the toxicity of nanotechnology, partly because the negative effects are difficult to assess due to their particularities and unpredictability. This panorama highlights the need for continuous and in-depth research to guarantee the safe use of nanotechnology in society (Consales, 2022).

## CONCLUSIONS

The present research aimed to evaluate the applications and future trends of nanotechnology and thus obtained relevant conclusions concerning nanotechnology in the current scenario. One can observe the presence of nanoproducts in all segments of the present day and this is because everything that exists has atoms and everything that possesses atoms has there a possibility of creating a nanotechnological product (Consales, 2022). With this, the research gathered and classified, with the help of Iramuteq software, what are the main classes of action of nanotechnology, which allowed a detailed and segmented research in relation to the various areas of human knowledge.

The research has shown that nanotechnology is a topic that is being dealt with relevance by researchers. In fact, there is a significant amount of published articles that analyze the effects of nanotechnologies on society. These analyses highlight potential benefits in various areas, such as education, health, industry, agriculture and many others.

Applications of nanotechnology are very present in the area of health and this is because the encapsulation of some medicines potentiates its effects and makes it able to reach distant places within a tumor, for example.

It can also be observed that nanotechnology has a direct link with biotechnology and when these two areas are united, positive effects are potentialized. A great example mentioned in the research is the ease of finding host organisms in foods with the help of nanosensors applied to biosensors.

In addition to all the applications presenting the benefits of nano in the human environment, a study was also carried out based on the risks it brings to society. Indeed, as it is an area of recent studies, there are no concrete results regarding its harm to humans but there are many speculations for future results, such as the risk of a widespread contamination of the components of a nanoproduct.

The study has for limitation the selection of articles in only one database, being the Portal Periódicos CAPES, which in turn has a greater focus on the indexing and availability of materials produced in Brazil, which can impair the scope of the study. Therefore, an expanded study with other databases could be advantageous to explore more in depth the trends of nanotechnology, especially as regards its international scene. The rapid evolutionary dynamics of this area also suggest that the findings of this study reflect a specific moment and may not cover future developments.

In fact, nanotechnology is an area of knowledge that is updated over the years and with the advances of technologies and related areas, and therefore, the

existing applications demonstrated in this study are the doorway to future applications even more technological and modern. The certainty is that the future will rely even more on the contributive effects of nanotechnology on society. It is important that all these tendencies must take into account the point of view of cultural and societal differences

## **Cenário e tendências da nanotecnologia: uma revisão bibliográfica**

## RESUMO

A nanotecnologia é uma área do conhecimento que atua em escala nanoscópica, produzindo novos materiais a partir de átomos. O objetivo da pesquisa é apresentar e analisar as aplicações e tendências da nanotecnologia nas diversas áreas do conhecimento, com base na produção científica disponível, verificando também os possíveis riscos decorrentes do uso desta tecnologia. Os artigos foram selecionados no Portal Periódicos CAPES e os resumos foram analisados através do software Iramuteq. Os resultados obtidos são significativos para a compreensão do cenário atual da nanotecnologia, que possui inúmeras aplicações, ajudando a facilitar as ações humanas e a evitar problemas futuros, principalmente na área da saúde com o auxílio de equipamentos nanotecnológicos, e que produz potenciais benefícios em outras áreas como educação, indústria e agricultura. No que diz respeito aos riscos, os artigos analisados destacam a necessidade de pesquisas mais contínuas e aprofundadas para garantir o bem-estar da sociedade. A nanotecnologia é uma área do conhecimento que se atualiza ao longo dos anos e com amplas aplicações e que deve levar em conta as diferenças culturais e sociais. A certeza é que o futuro dependerá ainda mais dos efeitos contributivos da nanotecnologia na sociedade.

**PALAVRAS-CHAVE:** Nanotecnologia. Nanociência. Nanomedicina. Bem-estar da sociedade. Pesquisa bibliográfica.

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