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Nanotechnology And Development Of Biomaterials: Advances And Future, A Review

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Nanotechnology and the development of biomaterials represent two areas of research and development that have significantly transformed various scientific and engineering fields. Nanotechnology, which operates at a scale of 1 to 100 nanometers, allows the manipulation of materials at the atomic and molecular level, leading to the creation of new materials and devices with unprecedented properties. This advancement has been especially notable in medicine, where advanced drug delivery systems have been developed, improving efficacy and reducing side effects. Furthermore, in electronics, nanotechnology has allowed the manufacture of smaller, more efficient transistors, which has driven the development of faster electronic devices with lower energy consumption. On the other hand, biomaterials, both natural and synthetic, are designed to interact with biological systems with the aim of treating, increasing or replacing bodily functions. Natural biomaterials, such as collagen and alginate, are highly biocompatible, while synthetic ones, like polymers and ceramics, they are designed to meet specific strength requirements. The integration of nanotechnology in the development of biomaterials has facilitated the creation of more ecological and biodegradable materials, aligning with current trends towards sustainability and the circular economy. These advanced materials not only improve the quality of life of patients, but also offer innovative solutions to environmental problems, demonstrating the potential of science and technology to address global challenges.

Keywords: Nanoparticles; Biodegradability; Applications; Nanocomposites; Products.

1 Introduction

Nanotechnology has created a significant revolution in various fields of science and engineering, offering innovative solutions to today's challenges. One of the sectors that has shown the greatest potential in this context is the production of biomaterials. The integration of nanotechnology in the creation of these materials has enabled remarkable advances in medicine, biotechnology, and materials engineering. Biomaterials, designed to interact with biological systems, have seen a major evolution thanks to nanotechnology's ability to manipulate matter at the nanometric scale. (Mohammad, Zohreh, & Djalilian, 2023) (Dalwadi, Goel, Constantine , Salas-de la Cruz, & Xiao, 2023)(Adebayo, Fasiku, Ojo , & Oke, 2023) (Bermudez, Asgharian, & Warheit, 2020)

Recent advances in nanotechnology have made it possible to manufacture biomaterials with improved properties and specific functionalities. These materials can be designed to have outstanding biocompatibility, increased strength, and adjustable mechanical properties, making them ideal for medical applications such as tissue regeneration, controlled drug release, and advanced prosthetic production. For example, polymeric nanocomposites have shown great potential in tissue engineering, allowing the creation of three-dimensional structures that can mimic the structure and function of natural tissues.(Chen, Chunyan, & Qiangbin, 2023)(Zhang, Kingsley, P. Masonsong , & Ramaswamy, 2023) (Gonçalves, Araújo, Reis, & Pereira, 2021)

In addition, nanotechnology has opened up new possibilities for the detection and treatment of diseases. Nanomaterials, such as nanoparticles and carbon nanotubes, are being used to develop highly sensitive diagnostic systems and targeted therapies that can localize and treat diseases at the cellular and molecular level. These advances not only increase the precision and effectiveness of treatments, but also reduce side effects, providing a more personalized and efficient approach to healthcare.(Abaszadeh1, Hossein Ashoub, Khajouie, & Mahnaz, 2023)

Looking ahead, the combination of nanotechnology and biomaterials promises to continue transforming medicine and other industries. Current research focuses on developing smart biomaterials that can respond to external stimuli, such as changes in pH or temperature, and integrating artificial intelligence to design materials with specific and predictable properties. Likewise, sustainability is a growing concern, with efforts focused on the creation of ecological and biodegradable biomaterials that can minimize environmental impact.(Abraham & Venkatesan, 2023)(Yamuna, y otros, 2023) (Peso de Pralhad & Shivprakash, 2023)

In short, nanotechnology plays a critical role in the evolution of biomaterials, providing tools and techniques that enable unprecedented advances in a variety of applications. Continuous exploration and development in this field not only has the potential to improve the quality of life, but also to open new frontiers in science and technology. These developments promise a more innovative and sustainable future, where technology and nature can work hand in hand to offer efficient and environmentally friendly solutions. (Vidyasagar, Patel, & Singh, 2023)

The nanotechnology-driven evolution of biomaterials is an ever-expanding field, with new research and emerging applications continually redefining what's possible. As scientists and engineers explore new ways to manipulate materials at the nanometer scale, endless possibilities open up to improve human health and quality of life. Nanotechnology, with its ability to operate in the realm of atoms and molecules, offers an unprecedented platform to innovate and improve biomedical materials, making the future of medicine brighter and more promising.(Rovshan, 2023) (Gonçalves, Araújo, Reis, & Pereira, 2021)

2 Nanotechnology

Nanotechnology is a field of science and engineering dedicated to the creation and manipulation of materials at an extremely small scale, typically between 1 and 100 nanometers. A nanometer is a billionth of a meter, which means that we are working at a level where atoms and molecules constitute the basic unit of measurement.

This technology allows the construction of new materials and devices with unique properties due to the alteration of their structures at the atomic level. At the nanometer scale, materials can exhibit significantly different physical, chemical, and biological characteristics compared to their counterparts at the macro or micro scale. For example, gold, which is inert at the macro scale, can become catalytically active in its nanometer form. (Valdivieso & Mollinedo Portugal, 2021)

One of the major advances in nanotechnology has been in the field of medicine. Nanomedicine deals with the design of drug delivery systems, where nanoparticles can specifically target diseased cells, such as cancer cells, minimizing side effects on healthy tissue. In addition, nanomaterials are used to improve medical imaging and develop new types of diagnostics. (Herrera, 2020)

In the field of electronics, nanotechnology has enabled the creation of much smaller and more efficient transistors, which has led to the production of faster and less energy-consuming electronic devices. Carbon nanotubes and graphenes are examples of advanced materials that are revolutionizing the electronics industry due to their extraordinary conductive and mechanical properties.(Omietimi, y otros, 2023)

Nanotechnology is also influencing the manufacture of lighter and stronger materials for applications in aerospace, automotive, and construction. Nanocomposites, for example, offer significant improvements in the strength and durability of materials, opening up new possibilities in design and engineering.

3 Biopolymers

Biomaterials are materials designed to interact with biological systems in order to treat, augment, or replace tissues, organs, or functions of the body. These materials can be natural or synthetic, and their development has revolutionized modern medicine, providing innovative solutions for a wide range of medical applications. (Gonçalves, Araújo, Reis, & Pereira, 2021)

Natural biomaterials include components such as collagen, fibrin, and alginate, which are found in the human body or other organisms. These materials are biocompatible and can be easily integrated with the body's tissues, minimizing adverse immune responses. On the other hand, synthetic biomaterials, such as polymers, ceramics, and metals, are specifically designed to meet certain mechanical, chemical, and biological requirements. These materials can be more durable and resistant than natural materials, and their composition can be adjusted to optimize their performance in specific applications. (Vazquez, y otros, 2020)

One of the main advantages of biomaterials is their ability to be customized according to the patient's needs. For example, in tissue engineering, biomaterials can be molded into specific shapes and combined with patient cells to create structures that resemble and function like natural tissues. This is particularly useful in repairing damaged tissues or creating implantable prostheses and medical devices. (Gómez, Villagra, & Solorzano, 2019)

In addition, biomaterials are used in the controlled release of medicines. In this field, biomaterials can be designed to release drugs in a controlled and sustained manner, which improves treatment efficacy and reduces side effects. Hydrogels, for example, are used as matrices for drug delivery, allowing precise and localized delivery.(Orozco , 2023)

However, the development and use of biomaterials also present challenges. Biocompatibility and the body's response to these materials are critical factors that must be considered to avoid adverse reactions. Research in this field continues to advance, with the aim of improving the integration of biomaterials and their long-term functionality. (Herrera, 2020)

China leads scientific production in nanosciences and nanotechnology, followed by the United States, which has the highest number of citations and an H-index that measures both the scientific productivity of journals and their global impact. The largest amount of scientific production comes from countries in Europe, Asia and North America. When evaluating the coefficient of variation, a great heterogeneity is observed among the countries listed in Table 1.

Board 1

Scientific production in nanotechnology

N°	Country	Publications	Citations	Self-Appointments	H-Index
1	China	148821	5515802	3518478	542
2	USA	115276	6619469	1995361	712
3	South Korea	38161	1351802	270020	362
4	Germany	36340	1474027	288778	371
5	Japan	33215	1176119	247874	331
6	India	25190	620163	185480	241

7	United Kingdom	23687	1072172	155567	343
8	France	22149	727058	131962	261
9	Italy	15111	521847	102674	234
10	Taiwan	14913	471037	69229	229
11	Spain	13883	509233	86641	237
12	Russia	13046	204455	58391	150
13	Australia	12847	598316	82841	270
14	Canada	12580	536083	69372	251
15	Singapore	11955	708200	69284	314
16	Switzerland	8925	462285	48353	261
17	Netherlands	8204	412150	44759	251
18	Iran	7966	175180	57705	134
19	Hong Kong	7192	358211	34506	234
20	Sweden	6900	282869	36173	198

Source: Restrepo-Betancur, Modified by Pilco Carlos & Vázquez Calome Hugo (2024)

3.1 Types of Biopolymers

3.1.1 Cellulose

Cellulose is the most abundant biopolymer in nature, composed of long chains of glucose molecules. It is mainly found in the cell walls of plants, where it provides structure and support. In industry, cellulose is widely used for the production of paper, textiles, and as a food additive. Its ability to form films and fibers makes it ideal for applications in sustainable and biodegradable materials. Cellulose can be chemically modified to produce derivatives such as microcrystalline cellulose, used in pharmaceuticals, and nitrocellulose, used in the manufacture of explosives and lacquers. In addition, cellulose is a key component in the production of bioplastics, offering an eco-friendly alternative to traditional plastics. Its biodegradability and abundance make cellulose a material of growing interest in research into sustainable materials and the circular economy.

3.1.2 Starch

Starch is an energy-storing polysaccharide, present in many vegetables such as potatoes, corn, and wheat. It is composed of two types of molecules: amylose and amylopectin. Starch is widely used in the food industry as a thickener, stabilizer, and gelling agent. In addition, in the pharmaceutical industry, starch is used as an excipient in the formulation of medicines. In recent years, starch has gained attention in the manufacture of bioplastics due to its biodegradability and abundance. Starch-based bioplastics can be used in disposable packaging, bags and utensils, thus reducing dependence on petroleum-based plastics. Starch can also be chemically modified to improve its mechanical and barrier properties, making it more suitable for various industrial applications. Ongoing research in the field of biopolymers seeks to optimize the use of starch as a renewable and sustainable resource. (Chatterjee, et al., 2023) (Sha Li , y otros, 2023) (León & Noreño, 2023) (Saldivar Tanaka, 2024)

3.1.3 Chitin and chitosan

Chitin is a polysaccharide found in the exoskeletons of insects and crustaceans, as well as in the cell walls of fungi. Chitosan is a derivative of chitin, obtained through a process of deacetylation. Both materials are known for their biocompatibility and antimicrobial properties, making them ideal for applications in medicine and the food industry. Chitosan, in particular, is used in the manufacture of wound dressings, drug delivery devices, and in water purification due to its ability to adsorb heavy metals and contaminants. In addition, chitin and chitosan are used as thickening and stabilizing agents in the food industry, and as additives in cosmetic products to improve skin hydration and elasticity. Biopolymer research continues to explore new applications for these materials, taking advantage of their unique properties and sustainable origin. (Sandra, Sill, Patra, & Stela, 2019)

3.1.4 Collagen

Collagen is a fibrous protein found in abundance in the connective tissue of animals, including skin, bones, tendons, and ligaments. It is essential to maintain the structure and elasticity of the tissues. In the cosmetics industry, collagen is used in anti-aging creams and treatments due to its moisturizing and regenerating properties. In medicine, collagen is used in the manufacture of sutures, implants and matrices for tissue engineering. It is also used in the production of gelatin, which is widely used in the food and pharmaceutical industry. Collagen can be extracted from various animal sources, including cows, pigs, and fish, and can be hydrolyzed to improve its solubility and bioavailability in dietary supplements. Biopolymer research focuses on developing plant-based collagen and improving extraction and processing methods for more sustainable and efficient applications.(Jian, Solomon, Mostovei, & Viorel, 2023) (Vazquez, y otros, 2020)

3.1.5 Gelatin

Gelatin is a biopolymer derived from collagen, obtained mainly from the bones and skins of animals such as cows and pigs. It is known for its ability to form gels, which makes it invaluable in the food industry for the production of jellies, candies, yogurts, and meat products. In the pharmaceutical industry, gelatin is used in the manufacture of soft and hard capsules, as well as in the formulation of controlled-release drugs. Its viscoelastic properties and ability to retain water make it useful in cosmetic and personal care products, such as face masks and hair products. In addition, gelatin is used in biomedical applications, including matrices for tissue engineering and as a hemostatic agent in surgery. Gelatin is prized for its biocompatibility and ease of degradation in the human body, making it safe and effective for a wide range of applications. (Valdivieso & Mollinedo Portugal, 2021)

3.1.6 Soy and wheat gluten

Biopolymers derived from soy and wheat gluten are used in the manufacture of bioplastics and adhesives due to their mechanical properties and biodegradability. Soy protein is extracted from soybeans and processed to create bioplastics that can be molded into various shapes, used in packaging, disposable utensils, and agricultural products. Wheat gluten, on the other hand, is a protein found in wheat and is known for its ability to form elastic networks, making it suitable for the production of bioplastics and eco-friendly adhesives. Both materials are renewable and biodegradable, reducing reliance on petroleum-based plastics and contributing to environmental sustainability. Biopolymer research continues to explore new applications and improve the properties of these materials to make them more competitive and efficient in various industries. (Vidyasagar, Patel, & Singh, 2023)

3.1.7 DNA and RNA

DNA (deoxyribonucleic acid) and RNA (ribonucleic acid) are biopolymers essential for life, as they contain and transmit the genetic information of organisms. DNA is a double-helix molecule that stores genetic information in the form of nucleotide sequences, while RNA is a single-stranded molecule that transcribes and translates this information for protein synthesis. In biotechnology and medicine, DNA and RNA are used in a variety of applications, including gene therapies, vaccines, and gene editing. Messenger RNA (mRNA)-based therapies, such as COVID-19 vaccines, have proven to be highly effective and have revolutionized the field of immunization. Research continues to develop new techniques for the manipulation and delivery of DNA and RNA, with the aim of treating genetic diseases and improving human health. (Watson & Compton, 2021)

3.1.8 Polylactic Acid (PLA)

Polylactic acid (PLA) is a biodegradable polyester derived from lactic acid, which in turn is obtained from the fermentation of renewable raw materials such as corn and sugarcane. PLA is widely used in the manufacture of packaging, disposable utensils, and medical products due to its biocompatibility and favorable mechanical properties. In the packaging industry, PLA is used in the production of bottles, films and trays, offering a sustainable alternative to traditional plastics. In addition, in medicine, PLA is used in the manufacture of sutures, implants, and drug delivery devices. PLA is valued for its ability to biodegrade under industrial composting conditions, reducing the environmental impact of disposable products. Biopolymer research focuses on improving the properties of PLA and developing new applications for this versatile and environmentally friendly material. (Silva, Amaral, Leão, Gomes, & Sant'Ana, 2019)

3.1.9 Polyhydroxyalkanoates (PHAs)

Polyhydroxyalkanoates (PHAs) are a class of polyesters produced by bacteria as a carbon and energy storage medium. These biopolymers are completely biodegradable and biocompatible, making them ideal for a wide range of medical and packaging applications. PHAs can be processed into a variety of forms, including films, fibers, and molded objects, and are used in the manufacture of packaging, disposable utensils, and agricultural products. In medicine, PHAs are used for the production of sutures, matrices for tissue engineering, and drug-delivery devices. Their ability to biodegrade in different environments, including seawater and soil, makes PHAs an attractive option for reducing plastic pollution. Research continues to explore new bacterial strains and culture conditions to optimize PHA production and expand its industrial applications. (Vazquez, y otros, 2020)

Table 2 below presents a summary table on biopolymers highlighting their origin, applications and main properties

Board 2 Comparison of the types of biopolymers

Biopolymer Type	**Origin**	**Main Applications**	**Key Properties**
Cellulose	Plants	Paper, textiles, bioplastics, food additives	Abundance, biodegradability, film and fiber formation
Starch	Vegetables (potatoes, corn, wheat)	Bioplastics, thickener, stabilizer, gelling agent	Biodegradability, abundance, chemically modifiable
Chitin and Chitosan	Exoskeletons of insects and crustaceans, fungi	Bandages, drug delivery devices, water purification, cosmetics	Biocompatibility, antimicrobial properties

Collagen	Connective tissue of animals	Creams, anti-aging treatments, sutures, implants, gelatin	Hydration, regeneration, biocompatibility
Gelatin	Animal bones and skins	Food (jellies, candies), pharmaceutical (capsules), cosmetics	Gel formation, viscoelasticity, biocompatibility
Soy and Wheat Gluten	Soybeans, wheat	Bioplastics, adhesives	Renewability, biodegradability, mechanical properties
DNA and RNA	Genetic	Gene therapies, vaccines, gene editing	Transmission of genetic information, biocompatibility
Polylactic Acid (PLA)	Fermentation of renewable raw materials (corn, sugar cane)	Packaging, disposable utensils, medical devices	Biodegradability, biocompatibility, mechanical properties

Polyhydroxyalkanoates (PHAs)	Bacteria	Packaging, disposable utensils, agricultural products, medical applications	Biodegradability, biocompatibility, versatility

Source: Modified by Pilco Carlos & Vázquez Calome Hugo (2024)

4 Products made from biopolymers

4.1.1 Products made from cellulose:

- **Paper and cardboard**: Used in packaging, books, notebooks and other paper products.
- **Textiles**: Viscose and rayon are fibers derived from cellulose.
- **Bioplastics**: Disposable containers, bags and utensils.
- **Filters**: Used in cigarettes and water filtration systems.
- **Pharmaceuticals**: Microcrystalline cellulose as an excipient in tablets.(Arias-Aguilar, Araya-Salas, & Arias-Ceciliano, 2023)

4.1.2 Products made from starch:

- **Bioplastics**: Bags, containers, and disposable utensils.
- **Foods**: Thickeners in sauces, soups, and desserts.
- **Adhesives**: Adhesives for the paper and cardboard industry.
- **Medical products**: Controlled release capsules of medicines.
- **Cosmetics**: Ingredient in powders and skincare products.

4.1.3 Products made from chitin and chitosan:

- **Medical products**: Wound dressings, drug delivery devices.
- **Water purification**: Absorbents of heavy metals and pollutants.
- **Agricultural products**: Biofertilizers and seed coatings.
- **Food**: Preservatives and thickening agents.
- **Cosmetics**: Creams and skin care products.(Jáuregui-Nongrados, y otros, 2023)

4.1.4 Products made from collagen:

- **Medical Products**: Sutures, implants, and matrices for tissue engineering.
- **Cosmetics**: Anti-aging creams and moisturizing products.
- **Food**: Gelatin for desserts and dietary supplements.
- **Supplements**: Hydrolyzed collagen powder or capsules for joint health.
- **Biomedical materials**: Scaffolding for tissue regeneration.(Grandal-d'Anglade, 2024)

4.1.5 Products made from gelatine:

- **Foods**: Desserts, candies, and thickeners in yogurts.
- **Pharmaceuticals**: Soft and hard capsules.
- **Biomedical products**: Matrices for tissue engineering and hemostatic agents.
- **Photography**: Emulsions on photographic films.
- **Cosmetics**: Face masks and hair care products.(Arias-Aguilar, Araya-Salas, & Arias-Ceciliano, 2023)

4.1.6 Products made from soy and wheat gluten:

- **Bioplastics**: Disposable containers and utensils.
- **Adhesives**: Eco-friendly glues for wood and paper.
- **Foods**: Textured plant proteins and supplements.
- **Cosmetics**: Ingredients in skin and hair care products.
- **Compostable materials**: Biodegradable plastics for agricultural use.(Bernadette-Emőke, Gheorghe Adrian, Floricuța, Ioana Delia, & Vodnar, 2022)

4.1.7 Products made from DNA and RNA:

- **Gene therapies**: Treatments for genetic diseases.
- **Vaccines**: Messenger-RNA-based vaccines, such as COVID-19 vaccines.
- **Biotechnology**: Tools for gene editing and cloning.
- **Diagnostics**: Test kits based on DNA/RNA amplification.
- **Medical research**: Experimental models to study diseases.

4.1.8 Products made from polylactic acid (PLA):

- **Packaging**: Bottles, films and trays for food.
- **Disposable utensils**: Plates, glasses and cutlery.
- **Medical products**: Sutures, implants, and drug delivery devices.
- **Textiles**: Fibers for clothing and packaging materials.

- **3D printed products**: Filaments for 3D printers.

4.1.9 Products made from polyhydroxyalkanoates (PHAs):

- **Packaging**: Containers for food and beverages.
- **Disposable utensils**: Plates, glasses and cutlery.
- **Medical products**: Sutures, matrices for tissue engineering, and drug delivery devices.
- **Agriculture**: Biodegradable films and covers for crops.
- **Industrial materials**: Biodegradable for automotive and construction applications.

5 Methodology

The present research used a mixed method with an exploratory nature, focusing on the literature review on nanotechnology and the development of biomaterials: advances and future perspectives. An analysis was carried out that included the selection of articles published in relevant scientific journals, thus configuring a theoretical research with a documentary approach. This approach was specifically tailored to the identification and collection of data through a critical reading of documents and bibliographic sources.

The literature review provided crucial background that facilitated a deeper understanding of existing theories and previous contributions. This process helped to consolidate the necessary basis to address research on nanotechnology and the creation of biomaterials: advances and future developments.

(Herrera, 2020)The methodological approach used was based on bibliographic reviews carried out in various academic sources, such as scientific articles, books, technical journals and thesis projects. The main purpose was to evaluate nanotechnology technology and biomaterials development: advances and future developments. In addition, online resources were used, using electronic libraries and scientific platforms such as Scielo, Dialnet, Science Direct, and search engines such as Google Scholar.

In other words, the research combined an exploratory approach with a documentary analysis, using an exhaustive literature review as a basis to understand the use of starches and their applications. The mixed method made it possible to address the complexity of the topic from different perspectives, taking advantage of the abundance of data available in various academic and online sources. (Vazquez, y otros, 2020)

The choice of the mixed method and the literature review were based on the need to understand in depth the intersection between nanotechnology and biomaterials. This approach allowed for a detailed exploration of current trends, technological advancements, and future challenges in the field. By selecting scientific articles and other academic sources, the inclusion of accurate and up-to-date information was ensured, which enriched the quality and relevance of the findings.

The use of scientific platforms and online search engines was essential to access a wide range of recent studies and publications. These tools provided access to electronic libraries and databases that were essential for data collection and comprehensive analysis. The use of these platforms allowed for a thorough review and critical analysis of the existing literature, facilitating a comprehensive understanding of advances in nanotechnology and biomaterials. (Madrid, 2020)

In addition, the combination of an exploratory approach with a documentary analysis made it possible to approach the topic from multiple angles. This methodological approach facilitated the integration of diverse perspectives and the identification of key areas of innovation and development in the field of nanotechnology and biomaterials development. The literature review, by covering a wide range of sources, provided a holistic view of the current state of technology and future research directions. (Herrera, 2020)

6 Discussion

(Liu, De Haifeng, & El rey Yanjun, 2023)Nanotechnology and the development of biomaterials reveal the significant impact that they advance in medicine and other industrial applications. The integration of nanotechnology has enabled the creation of biomaterials with improved properties, offering innovative solutions to existing challenges in the treatment of diseases and the production of medical devices.(Soleimani, Zohreh, & Djalilian, 2023)

(Karakullukcu, Taban , & Olatunji Oladimeji, 2023)The biocompatibility of biomaterials made with nanotechnology, such as polymer nanocomposites, improves their functionality in medical applications, including tissue engineering and controlled drug release. This ability to customize and mechanical adjustment is crucial to the development of more effective treatments, resulting in a more precise and efficient approach to healthcare.

The research highlights how nanotechnology has revolutionized the creation of biomaterials, enabling the development of materials with improved properties, such as greater strength, biodegradability and specific functionalities. These advances are crucial for a variety of sectors, including medicine, agriculture, and the food industry.

For example, biopolymers such as cellulose, starch, chitin and collagen have been studied for their ability to be modified at the nano level as mentioned by the authors, improving their properties for specific applications. The research showed that these materials, when manipulated at the nanometer scale, can offer innovative solutions to traditional problems in tissue engineering, controlled drug release, and biodegradable packaging. (Vazquez, y otros, 2020)

Likewise, the move towards smart biomaterials that respond to external stimuli represents an emerging frontier in the field, encouraging research towards more sustainable and adaptive solutions. In addition, the growth of bioplastics and other eco-friendly biomaterials responds to growing concerns about the environmental impact of conventional plastics, aligning with sustainability initiatives.(Vineet Pramod, y otros, 2023)(Mahendra, Yadav, & Prasad Tiwari, 2023)

Taking into account what was researched by the author, Pérez Davila (2023), in her doctoral project entitled Biocomposites by 3D printing based on polylactic acid and Hydroxyapatite, the applications of these advances are diverse. In the field of medicine, nanocomposite biomaterials are being used in the creation of sutures, implants and devices for the controlled release of drugs, which improves the effectiveness of treatments and reduces side effects. In addition, in agriculture, biodegradable films based on starch and other biopolymers can replace conventional plastics, reducing environmental impact and improving the sustainability of agricultural practices.

However, the implementation of these materials faces challenges. Biocompatibility and the behavior of the body in the face of biomaterials must be carefully considered to minimize adverse reactions, research continues in search of optimizing and validating these new materials under clinical conditions.(Mahendra, Yadav, & Prasad Tiwari, 2023)(Mahendra, Yadav, & Prasad Tiwari, 2023)

According to the authors, in their research paper entitled Biological synthesis of silver nanoparticles: review of the potential use of the species (Esquivel-Figueredo & Mas-Diego, 2021)Trichoderma, found that one of the main challenges is the scalability of the production of these materials. Although many processes have proven to be effective at the laboratory level, bringing these methods to large-scale production is still complicated and expensive.

Another challenge is the assessment of the safety and environmental impact of nanomaterials. This is consistent with the author's statement that while these materials offer significant advantages, it is crucial to ensure that they do not pose long-term risks to human health or the environment. Future research should focus on developing more efficient and safer methods for the production and application of these biomaterials, as well as establishing clear and precise regulations for their use.(Aznar-Mollá, 2023)

The combination of nanotechnology and biomaterials is constantly evolving, promising a future where innovation and sustainability intersect to improve the quality of human life. The continuous exploration and development of these technologies not only have the potential to solve contemporary problems, but also to open up new opportunities in various industrial fields, making this field one of the most promising in contemporary scientific research.(Megh , Santosh K, & Satish , 2020)

7 Conclusion

The integration of nanotechnology with the production of biomaterials represents a transcendental advance in the medical field and in various industrial applications. The ability to develop materials with enhanced properties, such as biocompatibility, biodegradability, and specific functionalities, has facilitated the creation of innovative solutions to address persistent challenges in disease treatment and medical device manufacturing.(Esquivel-Figueredo & Mas-Diego, 2021)

Nanotechnology allows precise customization of biomaterials, enhancing their application in tissue engineering and controlled drug release, in. This level of adjustment is crucial to develop more effective and targeted treatments, significantly improving efficiency in healthcare. Likewise, advances in biopolymers, such as cellulose, starch, chitin and collagen, demonstrate that manipulation at the nanometric scale can enhance their properties, offering sustainable and biodegradable alternatives to conventional materials.(Esquivel-Figueredo & Mas-Diego, 2021)(Aznar-Mollá, 2023)(Aznar-Mollá, 2023)

However, the implementation of these materials is not without its challenges. The scalability of nanomaterials production and the assessment of their safety and environmental impact are critical areas that require meticulous attention. It is essential to ensure that these materials do not pose long-term risks to human health or the environment.(Zheng, y otros, 2023)(Yamada & Shimanouchi, 2022)

Future research should focus on optimizing and validating these new materials in clinical contexts, developing more efficient and safer production methods, and establishing clear and precise regulations for their use. The combination of nanotechnology and biomaterials promises a future where innovation and sustainability are intertwined to improve the quality of human life, opening up new opportunities in various industrial sectors. This field of study is emerging as one of the most promising in contemporary scientific research, offering vast potential to revolutionize our current practices and foster more sustainable development. (Silva, Amaral, Leão, Gomes, & Sant'Ana, 2019) (Zhao , Fan, & Li, 2023)

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