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BIOTECHNOLOGY AND GENETIC ENGINEERING: CURRENT ADVANCEMENTS, EMERGING CHALLENGES, AND FUTURE HORIZONS IN MODERN SCIENCE

BIOTECNOLOGIA E ENGENHARIA GENÉTICA: AVANÇOS ATUAIS, DESAFIOS EMERGENTES E HORIZONTES FUTUROS NA CIÊNCIA MODERNA

BIOTECNOLOGÍA E INGENIERÍA GENÉTICA: AVANCES ACTUALES, DESAFÍOS EMERGENTES Y HORIZONTES FUTUROS EN LA CIENCIA MODERNA

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ABSTRACT
Biotechnology is the term given to the branch of science that employs knowledge, techniques, and genetic engineering methods for creating various products using living organisms as raw material. Although this term has been recently adopted, humans have long been manipulating biological processes for their own benefit. Biotechnology is multidisciplinary and encompasses various fields of knowledge, with significant progress achieved over the years, particularly in the medical and cosmetic sectors. Through genetic engineering, it has become possible to edit genes more precisely, revolutionizing the study and manipulation of DNA and allowing the proposal and use of strategies that were once unthinkable in the scientific field to address contemporary issues. Among its most recent contributions are the development of new drugs and biopharmaceuticals, vaccines, cellular, genetic, and protein therapies, as well as the production of biocosmetics. However, there are still challenges to be faced in the extensive use of genetic engineering, ranging from production costs and the success of the technique at the molecular level to ethical issues surrounding the application of this technology. Thus, this literature review aims to discuss the most recent advances, applications, and future perspectives of biotechnology and genetic engineering in the scientific realm.

KEYWORDS: Biotechnology. Genetic Engineering. Diseases. Gene Therapy. Technological Development. Biopharmaceuticals.

RESUMO
Biotecnologia é o nome dado ao ramo da ciência que se utiliza de conhecimentos, técnicas e métodos da engenharia genética para a criação de diversos produtos a partir do uso de seres vivos como matéria-prima. Embora esse termo tenha sido adotado recentemente, há muito tempo o ser humano já utiliza a manipulação de processos biológicos visando o seu benefício próprio. A biotecnologia é multidisciplinar e envolve várias áreas do conhecimento, sendo que no decorrer dos anos tem alcançado importantes progressos, notadamente nas áreas médica e cosmética. Através da engenharia genética tornou-se possível editar genes de forma mais precisa, o que revolucionou a maneira de estudo e manipulação do DNA, permitindo a proposição e uso de estratégias outrora impensáveis no campo científico para o enfrentamento dos problemas contemporâneos. Dentre suas contribuições mais recentes estão o desenvolvimento de novos fármacos e biofármacos, vacinas, terapias celular, gênica e proteica, além da produção de biocosméticos. Contudo, ainda existem desafios a serem enfrentados no uso extensivo da engenharia genética, os quais permeiam desde os custos de produção e o sucesso da técnica no nível molecular até às questões éticas envolvendo a aplicação dessa tecnologia. Dessa forma, a presente revisão literária buscou discorrer sobre os avanços mais recentes permeando também as aplicações e perspectivas futuras do uso da biotecnologia e da engenharia genética no campo científico.

PALAVRAS-CHAVE: Biotecnologia. Engenharia Genética. Doenças. Terapia Gênica. Desenvolvimento Tecnológico. Biofármacos.

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RESUMEN
La biotecnología es el nombre dado al campo de la ciencia que utiliza conocimientos, técnicas y métodos de la ingeniería genética para crear diversos productos a partir del uso de seres vivos como materia prima. Aunque este término ha sido adoptado recientemente, durante mucho tiempo, los seres humanos han utilizado la manipulación de procesos biológicos buscando su propio beneficio. La biotecnología es multidisciplinaria e involucra varias áreas del conocimiento, y a lo largo de los años ha logrado importantes avances, especialmente en las áreas médica y cosmética. A través de la ingeniería genética, se ha vuelto posible editar genes de manera más precisa, revolucionando la forma de estudio y manipulación del ADN y permitiendo la propuesta y el uso de estrategias antes impensables en el campo científico para abordar los problemas contemporáneos. Entre sus contribuciones más recientes se encuentran el desarrollo de nuevos fármacos y biofármacos, vacunas, terapias celulares, genéticas y proteicas, así como la producción de biocosméticos. Sin embargo, existen desafíos en el uso extensivo de la ingeniería genética, que van desde los costos de producción y el éxito de la técnica a nivel molecular hasta las cuestiones éticas que rodean la aplicación de esta tecnología. Por lo tanto, esta revisión buscó abordar los avances más recientes, así como las aplicaciones y perspectivas futuras del uso de la biotecnología y la ingeniería genética en el campo científico.

PALABRAS CLAVE: Biotecnología. Ingeniería Genética. Enfermedades. Terapia Génica. Desarrollo Tecnológico. Biofármacos.

INTRODUCTION

Hundreds of years ago, humans were already using biotechnological processes, even without being aware of it. Traditional biotechnology encompasses the selective breeding of animals and plants, the invention of alcoholic beverages, dairy products, paper, silk, and other natural products (Clark & Pazdernik, 2016). Over the years, with recent technological advances, biotechnology has evolved from its traditional form to a modern one that employs the latest technologies for various purposes. The genetic edition initially emerged as a powerful tool for improving crop productivity, and today, this technique is used not only for plant manipulation but also for animal manipulation (Clark & Pazdernik, 2016). Nanotechnology has also emerged as a tool for studying extremely small particles: atoms. Studies at the nanoscale have marked significant advances in biotechnology (Clark & Pazdernik, 2016).

Therefore, with a broad application, it is noteworthy that biotechnology encompasses various fields, including industry and the healthcare sector, for example. However, defining biotechnology is still not simple, mainly due to the different perspectives with which it has historically been associated. Some approaches, however, consider it broadly as a convergence of classical biotechnology with the latest technologies, such as modern genetics, molecular biology, computational technology, and nanotechnology (Clark & Pazdernik, 2016).

Genetic engineering, in turn, has become one of the pillars of modern biotechnology. DNA manipulation has enabled genetic enhancement, bringing a new perspective to science. The advantages of modulating genes are numerous, with a notable emphasis on creating species better adapted to unfavorable environments, which, even under such conditions, remain capable of sustained productivity. However, it is important to emphasize that the impact of Genetically Modified

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Organisms on other species and the environment still poses a risk, potentially leading to unknown consequences.

Although there is still an important need for caution regarding the applications of genetic editing across various branches of science, it is noteworthy that the rise of biotechnology has yielded important advancements in the field of healthcare. Through genetic engineering, progress has been achieved in the production of pharmaceuticals, vaccines, and gene therapies, as well as in the development of antiviral defenses, control of disease vectors, and human reproduction (Dos Santos; Wiethölter, 2021).

Furthermore, bioprospection for cosmetic purposes in biotechnology is also a frontier that has been growing significantly in recent years, as there is an increasing demand for more natural and hypoallergenic products among consumers. The intent of biotechnology in this domain is linked to the creation of new products and concepts and the optimization of existing processes (Beli; Mageste; Taketani, 2020). Raw materials such as functional biopolymers, fermentative derivatives, recombinant DNA technologies, and enzymes are brief examples of the most recent applications of biotechnology in this sector (Beli; Mageste; Taketani, 2020).

Within this context, the present review aims to discuss the most recent applications of biotechnology and genetic engineering in human health, with a focus on three major fronts: (i) Gene and Cellular Therapies, (ii) Development of New Biotechnological Resources, and (iii) Biopharmaceuticals and Marine Products. Additionally, this review seeks to describe how genetic engineering and biotechnology can be employed to create various products from living organisms as raw materials, showing significant advances, particularly in the medical and cosmetic domains, despite facing challenges such as production costs, molecular success, and ethical considerations.

1. GENIC AND CELLULAR THERAPIES

Genetic diseases are conditions caused by one or more mutations in the genome and are ideal targets for gene therapy or genetic editing; treatments aimed at correcting the function of the abnormal gene. Gene therapy represents a radical transformation in the approach to disease treatment, directly impacting the modification of the patient's gene expression or correction of anomalous genes (Salzman et al., 2018). Meanwhile, genetic editing alters the genome at a specific location to correct or modify the genetic sequence (Delhove et al., 2021). Gene overexpression can be achieved by directly delivering the gene, organized as plasmid DNA, into the cell, thus employing gene replacement therapy. This method enables the transient or persistent production of the protein that is abnormal or deficient in the diseased organism. On the other hand, corrective gene therapy involves the use of modified or bacterial nucleases to induce targeted modification of genomic sequences in all eukaryotes (Sayed et al., 2022).

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Essentially, gene therapy comprises three main steps: (1) induction of double-strand breaks in specific regions of the genome, (2) correction of defective endogenous genes or introduction of exogenous genes, and (3) repair of double-strand breaks. In eukaryotes, these breaks are repaired through one of two endogenous mechanisms: non-homologous end-joining or homology-directed repair (Lino et al., 2018).

Programmable nucleases refer to specific enzymes, with examples including zinc finger nucleases (ZFNs), clustered regularly interspaced short palindromic repeats (CRISPR) nucleases along with CRISPR-associated proteins (Cas), and transcription activator-like effector nucleases (TALENs). These are currently the primary technologies used for genomic editing (Sayed et al., 2022). It is important to note that CRISPR/Cas9 is widely used for gene editing compared to ZFNs and TALENs due to its cost-effectiveness, high efficiency, and ease of implementation (Naeem et al., 2020). One of the early approaches in genomic editing involved the use of zinc finger proteins. These belong to the predominant class of DNA-binding proteins, enabling the regulation of endogenous genes at their usual sites. This technique facilitates the creation of artificial proteins and enzymes with the ability to intervene in gene regulation (Wani et al., 2023).

Transcription activator-like effector nucleases (TALENs) are another tool used for gene editing. TALENs are non-specific DNA cleavage nucleases fused to a DNA-binding domain, enabling the modification of virtually any gene in various cell types and organisms (Bhardwaj et al., 2021). This versatility makes TALENs valuable in genetic manipulation across a wide range of biological contexts. TALEN proteins were initially identified in 2009, and they derive from the plant-pathogenic bacterial genus Xanthomonas (Boch et al., 2009). These proteins can form different associations with transcriptional activators, repressors, or endonucleases, giving them transformative potential in transcriptional regulation and making them versatile tools for genome editing (Bhardwaj et al., 2021).

The progress of CRISPR-Cas systems, highly adaptable as molecular scissors, has revolutionized the life sciences, allowing for the redefinition of nuclease specificity through a simple change in the guide RNA sequence (Paul et al., 2020). CRISPR repeats, associated with Cas proteins, form an adaptive immune system in bacteria and archaea, protecting against external mobile genetic elements (Paul et al., 2020). The CRISPR/Cas9 system enables genome editing through the cleavage of DNA by an endonuclease (Cas9), guided by an RNA sequence known as guide RNA (g-RNA). This sequence can base-pair with the bases of a target sequence. The system can be employed both to correct existing mutations and to introduce new mutations, resulting in what is known as gene "knockout". Both guide RNA and Cas9 can be produced *in vitro* and delivered to cells using vectors or chemical agents (Chen et al., 2019).

The use of CRISPR/Cas systems has proven to be a significant ally in cancer treatment. Recent advances in this field demonstrate promising therapeutic potential, with high remission rates in patients. Currently, there are several clinical studies for the treatment of esophageal, prostate, bladder, renal cell carcinoma, melanoma, sarcoma, and metastatic multiple myeloma cancers (Huang

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et al., 2018). Additionally, the integration of the CRISPR/Cas9 genetic manipulation technique with antiretroviral drugs has resulted in the development of the innovative therapy known as LASER ART+, as demonstrated by Dash et al. (2019). This approach has been successfully applied to eradicate HIV in mouse cells. At the end of the treatment, approximately one-third of the infected mice were completely cured of the disease, showing no signs of the presence of HIV in their organisms (Dash et al., 2019). The results of this study have sparked considerable expectations in the scientific community, indicating the possibility of permanent viral elimination.

The widespread acceptance of the therapies in question is a crucial element to enable future clinical trials and, above all, their application in medical practice. In this context, scientists, healthcare professionals, and physicians must be well-informed about the risks and benefits associated with these technologies, to facilitate the dissemination of this knowledge to the general population (Delhove et al., 2021). Additionally, it is essential to adopt a perspective that transcends the individual scope in the employment of these innovations. While the use of biotechnology for the cure of individuals raises a few questions, the paradigm shifts when science is considered as a means of enhancing the human condition as a whole.

2. DEVELOPMENT OF NEW BIOTECHNOLOGICAL RESOURCES

Upon realizing its low costs and multiple utilities, the CRISPR-Cas toolkit is being expanded. A total of six types (I to VI) and two classes are recognized: class 1 (types I, III, IV) and class 2 (types II, V, VI). The typing and classification are based on the analysis of numbers and gene sequences associated with the CRISPR array. Among them, I, II, and III are highlighted. Type II uses a single DNA endonuclease, Cas9, to recognize and cleave dsDNA substrates, while types I and III encode a multi-Cas protein complex capable of binding to crRNA and degrading the target sequence (Huang et al., 2018).

One of the elements that has been studied in the CRISPR-Cas toolkit is the Protospacer Adjacent Motif (PAM) sequence. This is a small genomic sequence that is adjacent to the target gene recognized by crRNA, serving as a cleavage point. This PAM sequence varies depending on the Cas protein associated with CRISPR. However, new studies indicate that it is possible to access other cleavage points as the expanded variant of the Cas9 PAM (xCas9), which expands the use of CRISPR-Cas mechanisms (Huang et al., 2018).

Recently, the anti-CRISPR has been added to the CRISPR-Cas toolkit, which promises to be an important therapeutic resource as it may reduce or deactivate the off-target effects of CRISPR-Cas. So far, 21 proteins from the anti-CRISPR family inhibiting type I and II systems have been identified, and some have well-described mechanisms (Huang et al., 2018). However, as this is a recent discovery, a deeper understanding of the subject is needed to apply the anti-CRISPR system in clinical studies.

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In the clinical aspect, when considering the need to target specific physiological goals in the use of CRISPR-Cas systems, AAVs (Adeno-Associated Viruses) delivery mechanisms are widely employed. An example is the study that combined the LASER ART method with an AAV carrier, a CRISPR-Cas9 transporter, for the elimination of HIV-1 viral DNA (Dash et al., 2019). However, due to its small size and capacity, several viruses may be required to carry the components of CRISPR-Cas9 (Cas9, sgRNA, and donor DNA). This criterion can lead to a decrease in efficiency and the occurrence of unwanted immune responses (Huang et al., 2018). Considering this issue, non-viral delivery technologies can be an alternative approach.

In this context, the use of carriers such as lipid and polypeptide nanoparticles is widely researched. Like the use of albumin nanoparticles for drug delivery to reduce neuroinflammation, the use of carriers has several advantages, including low cost, easy manipulation, biodegradability, and numerous sites for drug binding. Furthermore, their association with surfactants and emulsifiers can facilitate passage through the blood-brain barrier and prolong the circulation of nanoparticles. When analyzing the administration of ipriflavone-loaded albumins (IP-Np) compared to IP-Np coated with polysorbate 80 (IP-Np-T80) in rats, the surfactant-coated nanoparticles showed superior performance in reducing pro-inflammatory markers, allowing for the use of a lower dosage with increased efficiency (Yassa et al., 2020).

In the case of CRISPR systems, the use of cationic lipid nanoparticle carriers, synthetic zwitterionic amino acids (ZALs), and gold nanoparticles conjugated with DNA have been studied and are efficient carrier options for various organs (Huang et al., 2018). The use of nanoparticles could represent a significant advancement in the applicability of in vivo CRISPR studies due to being highly safe, efficient, and precise.

Another technology that has been utilized is the application of Cas protein variants for nucleic acid detection. Among them, Cas13a stands out, first discovered through bioinformatics studies, and later found homologously in bacteria. Generally, most CRISPR systems target dsDNA. However, Cas13a has a different target, which is single-stranded RNA (ssRNA). Additionally, Cas13a has two higher eukaryotic and prokaryotic nucleotide-binding domains (HEPN). Thus, when an active Cas13a HEPN associates with various ssRNA substrates, it amplifies a fluorescence behavior generated by the specific cleavage of the ssRNA reporter (Huang et al., 2018).

Recognizing this biochemical nature, the Specific High-Sensitivity Enzymatic Reporter UnLOCKing (SHERLOCK) platform was created for nucleic acid detection. The method includes recombinase polymerase amplification (RPA), transcription of T7 RNA polymerase from DNA to RNA, and finally, Cas13a RNase activation. The SHERLOCK system can detect nucleic acids with attomolar (aM) concentration in the serum or urine of patients (Huang et al., 2018).

Analogous to Cas13a, the activated Cas12a tool has become a powerful high-sensitivity detection tool. However, Cas12a differs in having a RuvC endonuclease domain and a PAM with

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distinct target cleavage. Additionally, when activated, it cleaves a non-complementary sequence to its guide RNA, cleaving ssDNA strands in trans, thus becoming a DNA detector (Huang et al., 2018).

Understanding the mechanisms of Cas12a, the system called DNA Endonuclease Targeted CRISPR Trans Reporter (DETECTR) was developed. It involves isothermal RPA amplification, subsequent binding of the crRNA complementary DNA by Lachnospiraceae ND2006 Cas12a (LbCas12a) bacteria, followed by cleavage of the unrelated ssDNA-fluorophore-quencher (ssDNA-FQ) reporter and, finally, a fluorescent signal. The DETECTR has already been used in studies to differentiate 2 types of human papillomavirus (HPV), both in cells and in patient samples, maintaining an attomolar sensitivity (Huang et al., 2018).

In general, the DETECTR and SHERLOCK systems prove to be very promising for early cancer detection due to their low cost, speed, high sensitivity, and specificity. However, the false-positive relationships associated with these new techniques need to be further explored (Huang et al., 2018).

Furthermore, it is relevant to highlight the significant influence of biotechnology in vaccine manufacturing. Through the application of recombinant DNA technology, the creation of vaccines for various diseases has become feasible, including but not limited to influenza types A and B, polio, herpes, and hepatitis A and B. In general, similar to the method used in insulin production, the vaccine production process involves cloning the genetic information of the pathogen into bacteria, often *Escherichia coli* (Dos Santos; Wiethölter, 2021).

Currently, various technologies are available for vaccine development, including those employing messenger RNA (mRNA), which has demonstrated a safe and durable immune response in both animal models and humans. These vaccines simulate infection by live microorganisms, promoting the activation of helper T lymphocytes and the immune response of B cells in the germinal center.

Additionally, the production of this type of vaccine has a significant advantage compared to other approaches, as it eliminates the need for large-scale cultivation of pathogenic organisms. This results in a reduced time required for production and minimizes the risks of contamination by live infectious agents, as well as the release of dangerous pathogens. However, it is imperative to deepen the understanding of the mechanism of action of these vaccines while seeking to identify and develop more efficient delivery systems (Zhang et al., 2019).

3. BIOPHARMACEUTICALS AND MARINE PRODUCTS

In the 2000s, total aquaculture production was 45.71 million tons, representing a 6.3% increase in weight since 1999. In comparison, by the year 2018, this production reached 114.5 million tons, with a yearly growth rate of 5.3% from 2001 to 2018. This signifies an expanding market in the food, cosmetic, and pharmaceutical industries (EMBRAPA, 2020; Cardozo et al., 2007). With the advances achieved in the genetic engineering of algae in recent decades, a path for sustainable

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bioprospecting associated with a zero-carbon production system is opened. The use of nutrients present in the water and in an open environment reduces the production costs of algae and the active compounds that can be extracted from them (EMBRAPA, 2020; Rosales-Mendoza et al., 2020).

Concerning plants, algae and microalgae for industrial and commercial applications offer many advantages. High scalability, improved growth rates, low production costs, and higher biomass cultivation with lower mineral requirements are characteristics that make them more attractive to the market to produce bioactive metabolites and biopharmaceutical products. Additionally, another advantage is the non-competition for agricultural land, also contributing to the reduction of carbon dioxide levels generated by anthropic activities. However, due to phycocolloids (agars, alginates, and carrageenans) and their capacities of gelation, water retention, emulsification, and other biochemical aspects, the industrial exploration of compounds derived from algae and microalgae on a large scale becomes limited (Rosales-Mendoza et al., 2020).

Currently, some algae species are most used by the industry, such as *Dunaliella salina*, *Haematococcus lacustris*, Chondrus, Eucheuma, *Sargassum sinicola*, *Undaria pinnatifida*, and *Chlorella vulgaris* (Rosales-Mendoza et al., 2020). Among microalgae, the most promising for pharmaceutical production is the species *C. reinhardtii*. However, due to recent advances in genetic engineering and genomic research, the species *Chlorella* spp. and *Phaeodactylum tricornutum* have shown even more potential compared to *C. reinhardtii* (Yan et al., 2016). Additionally, besides the bioactive compounds produced by algae and microalgae, such as fucoidans, lectins, polysaccharides, and proteins, they can also synthesize growth and blood coagulation factors, hormones, monoclonal antibodies, enzymes, immunological regulators, viral vaccines, and other natural products, in addition to their potential for recombinant protein production (Rosales-Mendoza et al., 2020; Yan et al., 2016).

Notably, changes in culture conditions are commonly used as resources to increase the production of desirable metabolites; however, this technique is not always successful. The application of genetic engineering in algae and microalgae represents an advancement. It can be used to induce positive or negative regulation of the transcription and translation of key enzymes in metabolic pathways or to eliminate and insert desired genes, leading to the efficient production of a target metabolite (Rosales-Mendoza et al., 2020). Additionally, algae and microalgae are used to produce recombinant proteins, which are typically expressed by the nucleus or chloroplast genome. However, this production depends on stable transformation systems, including vector construction and transformation methods. Nuclear transformation is a successful tool in this regard, with the most common methods for algae and microalgae transformation based on the transient permeabilization of the cell membrane, allowing plasmid DNA to pass through the membrane and enter the cell.

Among the methods for cell permeabilization, the one that yielded the best results involves vortexing cells with DNA, polyethylene glycol (PEG), and glass beads. Another method frequently used for the transformation of previously non-transformed microalgae species is particle bombardment, which is also employed for the transformation of plant tissues and cells, as well as

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prokaryotes. Finally, the transposon approach may also be suitable for eukaryotic algae and microalgae when no host factor is required, although their transformation using this method has not been reported to date (Yan et al., 2016).

Despite numerous advances, genetic engineering of algae and microalgae faces some challenges, such as overcoming low transformation efficiency, positional side effects, and transcriptional/post-transcriptional gene silencing, frequently observed for nuclear expression. The most significant challenge involves improving protein yield and stability in genetically modified algal strains. These challenges can be addressed with recent advances in the field of genetic engineering, such as the use of new selectable markers, UV mutants, and efficient promoters (Yan et al., 2016).

Ultimately, the use of algae and microalgae holds significant value for the drug discovery process, representing a promising area in pharmaceutical and biopharmaceutical studies. Numerous studies have been published demonstrating the ability of these organisms to produce metabolites different from those found in terrestrial species, with isolated compounds exhibiting high biological activity, high complexity, and an unlimited diversity of pharmacological and/or biological properties (Cardozo et al., 2007). Additionally, other authors have proposed the implementation of oral treatments using pills or tablets with lyophilized biomass. However, this proposal requires precise optimization regarding the oral bioavailability of the target biopharmaceutical, especially if the target of interest is systemic (Rosales-Mendoza et al., 2020).

4. METHOD

The present review consists of a narrative addressing biotechnology in three main aspects: Gene and Cellular Therapies, Development of New Biotechnological Resources, and Biopharmaceuticals and Marine Products. Textual sources from the international PubMed database were used, with articles selected based on the following keywords: Biotechnology AND Genetic Engineering AND Disease AND Gene Therapy AND Technological Development AND Biopharmaceuticals. Only open-access articles from the last 5 years, i.e., from 2018 to 2023, were included. In a subsequent qualitative selection, articles outside the theme were disregarded, and some outside the 5-year range were included only for contextualization purposes, resulting in a total of 22 references.

5. CONCLUSION

Genetic engineering has brought many advancements to biotechnology, which has been able to evolve in a scalable manner across various fields in recent years. Genetic manipulation mechanisms have widely contributed to the improvement of human health. The achieved development ranges from therapies for disease treatment to the creation of more sustainable health and economically oriented products. Consequently, bioprospecting, in conjunction with DNA manipulation, remains a crucial objective of science for the upcoming years.

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It is a fact that science is advancing towards an era where the human species gains significant transformative power over its surroundings. In this context, due to the widespread application of biotechnology in everyday life, ethical considerations around it cannot be disregarded or suppressed. Ethical debates, such as the manipulation of embryos, transgenics, and human cloning, always stir controversy as they extend beyond the scientific realm into religious, cultural, social, and other domains. Pondering this, it is pertinent to reflect on the subject ethically, considering the social impact caused.

According to current advancements, it is likely that in the near future, genetic diseases could be resolved through gene editing. However, given that humanity resides in a world where access to healthcare is highly unequal, genetic advances could create two distinct populations, one being genetically edited and the other not. From this perspective, the impact of these technologies needs to be mediated to avoid potential eugenic discourses. Moreover, if genetic engineering becomes massively adopted, there is a risk of converging edited species towards a common standard, a "genetic model," which could be deemed superior. The implications of this situation could be hazardous, favoring susceptibility to specific parasitic infections, as well as the beginning of a new pandemic.

Therefore, societal participation in debates about the limits and prospects of biotechnology and genetic engineering in the coming years is imperative. This should not serve to impede scientific progress but rather the opposite. Active societal involvement in the decisions made by science to improve people's lives contributes to scientific development by bringing a more holistic perspective to the process, allowing innovation to align with human rights and moral principles. Thus, the use of new technologies for genetic editing must be carried out more responsively, understanding the potential generated by their development.

In summary, it is concluded that genetic engineering has already propelled scalable advancements in biotechnology, benefiting human health with therapies and sustainable products. Additionally, it opens many opportunities, including the cure of genetically related diseases. However, crucial questions surround it, permeating aspects of what humanity will be like in the future and whether human beings will take control of their genetic destiny (Dos Santos; Wiethölter, 2021). Therefore, ethical issues, such as genetic manipulation, require active societal participation, enabling scientific development aligned with social values.

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