Improving One Health using Biotechnology and Nanotechnology

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Abstract

Biotechnology and Nanotechnology are two fields in an advanced era that are being used in improving One Health. Biotechnology has transformed our lives by creating vaccines, antibiotics, and diagnostic tools. The cutting-edge technologies, such as CRISPR-CAS9, are used to edit genes to acquire desired traits. GMOs are being produced at a higher rate to feed crops and animals for human consumption. Nanotechnology includes the manipulation of atoms and the evolution of systems, which provide targeted therapies for the betterment of health. These branches of science led us to advancements in human, animal, and plant health by using nanoparticles or microorganisms. Tissue regeneration, boosting sperm viability, nano vaccines, and disulfiram nano capsules for anticancer activity are advanced techniques for a better future. In this chapter, tools and techniques regarding biotechnology and nanotechnology are discussed that provide a promising solution for health-related challenges among living organisms.

Keywords: Tissue regeneration, GMOs, Disulfiram capsule, Antibiotics, CRISPR-Cas9, Genes, Targeted therapies

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Introduction

Biotechnology is an interdisciplinary field that employs biological systems, living organisms, or their cellular components to create practical solutions and cutting-edge technologies in healthcare, agriculture, industry, and environmental conservation (Anyanwu et al., 2024). It brings together insights from molecular biology, genetics, engineering, and computational sciences to precisely modify biological processes in order to address real-world problems, improve quality of life, and promote sustainable development (El Dosary, 2023). Biotechnology plays a crucial role across various sectors, such as medicine, industry, farming, and environmental conservation. It has transformed how we prevent and treat diseases by creating vaccines, pharmaceuticals, and diagnostic tools. By combining technology and biological sciences, biotechnology promises continuous innovation, and it also plays an important role in global health advances (Gupta et al., 2017).

The history of biotechnology starts from different ancient techniques, such as fermentation, but the scientific evolution of biotechnology began in the 19th century. The experiment of Louis Pasteur showing that microorganisms not only cause illness and disease but can also be used in other ways that are beneficial in many ways was a significant breakthrough. Modern genetics that we know today is the result of Watson and Crick's 1953 discovery of DNA's double helix (Verma et al., 2011; Anyanwu et al., 2024).

Biochar is a carbon-rich product produced by the process of pyrolysis from crop residues, wood, and agricultural wastes. In a recent study, it was revealed that biochar increases the availability of nutrients in soil, enhancing its quality as a soil supplement in arable territories. Biochar has also been observed to minimize environmental pollution, enhancing soil health. Microalgae are a green technology providing an eco-friendly solution for converting CO_2 into valuable biomass (Osorio-Reyes et al., 2023). Microalgae as bio fertilizers enrich soil in micronutrients, macronutrients, and phytohormones (plant hormones that regulate physiological processes in plants). They foster beneficial interactions between crops and the soil microbiome. Microalgae can also enhance nitrogen fixation and maximize growth. Some prokaryotic organisms, i.e., cyanobacteria and *Bacillus,* are known for their nitrogen-fixing abilities. Mitigation of phosphorus contamination in water bodies can also be carried out by microalgae by absorbing excess phosphorus (Yadav et al., 2023).

Transforming Agriculture through Biotechnology to Improve One Health

The first agricultural communities were formed about some 10,000 years ago by people in order to improve their quality of life by harnessing the biological processes in sight at that time (Das et al., 2023). Approximately 6,000 years ago, humans began to harness the biological processes of microorganisms to produce bread, cheese, and alcoholic beverages, and to preserve dairy products. But such processes are not how biotechnology is perceived today, a term first widely perceived as the molecular and cellular technologies that started to emerge in the late 1960s to mid70s (Verma et al., 2011). Genentech was established to commercialize recombinant DNA technology in 1976 by Robert A. Swanson and Herbert W. Boyer. This initiative catalyzed the modern definition of biotechnology as the exploitation of biological processes

for the benefit of mankind, which includes the use of microorganisms, manipulation of genes, and use of other such advanced techniques for the production of antibiotics and hormones.

In agriculture settings, biotechnology significantly influences modern farming by supporting innovations that make crops more resistant and adaptable to threats like pests, diseases, and extreme climate conditions (Das et al., 2023). Crops that are engineered to have essential nutrients, like golden rice, that have vitamin A added, are used in backward areas to help deficiencies and solve health issues in those areas. These crops also dramatically decrease the need and use of chemical pesticides, which leads to lower health risks. This leads to food systems that are safe and environment friendly. If we look into our past, enhancement in our livestock depended on traditional techniques like selective breeding. These techniques improved traits like fertility, resistance to diseases, and growth. (Funahashi et al., 2020; El Dosary, 2023).

PLF, also known as precision livestock farming, is the technique in which we use modern technologies for managing, monitoring, and improving the overall health of livestock animals in real time. Modern technology, like biosensors in cattle industries, has given us the ability to monitor animal issues beforehand. This helps in treatment before the condition gets worse or severe (Neethirajan et al., 2021). The role of genetically engineered crops is shown in Figure 1. Veterinary biotechnology is an emerging field in the discipline of biotechnology. Cancer in animals is a major concern in this field. Veterinary oncology is determined to identify, manage, and treat cancer in animals (Prasad et al., 2023).

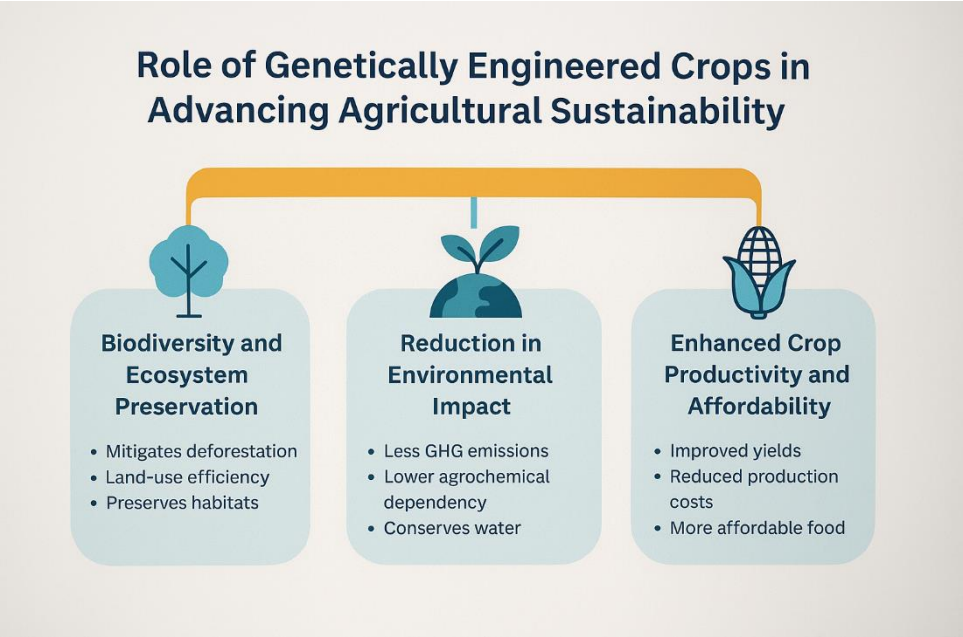

Fig. 1: Contribution of genetically engineered crops to sustainability

Through transgenic technology, foreign gene expression has resulted in the large-scale production of valuable products. Genetically modified crop (GMC) is the world's fastest-growing agricultural technology. Utilizing new breeding techniques can ensure food security, sustainability, and a broader range of desirable food products (Sharma et al., 2022)

Biostimulants have emerged as an essential supplement in agricultural practices, boosting plant growth, development, and stress resilience (Hamid et al. 2021). EPHs- Enhanced Plant Holoboints represent an innovative strategy for sustainable agriculture, employing beneficial plant-microbe interactions to improve crop resilience, accelerate productivity, and enhance environmental health. On the other hand, it also highlighted the use of several species and strains of *Bacillus* spp. as biofertilizers, biopesticides, and other biotechnological tools (Ortiz & Sansinenea, 2022).

Genetically engineered animals, such as transgenic goats that produce human insulin in their milk and genetically modified pigs resistant to porcine reproductive and respiratory syndrome (PRRS), offer groundbreaking solutions for medical treatment and improve livestock health (Whitworth et al., 2016). Gene-editing technologies such as CRISPR have given us humans the ability to create livestock of our own choice with desired specific traits such as enhanced disease resistance (Golovan et al., 2001).

MAS systems (Marker-Associated Selection) link desired traits to specific genetic markers. This system has revolutionized the way we breed traditional animals. Moreover, MAS has allowed us to specifically bind our desired traits to different genes (Bishop et al., 2014). These achievements have laid the foundation for future inventions and discoveries that will ultimately have a world impact. In the upcoming section, we will explore recent developments and other recent approaches in humans, animals, and the environment.

Transforming Healthcare through Biotechnology to Improve One Health

A state of complete physical, mental, and social well-being is defined as human health and not merely the absence of disease or infirmity alone (World Health Organization, 1946). The social determinants of health (SDOH) are grouped into five categories: economic stability, education, social context, neighborhood environment, and healthcare access. As the population diversifies, increasing evidence highlights the profound influence of SDOH on healthcare outcomes, including mortality, morbidity, life expectancy, healthcare costs, health status, and functional limitations (Agnikula et al., 2021). According to the World Health Organization (WHO), nearly 71% of global mortality is caused due to the surge in lifestyle diseases that have been precipitated as a result of rapid globalization and economic development. This has emerged as

a major global public health crisis and a leading concern in the past few decades. These conditions are preventable and can be controlled by regulating various controllable factors.

Cell-replacement therapies could have a favorable outcome in treating Alzheimer's disease. Such therapies involve induced pluripotent stem cells (iPSCs) or human embryonic stem cells (ESCs)-derived neural cells (Rahman et al., 2022). The stem cell's pluripotent properties, the unique property of stem cells to differentiate into various cell types, can be utilized to repair or replace neuronal loss. Mesenchymal stem cell (MSCs) is a form of stem cell therapy that is a clinically promising approach to treat chronic liver failure and liver cirrhosis (Li et al., 2022)

Recently, neutrophil-derived exosomes have been found to have antitumor properties. Zhang et al. (2022) generated a xenograft of BALB/c nude mice that was injected with HGC27 cells to evaluate the antitumor efficacy of N-Ex. His work not only demonstrated the role of exosomes as anticancer agents of neutrophils but also found it as a drug delivery nanoplatform. Bioinspired exosome mimetic nanovesicles (NVs) are artificial nanoparticles that mimic the structure and function of natural exosomes, have been developed to deliver chemotherapeutic drugs for cancer treatment. Also, monoclonal antibodies can be used for targeted chemotherapy (Mitra et al., 2021). Advancements in biotechnology have revolutionized healthcare by integrating artificial intelligence (AI) for sophisticated data analysis. These innovations have collectively transformed into a healthcare paradigm that is more precise, effective, and tailored to individual needs (Biswas et al., 2023).

Nanotechnology and One Health

The branch of science and technology that employs systems with at least one dimension on the nanoscale (one-billionth of a meter) at the cellular level is known as Nanotechnology. It consists of the manipulation of particles at the molecular, atomic, and sub-atomic levels. Nanoparticles are tiny particles that range from 1 to 100 nanometers in scale (Silva et al., 2004). It works depending on molecular size; particle properties and behavior change dynamically. The materialistic and systematic properties are affected by molecular composition and interactions at the molecular scale, which may alter and affect at macroscopic level. Nanotechnology allows the evolution of systems and devices that interact with the body at the microscopic level, which ensures high specificity and precision (Roco et al., 2003)

The development of novel engineered particles and materials for medicine over the past few years, especially nanomaterials, has ramped up rapidly. Nanotechnology has been playing a key role in human health and research, especially in nanomedicine, as in the first nano-based treatments, i.e., vaccines, drugs, and diagnostic devices (Ambrose et al., 2025). Nanomaterials have specific properties unlocking great potential in disease detection that enable targeted manipulation, as in biomarkers at the nanometer scale, which execute targeted drug-based delivery to the cells. Additionally, the Nanoparticles are used broadly, involving both the organic (e.g., liposomes, biopolymers) and inorganic materials like silver, iron oxide (Contera et al., 2020).

Nanotechnology and Healthy Ecosystem

For centuries, scientists have been rearranging the patterns of atoms by using diverse types of techniques, such as heating the atoms, mixing, or even pounding them to get firsthand control over the structure of matter, and this has significantly advanced both animal and human health sectors. Nanomaterials have been used in procedures like therapeutic techniques and targeted drug delivery (Rizvi et al., 2018).

Most of the work on nanotechnology remains under research in laboratories. By homogenizing nano- and biotechnology, major breakthroughs in the fields of medicine have been derived that have helped us in techniques like regenerative medicine and targeted drug delivery (Contera et al., 2020). Recent research in nanotechnology has led to several revolutionary discoveries. This revolution of nanoscale science is evidence that, in the near future, nanotechnology will be integrated into almost every field of research and development (Malik et al., 2023). The ability to regulate matter at the nanoscale has facilitated revolutionary advancements, innovations in diagnostics, clinical interventions, and overall patient care (Ma et al., 2024).

Transforming Agriculture through Nanotechnology to Improve One Health

The latest research in nanotechnology has been focused on its applications in sustainable agriculture and nutrition science. Scientists have been investigating uses of nanotechnology in agricultural fields in order to enhance the growth of crops and their yields, reduce the use of chemical growth enhancers like fertilizers, and to get rid of the use of pesticides. Newer research has found that nanoformulations like nanogels, nanosuspensions, and nanoemulsions are a very useful alternative to pesticides. These are called nano-pesticides that enhance plant productivity without harming the crop or the soil in any way (Munir et al., 2023).

Types of Nanoparticles Used in Improving Soil Health

Titanium Dioxide Nanoparticles:

Plant growth and disease management have been greatly improved by using titanium dioxide nanoparticles. TDNs have properties like photocatalysis, which are effective against plant pathogens. The combination of nanotechnological particles like TDNs in the field of agriculture has positively impacted agriculture and has changed the way we approach agriculture. This has led us to better and more sustainable food productivity systems. (Malik et al., 2023). Nanotechnology offers sustainable solutions for plant nutrition by replacing bulk fertilizers with different nanoparticles like TDNs. It helps in improving the availability of nutrients, mineral uptake, and crop yield while limiting the use of fertilizers. These nanoparticles or nano-fertilizers are applied through soil routes or foliar systems. (Gauri et al., 2018).

Nanotechnology for Animal Health

Use of nanotechnology in veterinary and animal sciences is being increased due to its potential benefits, with very low to no harmful effects. It helps in advanced techniques such as specific drug delivery systems to treat diseases like trypanosomiasis. Nanotechnology is also being used to create biological sensors that detect changes natural body changes or germ-caused changes in the body. Also, metallic nanoparticles help in maintaining, controlling, and enhancing the fertility of animals. PCNs (protein cage nanoparticles) are being widely used in virus removal in models of flu and SARS, and it has shown success in improving the survival of the animal, which improves how the body

reacts to disease and creates strong antibody responses (Malik et al., 2023). Moreover, sperm and embryos are safely preserved by cryopreservation using nanotechnology. Nanotechnology has also allowed us to create slow-release systems for active substances such as hormones. These efforts in nanotechnology are being done due to its cost-effectiveness and its ability to control matter at the nanoscale, which causes no harmful side effects and is eco-friendly for animal health and reproduction (Muktar et al., 2015).

Researchers have also found out that nano-particles carry reproductive hormones that have very less side effects and they boost fertility greatly as compared to other modes of enhancing fertility. Use of nanotechnology in fertility follows ethical and moral rules and also ensures good reproduction (Hashem et al., 2021)

While nano-diagnostics have been the center of attention due to their application in early detection of diseases using tiny materials called "Nanobots," which can detect diseases like tumors and cancers by working as markers at early stages with very high accuracy. Nano-particles are integrated with other binding molecules (aptamers) to detect germs like "*Mycobacterium Tuberculosis*" in farm animals for early diagnosis (Singh et al., 2018)

Tissue Regeneration and Wound Healing

The antimicrobial nature of some nanoparticles helps in the treatment of open wounds, thus promoting wound healing. AgNPs (Silver Nanoparticles) help in boosting tissue regeneration and promoting the wound healing process. Due to this natural and unique antimicrobial property, AgNPs are also used in dressings that are used to cover the wound in order to reduce or completely stop inflammation and help in the healing process. Some of the medical-grade bandages are also coated and fused with silver nanoparticles that are used in post-surgical practices to promote tissue regeneration and boost healing in livestock or pets. (Ghosh et al., 2014). Biodegradable polymers such as Polylactic acid (PLA) or Polycaprolactone (PCL) are used to construct materials called "Nano-Fibers". Damaged tissues or traumatic injuries in livestock are treated and repaired with the help of these nano-fibers. When these nano-fibers are attached to the affected areas, they attach to the surface of the wound and instantly start cell division and cell migration, which leads to faster tissue regeneration and healing (Zhang et al., 2016)

Hydrogels are combined with different nanomaterials, which creates a unique material known as "nanocomposites". This unique material is used in drug delivery systems for more controlled delivery of drugs and is also used in tissue regeneration. The quantity of water that hydrogels contain develops a very moist environment, which induces healing of tissues at a greater speed. Carbon Nanotubes (CNTs) and graphene oxides are combined together and then fused with hydrogels to improve healing time and effectiveness. These nanocomposite materials are widely used in burn wounds of animals to accelerate tissue repair and skin regeneration (Li et al., 2015).

Boosting Sperm Viability

Nanotechnology has been embedded within *in vitro* reproductive techniques to ensure that these techniques will surely serve the purpose and to improve the effectiveness of these techniques, such as artificial insemination, in vitro fertilization, and embryo transfer. This combination of nanotechnology with reproductive techniques has boosted the success rate of reproduction in animals. This collaboration has changed animal breeding, which is leading to more sustainable livestock production in tough environments, which ultimately leads to more genetic diversity. When the sperm cells are added to semen extenders, zinc oxides and Selenium nanoparticles are added to ensure the survival of sperm cells and to improve their longevity. Moreover, magnetic nanoparticles (MNPs) are also added to the extenders in order to get more genetic diversity and desired phenotypes (Kandil et al., 2019; Martins et al., 2020).

Nano-Vaccines

The focal point of scientists from all over the world has been redirected from traditional vaccines due to their low effectiveness. As medicine excels towards modernization and biotechnology progresses, scientists have developed newer techniques using nanoparticles to produce new types of vaccines called "Nano-Vaccines". These vaccines mainly use lipid nanoparticles (LNP's) and virus-like nanoparticles (VNP's). As of now, these vaccines are being used to cure animal diseases relating to FMD (Foot and Mouth Disease). These vaccines have also shown effectiveness against Influenza and PRRSV (porcine reproductive and respiratory syndrome) (Zhang et al., 2016; Zhao et al., 2023).

Transforming Healthcare through Nanotechnology to Improve One Health

Groundbreaking revolutionary breakthroughs in diagnostics, treatment modalities, patient care, targeted drug delivery, etc. have been achieved so far by manipulating matter at the nanoscale, ensuring more promising advancements in the future. Nanotechnology holds immense promise in revolutionizing our daily lifestyle, such as healthcare, offering record-breaking breakthroughs in diagnostics, drug delivery, cancer therapy, and combating infections and diseases in the modern era and in the future (Ma et al., 2024).

Nanotechnology has been greatly involved in the transformation of healthcare diagnostics, offering precision accuracy in disease detection and management at the cellular level. Nano devices have been enabling early disease detection and providing vigilant medical contributions. Nanoparticle-enhanced diagnostic imaging has increased the accuracy of disease detection, such as in magnetic resonance imaging (MRI), computerized tomography (CT), and positron emission tomography (PET) (Malik et al., 2023).

Disulfiram Containing Polymeric Nano-capsules with Anticancer Activity

Disulfiram-loaded polymeric nano capsules exhibit potent anticancer activity by obstructing aldehyde dehydrogenase enzymes and proteasome function. It leads to the accumulation of defective proteins in cancerous cells, causing oxidative stress, which leads to cellular death (Ambrose et al., 2025). They also target cancer stem cells, which are implicated in relapse, offering a promising strategy for preventing relapse. It is effective against breast, lung, and colorectal cancers. The nano capsules enhance solubility, enable targeted delivery, and overcome the limitations of poor water solubility. It provides controlled release of the drug where needed. These Nano capsules combine with liposomes to facilitate disulfiram delivery, ensuring stability in the bloodstream and promoting efficient cellular uptake within tumor tissues (Filipczak et al., 2025).

Nanotechnology in Drug Delivery

Observing, fabrication, overhauling, and controlling of human biological systems at the nano level by engineering nano devices and structures at the nanometer scale is known as nanomedicine. During the past 10 years, researchers and scientists have been understanding the drug delivery of different yet especially important drugs for human health. Decreasing the frequency of drug dispensing and enhancing the comfort level for the patients is the main goal of targeted drug delivery (Sahoo et al., 2017). Nanotechnology has been used in nanomedicine, where nanoparticles are crafted in such a way that they transport drugs directly to the point of disease. This has greatly reduced the side effects and has revamped therapeutic efficiency (Ambrose et al., 2025).

Lipid vesicles that were depicted in the 60s are known as the first nanotechnological drug delivery systems that later became the term "liposomes". On the other hand, in 1976, the first controlled release polymer system for the delivery of macromolecules was presented. As the years more efficient systems of drug delivery were developed that were competent enough to respond to changes like pH that triggered drug release. "Stealth Liposomes" were the first long-circulating liposomes that were characterized in 1987. The circulation time for the liposomes was significantly enhanced by using "polyethylene glycol" (PEG) in 1990. Furthermore, AIDS-associated Kaposi's sarcoma was treated by using "Doxorubicin Liposome," also known as Doxil (Farokhzad et al., 2009).

Nanotechnology and Stem Cell

The incorporation of nanotechnology with stem cells has opened various pathways to increase the efficacy of stem cell therapy by improving the delivery and differentiation of stem cells (Ding et al., 2021). Stem cells are cells that differentiate into other cells according to the needs of the body. Stem cells are produced in bone marrow and then differentiate into other cells in organs like the lymph nodes, etc. Table 1 gives us information on the different sizes in nanometers of various important objects used in nanotechnology.

Table 1: Some size ranges are connected to stem cell therapy

Object	Size (Nanometer)
Ions	0.1-0.5
Proteins	1-5
Quantum Dots	10-20
Liposomes	40-500
Carbon Nanotubes (CNTs)	100
Stem Cells	5,000-50,000
Metallic Nanoparticles	19-25
Gold nanoparticles (AuNPs)	1-100
Dendrimers	1-10
Silica nanoparticles	10-100

Stem cells have the capacity for self-renewal and play a critical role in regenerative medicine. They replace the damaged tissue and restore its normal function (Luo et al., 2022). Stem cells such as induced pluripotent stem cells (iPSCs) and embryonic stem cells (ESCs) are studied for their ability in organ repair and tissue engineering, thus helping in stem cell therapy (Patra et al., 2021).

Metallic nanoparticles such as gold and silver nanoparticles have been investigated to steer MSC differentiation into neurogenic lineages because of their distinctive physicochemical properties (Kim et al., 2021). With the integration of nanotechnology into medicine and surgical techniques, we can treat some really difficult-to-treat injuries, such as spinal cord injuries. "Carbon nanotubes" are nanostructures that were found to facilitate neural stem cell differentiation and axonal regeneration in the damaged areas of the spinal cord (Shao et al., 2020). Calcium phosphate nanoparticles have helped in bone healing by promoting osteogenic differentiation of MSCs (Bose et al., 2018).

Recent research in nanotechnology has yielded promising results, but has also created doubts regarding its impact on human health. Nanomedicine is a wide-ranging field of science and technology that unifies multiple streams of medical applications such as disease treatment and diagnosis, disease prevention, analgesic innovations, health-enhancing medications, nanoscale technology against traumatic injury, and healing approaches (Malik et al., 2023).

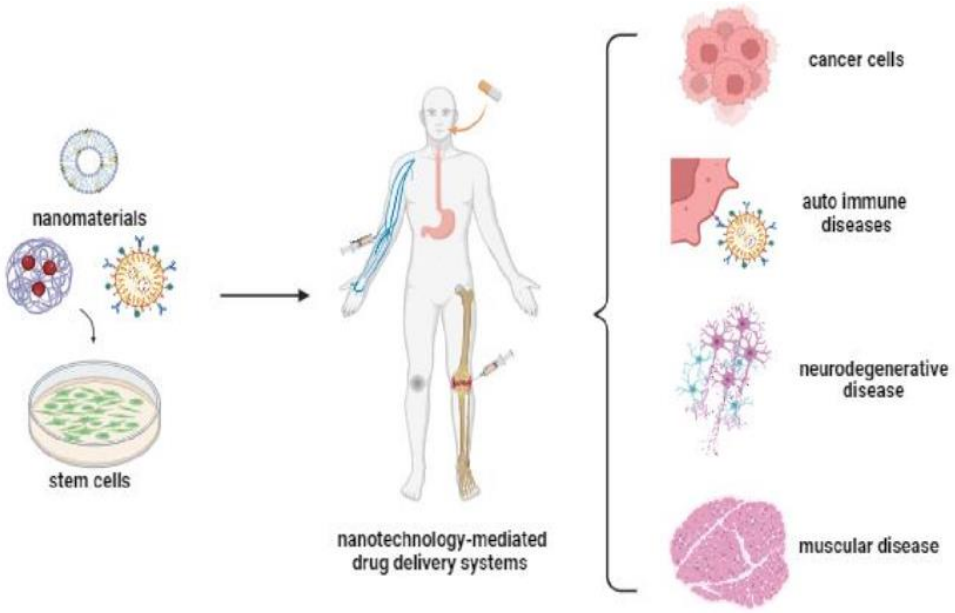

Fig. 2: Nanoparticles and stem cell integration for various treatments

In diagnosis, nanotechnology enables the development of imaging agents, biosensors, and lab-on-a-chip devices. In treatment, nanotechnology includes targeted therapy, drug delivery, and gene therapy as shown in Figure 2.

Nanotechnology provides simultaneous diagnosis and treatment of cancer using nanoscale theragnostic agents that facilitate early detection and targeted elimination of cancer cells. (Dessale et al., 2022). Silver-based therapies have been used in wound healing as they contain toxicity, bacterial resistance, which have limited their use. Now, silver nanoparticles (AgNPs) have shown the potential to avoid the limitations associated with conventional silver-based therapies (Nqakala et al., 2021).

Future Aspects

As these technologies continue to advance, they ensure more promising solutions for health-related challenges among living organisms. The major concern of biotechnology is to provide mankind with miraculous cures and solutions only with the application and manipulation of microorganisms. Along with generating such solutions, ethical concerns still need to be considered to ensure authenticity. Some cutting-edge genome editing tools like CRISPR/Cas9 are one of the most exciting frontiers in biotechnology.

Artificial intelligence (AI) and machine learning (ML) offer great prospects in advancing agricultural practices from predictive breeding to automated phenotyping. Firms of biotechnology are leveraging AI and ML solutions to carry out agricultural tasks such as harvesting crops at a faster pace than humans. Optimized product efficiency can be achieved by the combined use of tissue culture with AI and other optimization algorithms.

Conclusion

Biotechnology and Nanotechnology are reshaping the chemical processes, providing vaccines and biopharming, improving our environment, including soil health, air quality, animal, and ultimately human health. Extensive efforts are required in research and development to improve One Health and to control the escalating pollution. Green processes, biopesticides, and vaccines for emerging viruses are crucial to improve animal-, human health and to achieve a healthy and sustainable future. Biotechnology and nanotechnology are revolutionizing health, agriculture, and environmental sustainability through innovative tools like CRISPR, nano-vaccines, and regenerative therapies. Their integration offers targeted solutions for disease management, enhanced food security, and improved animal and plant health. With advances in AI and precision techniques, these fields promise transformative impacts across One Health. Continued ethical oversight and interdisciplinary collaboration are vital to ensure responsible innovation and long-term benefits for all living organisms.

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