COVID-19 and The World of Biotechnology

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Abstract: ***The era that saw the disruption of the human life at the hands of COVID-19, also saw the rise of the world of Biotechnology. When the whole world was feeling paralysed from helplessness in the face of the deadly SARS-CoV-2 virus, the sector of biotechnology was slowly but steadily beginning to grab the problem by it's neck. From producing lifesaving vaccines, effective drugs, diagnostics, nanotechnology and therapeutics to the emergence of new startups accelerating the growth of bioeconomy, the field of biotech fought and won on many fronts. This battle, however, of successfully harnessing the full potential of biotechnology for the benefit of humankind has been going on for decades. Through the years, biotechnology has been able to achieve various milestones. It has proved to be a boon for life every day and even more evidently on several such occasions when the existence of the human life was threatened by deadly diseases. The devastatingly challenging period of the pandemic withered countless lives, and yet the power of biotech continued to save lives and bloom them with a new hope. In this period of rise and fall, we saw a new world taking shape.***

Keywords: COVID-19; Biotechnology; SARS-CoV-2 virus; Biotech Industry; Vaccines

1. Introduction

The year of 2020 has been etched in our memories and in the history as one of the most challenging times for the human kind.2020 was the tumultuous year that saw the onset of the deadly pandemic of COVID-19 worldwide. The Coronavirus Disease or COVID-19 is caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). The outbreak was first identified in the city of Wuhan, China in December 2019, with the virus spreading rapidly to other countries across the world. The World Health Organisation (WHO) declared the outbreak a public emergency of international concern (PHEIC) on 30th January, 2020, and began referring to it as a pandemic from 11th March, 2020. The WHO ended its PHEIC declaration on 5th May, 2023; earlier, some countries had already begun to regard COVID-19 as an endemic disease. As of 10th August, 2023, the pandemic had caused 769, 369, 059 cases and 6, 954, 323 confirmed deaths, ranking it fifth in the deadliest epidemics and pandemics in history [1].

Effects of COVID-19:

The outbreak of the deadly pandemic of COVID-19 has resulted in a worldwide crisis like no other. It triggered the deepest global recession since the Second World War. The pandemic led to dramatic loss of human life worldwide and presented an unprecedented challenge to public health, food systems and the world of work. Nearly half of the global workforce was at risk of losing their livelihoods. From the poor farmers to the wealthy businessmen, COVID-19 treated everyone with equal disruption and devastation. Labourers did not only have the risk of loss of work but hazardous work conditions and lower pay. Migrant labourers faced a risk like no other with the disruption of transport, poor working and living conditions. With the bread winners losing their livelihood, malnutrition and crisis of food became the reason of inevitable death for many, besides the threat caused by the deadly virus. The low income countries became the hardest hit due to poor facilities for treatment and recovery. Work from home became a global motto and a boon for the employers and workers. The shift from large edifices to confined rooms was not only new but also limiting. Nevertheless, it allowed work to be completed from distant towns and remote villages.

The masked world also saw several innovations and new trends like the office shifting to home sweet-home with the revolutionary 'work from home', cashless transfer of money seamlessly from one account to another with the help of UPI, the convenience of Telehealth that made visiting with a doctor or medical profession over video or any another type of remote connection, the surge in popularity of QR codes, online studying, zooming, and the production of mRNA vaccines. These were some of the many innovations that made the restrictions put over us by the COVID-19 bearable and survivable [2].

The virus also turned the world of Biotech upside down resulting in the emergence of a new era of biotechnology.

Biotechnology

Biotechnology is the result of the meeting of two worlds namely, biology and technology, potent with the power to code life itself. Biotechnology is a multidisciplinary field that includes harnessing processes at cellular and bimolecular level to create products and develop technologies to meet our desired needs as well as ensure advancement of humankind and health of the planet [3].

The term *biotechnology* was first used by Károly Ereky in 1919, to refer to the production of products from raw materials with the aid of living organisms. The wide range of biotechnology encompasses procedures for modifying living organisms for human purposes, going back to domestication of animals, cultivation of the plants, and "improvements" to these through breeding programs that employ artificial selection and hybridization. Modern usage also includes genetic engineering, as well as cell and tissue culture technologies. Since the advent of agriculture, farmers have modified the genes of their plants by the methods of cross

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breeding and introducing their crops to new environments. In the lands of Mesopotamia, Egypt, China and India brewing was used to ferment the beer. But the remarkable breakthrough came when in 1857, Louis Pasteur realised that fermentation is a consequence of yeast multiplication which further led to the discovery of the method of pasteurisation. Based on the works of Gregor Mendel, Louis Pasteur and Joseph Lister, genetic engineering was discovered in 1973 which enabled the first direct manipulation of plant and animal genomes [4].

Throughout the years, biotechnology has proven to be a boon to human kind. The application of biotech has resulted in innovations and breakthroughs in medicines and therapeutics that prevent and treat disease; medical diagnostics such as pregnancy tests; biofuels that are sustainable, reducing waste and pollution; and genetically modified organisms (GMOs) that lead to more efficient and cost-effective agriculture [4].

Plant Biotechnology

Plant biotechnology (PBT) is a branch of biotechnology that encompasses a multitude of scientific tools and techniques for screening and genetic manipulation of plants to develop beneficial or useful plant and plant products. Plant biotechnology has been practised by man since the onset of human civilisation but as an industry, it was established only a century ago. The origin of plant biotechnology can be traced back to 1866 when an Augustinian friar, Gregor Mendel, postulated the fundamental laws of genetic inheritance, based on his work on pea plants. It was founded on the principles of cellular totipotency and genetic transformation. As of 2015, 26 plant species have been genetically modified and approved for commercial release in at least one country. The majority of these species contain genes that make them either tolerant to herbicides or resistant to insects. Plant biotechnologies that assist in developing new varieties and traits include genetics and genomics, marker-assisted selection (MAS) , and transgenic (genetic engineered) crops. These biotechnologies allow researchers to detect and map genes, discover their functions, select for specific genes in genetic resources and breeding, and transfer genes for specific traits into plants where they are needed [5].

Animal Biotechnology

Animal Biotechnology (ABT) is a branch of biotechnology in which biological techniques at molecular level to genetically engineer animals so to improve their suitability for agricultural, industrial and pharmaceutical applications. It is a rapidly growing field with the aim to advance breed development to improve animal health and welfare, reproduction, and animal-derived foods' nutritional safety and quality with the help of genome editing technologies such as CRISPR Cas, Zinc Finger Nucleases, TALENS etc. Animal Biotech has been used to produce medicines, vaccines, therapeutic proteins in their milk, eggs and blood by the use of Animal-made Pharmaceuticals (AMP), and to produce human compatible transplant organs, tissues and cells that can then be used in case of scarcity of organs for transplant for the enhancement of human health. It can also be used to improve animal health through the use of modern technologies such as genetic mapping, in vitro fertilisation, artificial insemination, embryo transfer and cloning [6].

Through the combination of the various branches of biology and engineering; biochemistry, biophysics, cell biology, chemistry, embryology, ecology, microbiology, genetics, molecular biology and immunology, biotechnology has been developed into many other categories.

Milestones Achieved in the Field of Biotechnology in the Last Two Decades:

Biotechnology is the reality and the future and hence the 21st century has been called as '**The Biotech Century.**'

The Human Genome Project

The beginning of the 21st century witnessed the success of the world's largest collaborative biological project called the 'Human Genome Project' (HGP). The aim of this project was to determine the base pairs that make up the human DNA and identify, map and sequence all of the genes of the human genome and provide scientists with powerful new approaches to understand the development of diseases and to create new strategies for their prevention and treatment, as almost all the diseases or medical conditions in a human body arise from mutations in gene. Since genes are the basic functional and structural unit of heredity, the discovery of disease-causing new genes can lead to the development of new cures and the eradication of that disease [7].

Cloning

In 1996, Dolly the sheep became the first mammal ever to be cloned from an adult cell. This feat was remarkable as at the time it was thought to be impossible and its success paved way for the successful cloning of many other organisms. Cloning means to create an exact replica and it allows for the creation of multiple copies of genes, expression of genes, and study of specific genes. There are many potential benefits of cloning in the field of agriculture and medicine. Cloning can be used for the treatment of coagulation disorders. Scottish researchers cloned another sheep that had been genetically modified to produce milk that contains a human protein essential for blood clotting [8].

Cloning can also be used for testing new drugs and treatments as the cloned animals have the same genetic makeup and therefore their responses cannot be variable. The potential benefit of cloning can be harvested in the food market for production of milk and other animal products.

In April 2003, Banteng became the first endangered species to be cloned and survive beyond infancy, the first ever to be cloned being a cattle-like Asian gaur that died two days later from an infection. The Banteng was cloned from the the extracted DNA of the preserved skin cells of a decades-dead male specimen [9]. This success would become a hope for the preservation and rescue of the endangered species. Although the same genetic makeup may make the population more susceptible to disease, it is still better option for a species that is on the brink of extinction [10].

Agriculture

In December of 2002, The International Rice Genome Sequencing Project (IRSGP) released a high quality map-based draft sequence of the genome of Rice (*Oryza sativa* L.) This transformed genetics research and rice breeding. The goal of the project was the improvement of rice. Rice is one

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of the most important food crop in the world and feeds over half of the world's population. The need to produce more quantities of rice to meet the ever growing human population is now more than ever. Ongoing work to understand the evolution and domestication of rice and to use this information on the genetic makeup underlying plant physiological responses and phenotypes is now being used to engineer superior rice strains to feed our growing population [11].

In 2017, Z. Jeffrey Chen led a team of researchers and took the first step toward a new way of breeding better cotton through a process called Epigenetic Modification. Epigenetics has been defined and today is generally accepted as "the study of changes in gene function that are mitotically and/or meiotically heritable and that do not entail a change in DNA sequence. " The information regarding the 500 genes identified by the researchers that are epigenetically modified between wild cotton varieties and domesticated cotton, could help in the selection of the kinds of traits that breeders want to alter, like fiber yield or resistance to drought, heat or pests [12].

DNA Fingerprinting

In the year 1984, Sir Alec Jeffreys, a British geneticist, discovered the technique of genetic fingerprinting in a laboratory in the Department of Genetics at the University of Leicester in U. K. [13]. DNA fingerprinting is a laboratory technique used to determine the probable identity of a person based on the nucleotide sequences of certain regions of human DNA that are unique to individuals [14]. Over 99 percent of the DNA sequence human genome is identical in all of the human population but certain regions of the genetic material are unique to each individual and can be used in the identification process. This remarkable discovery revolutionised forensic science forever by aiding in the identification of the criminals and became the key to the solving of many criminal cases. The first case it solved was an immigration dispute in the U. K. This discovery led to the conviction of the rapist and murderer, Colin Pitchfork, in the year 1988. With the introduction of Polymerase Chain Reaction (PCR), it became possible to analyse small amounts of DNA, even from somewhat degraded samples, through the process of DNA amplification. In the year 1992, PCR-based DNA typing was used to end the 40-year hunt for Nazi prison camp doctor Josef Mengele, nicknamed the "Angel of Death", who had escaped from the Allies at the end of World War II. DNA fingerprinting is also used in paternity testing by matching the DNA fingerprints of the parent and the child. DNA profiling is used to diagnose inherited disorders and human diseases. DNA identity testing can be used to evaluate tumour transmission after transplantation and thus determine whether a malignancy is of donor or recipient origin. In anatomic pathology, DNA identity testing can be used to determine the origin of mislabeled or mishandled specimens. The advantages and uses of this revolutionary discovery continues to increase with time and age [15].

Stem Cells

In the year 2012, the Nobel Prize in physiology and medicine was awarded to Shinya Yamanaka and John Gurdon for the discovery that mature cells can be converted into stem cells and thus can be manipulated to become pluripotent. This discovery proved that although the genetic modifications are inevitable in a maturing cell, it is not irreversible [16].

Stem cells are the basic undifferentiated cells that can develop into any mature cell of the body. They can become any and every cell type and thus are the basis of every cell, tissue and organ of the body. They are characterised by their ability of self renewal, potential to differentiate and their ability to clone. Under appropriate conditions, the stem cells of one tissue can be transformed into mature cells of a different tissue and thus act as omnipotent. This process is the foundation for cell therapy and is termed as Plasticity. Stem cells can be used for various purposes from research and development of drugs to treatment and repair of damaged tissues and organs of the body. Stem cell therapy can be effectively used for treatment of many diseases including cancerous conditions such as leukemia and lymphoma, disorders by blood cells such as Aplastic anaemia and Red cell aplasia, immune deficiencies such as SDIC or Severe combined immunodeficiency and LAD or Leukocyte Adhesion Deficiency, Hemoglobinopathies such Sickle cell anaemia and B Thalassemia, neurological diseases etc. It can also be used in the effective development of drugs [17].

Treatment for diseases such as Liver cirrhosis, heart diseases such as myocardial infarction, cardiomyopathy, heart failure, diabetes type 1, multiple sclerosis, lupus and multiple sclerosis are still under clinical trials, whereas treatment for Alzheimer's disease, Parkinsons's disease, Huntington's disease strokes, spinal injuries, rheumatoid arthritis and regeneration of tissues or organs are still in the experimental phase [17].

The isolation of cells and usage of stem cell therapy remains a challenging process. There are various ethical debates that surround its potential advancement. Scientists all around the globe are trying to combat such challenges and go on advancing in their research based on stem cells and their life generating power [17].

CRISPR Cas 9

Gene editing is proving to be a very important tool that can be used to modify the DNA of an organism and therefore altering its physical traits like the eye colour or for the prevention or cure of different diseases caused by a defect in the gene. CRISPR is a revolutionary technology that can be used to edit genes. CRISPR is an acronym for 'Clustered Regularly Interspaced Short Palindromic Repeats'. CRISPR and the associated proteins of Cas constitute the adaptive immune system of bacteria and archaea, against viruses and plasmids. The Cas 9 proteins are an enzyme that act as a pair of 'molecular scissors' that can be used to cut the two strands of DNA at specific locations. The gRNA or guide RNA are the predesigned RNA sequence with at least 20 base pairs that are located with a longer RNA scaffold. The pre-designed RNA sequence then guides the Cas 9 proteins to the specific location where the cuts are to be made, whereas the scaffold part binds to the DNA. Thus, it is ensured that the Cas 9 only makes cuts at the desired locations of both the strands of the DNA. The cell then recognises that the DNA is damaged and starts repairing it. This process of repairing of the cut DNA can be used to make desired alterations in one or more genes of the cell [18].

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This technology was discovered by Jennifer Doudna and Emmanuel Charpentier in 2011. They were conferred with the Nobel prize for Chemistry in the year 2020 for having discovered 'one of the gene technology's sharpest tools.' [19].

Over the years many methods of gene alteration have been introduced like Zinc-finger nucleases or ZFNs and Transcription activator-like effector nucleases or TALENs. However, the CRISPR Cas 9 technology has stood out as the cheapest, fastest and most reliable tool for gene editing.

The CRISPR Cas 9 technology has an ocean of potential and can be used in the treatment of various diseases like cancer, high cholestrol, hepatitis B, etc. Many malfunctions in the human body that arise due to some defect in the gene can also be prevented and cured by this system. The germinal cell gene editing still remain a topic of debate and is banned in most of the countries. However, CRISPR's potential can be exploited by its use in the somatic cells to cause various differences and make life easier for many patients.

The research on the CRISPR Cas 9 technology is being continued by scientists all over the globe. The researches are trying to find out possible ways to eradicate any possibility of 'off-target' effects which can arise if the Cas 9 protein cuts a different gene than the desired one. The researchers are focusing on developing the models in animals and isolated human cells, and then expanding it for other human purposes.

Although there is still time before CRISPR Cas 9 comes into the common uses of life, research for it's development is being conducted at a fast pace. Life with the development of this technology can become much easier and many life threatening diseases like cancer, can thus be prevented and cured. This tool is one of the greatest gifts to humankind and it's discovery proved to be the beginning of a new era for life sciences [19].

The Nobel Prize, 2023

The 2023 Nobel Prize in Physiology or Medicine was jointly awarded to Katalin Karikó and Drew Weissman for their discoveries regarding nucleoside base modifications that played the pivotal role in the development of effective mRNA vaccines against COVID-19. Since the 1990s, the Hungarian Biochemist Catalan Kariko had devoted herself to developing methods to use mRNA for therapy. She had already understood its importance and despite major obstacles was resilient [20].

The major breakthrough came in 2005 when Kariko with her colleague and immunologist Drew Weissman, observed that the dendritic cells recognise *in vitro* transcribed mRNA as a foreign substance, which leads to their activation and the release of inflammatory signaling molecules. They also observed that mRNA from mammalian cells did not give rise to a similar reaction. Using this as the basis of their research, they tried altering the base of different variants of mRNA, which were then delivered to dendritic cells. It was seen that the inflammatory response of the mRNA were nullified by the alterations in the bases. This led to a staggering shift in the understanding of cell's responses to different variants of mRNA. In further papers published, it was also concluded that modifications made in mRNA led to increase in the production of proteins [21].

Before the outbreak of COVID-19, many companies had already begun researching on mRNA vaccines for the Zika virus and MERS-CoV which is quite similar to the SARS-CoV-2. This discovery proved to be a boon when vaccines with base modified mRNAs were developed and proved to be highly effective against the virus. The vaccines saved countless lives and became a ray of hope in the pandemic. Besides this, the technology is also being developed to deliver therapeutic proteins and treat life-threatening diseases like cancer.

The Impact of COVID-19 on the Biotech Industry

The life saving sector during the era of COVID-19 was the Biotech Industry. The Biotech Industry is a rapidly rising sector that aims to combine the life sciences innovations with capitals to provide treatment, prevention and control of diseases as well as increase in quality of food, sanitation and lifestyle. The growth of biotech industry has been witnessed globally since the onset of the 21st century.

The biotech sector was growing at a steady pace and then almost overnight, the coronavirus hit the world and transformed the biotech industry by giving it a much needed stimulus. Now, it had become crucial to develop vaccines, test kits, efficient antibody tests and new effective drugs and supply them across the nation and across the world rapidly. The whole world was leaning on the biotech sector for the production and distribution of drugs to save lives.

Although the industry first met with a few setbacks, it proved to be resilient and was quick to recover. This led to a major shift in the ways of approach for problems and solutions relating to biotech.

Vaccinations

The onset of the era of the vaccine began when Edward Jenner, a British physician, inoculated an 8 year boy, James Phipps, with fresh cowpox lesions in May 1796 to study and develop a way resistance against cowpox disease as it came to his understanding that the once infected by the disease, the person won't catch it again. Thus when he inoculated James two months later, there were no signs of the disease and he concluded that the boy's body had developed an immune response and resistance against the cowpox disease [22].

A vaccine is a preparation that is administered into the patient to either prevent or treat a disease by stimulating the immune system of the organism. Vaccines are usually administered in the form of injections but some are also given orally or nasally. Vaccines can confer active immunity by stimulating the immune response of the individual against the harmful agents. It can also confer passive immunity by providing antibodies or lymphocytes made by an animal or human donor [23].

The research for producing an effective vaccine for COVID-19 began with the spread of the pandemic. From the July of 2021, nine different technology platforms were under research and development to create an effective vaccine against COVID-19 [24]. The vaccines introduced to combat

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the infectious disease were primarily either mRNA vaccines, Adenovirus vector vaccines, inactivated virus vaccines or subunit vaccines. The vaccines were administered by injections [25]. The vaccinations were planned to be phased and prioritising people with high risk of infections leading to deaths, including the elderly and the health care workers. Well established companies like Pfizer and BioNTech joined hands for a partnership that yielded one of the first approved vaccines for Sars-Cov-2, now called 'Comirnaty. ' Their partnership in 2018 led to the beginning of research for the development of mRNA vaccine for treating influenza. Other than producing vaccines for COVID-19, BioNTech is also aiming to produce vaccines for treatment of cancer by 2030. In China, the main vaccine administered was Coronavac produced by the firm Sinovac. Moderna became another key company for the production of COVID vaccine and also developed booster doses for the omicron variant. Johnson and Johnson became known for its vaccine requiring only one dose [26].

As of 4 December 2023, 13.53 billion COVID-19 vaccine doses have been administered worldwide, with 70.6 percent of the global population having received at least one dose [27].

Vaccines: *The Indian Scenario*

India is the largest producer of vaccines in the world and the largest vaccination program in the world commenced on January 16, 2021 in India with an ambitious target to immunise a population of 1.3 billion people. As of 4th March, 2023, India has administered over 2.2 billion doses overall, including first, second and precautionary (booster) doses of the currently approved vaccines. This was made possible by the scientists who developed COVAXIN, India's first indigenous COVID-19 vaccine by Bharat Biotech developed in collaboration with the Indian Council of Medical Research (ICMR)-National Institute of Virology (NIV) and Covishield (the Oxford-AstraZeneca Adenovirus vector-based vaccine AZD1222), produced under the "at-risk manufacturing and stockpiling license" from the Drugs Controller General of India (DCGI), and the Indian Council for Medical Research (ICMR). The Serum Institute of India (SII), Pune, has signed agreements with a few manufacturers such as Oxford-AstraZeneca, Codagenix, and Novavax for the production of Covishield [28].

CovaxinTM is an inactivated-virus vaccine, developed in Vero cells. The inactivated virus is combined with Alhydroxiquim-II (Algel-IMDG), chemosorbed imidazoquinoline onto aluminum hydroxide gel, as an adjuvant to boost immune response and longer-lasting immunity. This technology is being used under a licensing agreement with Kansas-based ViroVax. The use of the Imidazoquinoline class of adjuvants (TLR7/8 agonists), shifts the T-cell response towards Th1, a THelper 1 phenotype (which is considered safer than Th2 responses against SARS-CoV-2) and reduces the risk of immunopathologically mediated enhanced disease [29].

Nanotechnology

Personal Protective Equipments or PPE started being widely used for prevention against the coronavirus. Nanomaterials were used to develop the filtration efficiency of masks during the COVID era. The now nanofibers and NPs induced masks were better performers in terms of antiviral properties, filtering capacity and breathable properties. Nanotechnology was used in gloves as antibacterial silver nanoparticles to improve its virucidal activity. Nanoparticles coated ACE2 proteins could be used to neutralise viruses and prevent their entry into host cells. Although disinfectants such as alcohol, phenol and formaldehyde proved to be irreplaceable during the COVID era, their continuous usage for a long period of time can have harmful effects on the environment. Using NPs such as metallic silver, copper and titanium based disinfectants have not only showed virucidal activity but are also a safer option for the health of the environment. Using nanotechnology for detection of coronavirus played a significant role. Nanotechnology was also used in vaccines and drug delivery systems and proved very to be of great value during the challenging times [30].

Diagnostics

Diagnostics was very crucial in the COVID era for the successful detection and eradication of the coronavirus. Diagnostic tests are the approaches used in clinical practice to identify with high accuracy the disease of a particular patient and thus to provide early and proper treatment [31]. The diagnostics were done using three methods. The molecular or nucleic acid amplification tests (eg-PCR tests) provide the most effective way to detect the viral RNA. The antigen rapid detection tests (eg-nucleocapsid or spike proteins) detect the viral proteins, although less precise, are more cost effective and ensure faster results. The serology tests are able to detect the host antibodies in response to infection, or vaccination, or both [32]. The FIND data mentions a list of 2, 428 total tests at present out of which the number of antigen tests is the highest [33]. The different phases of the pandemic led to changes in approaches and different strategies for diagnostics. The pandemic showed us the importance of diagnostic tools and their proper usage. This should be an inspiration for investment in the diagnostic and surveillance systems and their developments to aid in the health care system as well as prepare for any future pandemics or outbreaks.

Therapeutics

Developing new therapeutics for COVID-19 was an essential strategy for survival. Therapeutics is the branch of medicine that is concerned with the treatment of disease. Repurposing of licensed drugs and monoclonal activities was given the primary preference. Existing antiviral drugs, previously used against diseases like HIV/AIDS, malaria, MERS and SARS, were studied and researched for the development of treatment against COVID-19 [34].

Three antiviral therapies i. e. molnupiravir, remdesivir, and nirmatrelvir/ritonavir were given global approval after promising hopes of recovery shown in randomised clinical trials. Molnupiravir (EIDD-2801) is a prodrug of EIDD-1931 (*N*4-hydroxycytidine, NHC) and it proved to be the most promising orally ingested small molecule treatment for COVID-19. It was developed by the collaboration of Merck and Ridgeback Biotherapeutics in 2020 and released under the brand name of Lagerio in 2021. It reduced the hospitalisations and deaths in the trials by 30 per cent [35].

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Nirmatrelvir (PF-07321332) is an antiviral agent which is administered with Ritovar (an inhibitor of cytochrome P450 3A4) the treatment of mild-to-moderate COVID-19 in adults and people 12 years of age and older. It was developed by Pfizer. It was recommended by WHO but due to high cost it's supply was restricted in developing countries [35].

Paxlovid is a co-packaged version of nirmatrelvir and ritovar, approved by FDA for oral use and treatment of COVID-19 in certain adults who are being treated outside the hospital [36].

Remdesivir is an antiviral drug which is intravenously administered. It was originally developed by Gilead Sciences in 2009 to treat hepatitis C and respiratory syncytial virus (RSV). In the October of 2020, Remdisivir became the first treatment for COVID-19 to get the FDA approval [35].

Vekluvir (remdisivir) was approved by FDA for intravenous therapy for treatment of COVID-19 in patients who do not require hospitalisation as well as the patients who are hospitalised [36].

The FDA has also approved Olumiant (baricitnib) and Actemra (tocilizumab) for certain hospitalised adults [37]. Monoclonal antibodies were used effectively in the detection and treatment of COVID-19. Various nAbs were studied and many countries authorised emergency usage and full approval in special cases. NAbs such as Bamlanivimab, Etesevimab, REGEN-COV (casirivimab and imdevimab), Xevudy (sotrovimab), Evusheld (cilgavimab and tixagevimab), and Bebtelovimab were granted the EUA from the US FDA [35].

The Emergence of New Startups

The complexity of the nature of Coronavirus paved way for a more than 800 clinical trials of drugs and vaccines. Many research companies with no prior experience or record in the infectious disease sector commenced their operations for the search of the perfect drugs and vaccines aiming control and eradication of COVID-19. Though all of them didn't succeed in building ideal drugs and vaccines, the movement became significant for the future of biotech. With the world now recognising the importance of investment in this field, biotech industry saw an increase in funding from the partnerships, venture capitalists and IPOs. In 2020, the amount of venture capital invested in the biotech sector reached $36.6 billion and joint partnerships and ventures reached a total of $170.6 billion. From cell therapy, gene therapy and cancer therapy to precision agriculture and synthetic biology, startups are aiming to work on a variety of branches and products of biotech ensuring diversity. The head of the startups are more likely to be the founders who care more about the research and innovations as investors acknowledge this blend of science and creativity [37].

According to Precedence Research, the global biotechnology market size was valued at USD 1, 224.31 billion in 2022 and is anticipated to surpass around USD 3, 210.71 billion by 2030 [38]. The global biotechnology market is growing at a CAGR of 12.8% from 2023 to 2030. In India, the biotech industry has been identified as a sunrise sector and is estimated at USD 92 billion in value for the year 2022. The biotech industry is a key part of India's vision of becoming a USD 4 trillion economy by 2024 [39].

Bioeconomy

The International Advisory Committee on Bioeconomy, set up on the occasion of the First Global Bioeconomy Summit in Berlin in November 2015, defines bioeconomy as "knowledge-based production and utilisation of biological resources, biological processes and principles to sustainably provide goods and services across all economic sectors. " [40]. Bioeconomy can be used to transform the ideas and innovations birthed in the laboratory into sustainable, ambitious and ecofriendly products. Countries across the globe are trying to accelerate the growth of the different sectors of biotechnology such as the red biotechnology sector which includes pharmaceuticals and personalised medicine, the green biotechnology sector which comprises of the transgenic plants and cloned animals and the white or industrial biotechnology sector, which uses renewable primary materials to make bioplastics, biofuels, and various other products. This would not only ensure development of biotechnology but would also help in creating job opportunities and promote economic growth. This would also limit the dependency on oil and help in combating climate change. It will also help in reducing the negative impacts on environment by using processes such as sequestration of carbon in bio-based products and using adept methods for production. The development of bioeconomy would also ensure better food security by providing good quality of a diverse range of foods in adequate amounts. Developing countries like India can aid the growth of rural areas by harnessing their raw materials and land required for bioeconomy growth. The promotion of the bioeconomy also deals with the transfer of laboratory innovations to the market [41].

According to National Biotechnology Development Strategy drafted by the Ministry of Science and Technology of India in the year 2007 and later updated in 2014, Bioeconomy is defined as "translating life sciences knowledge into socially relevant eco-friendly and competitive products". It aims in applying biotechnology in health, energy, agriculture, bio-manufacturing and environment [41].

The Indian biotechnology is dominated by the red biotechnology sector which mainly focuses on the production of vaccines and diagnostics. One of the main aims of the 2014 strategy is the eradication of malnutrition, such as iron and macronutrients deficiency, moderate and acute malnutrition in children etc. Processes of nanotechnology is also being used to maximise the shelf life of food products. In agriculture, the cultivation of genetically modified cotton as well as testing on other crops such as sorghum, rice, mustard and rubber is also going. Transgenic crops the ability of resisting biotic and abiotic stresses are being researched into in the laboratories [41].

Circular Bioeconomy

Circular bioeconomy is a new conceptual framework that aims in using renewable natural capital and limiting the waste and use of non renewable products to transform and manage our health, food, land and industrial systems, with the target of achieving sustainable wellbeing in harmony with nature. It relies on harnessing the power of evolving biodiversity. This concept was given to reduce the exploitation of nature and

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usage of non renewable, fossil based materials extravagantly [42]. The Circular Bioeconomy Alliance was established in the year 2020 by His Majesty King Charles III with the aim "to accelerate the transition to a circular bioeconomy that is climate neutral, inclusive and prospers in harmony with nature." It was guided by the '10 point action plan for a circular bioeconomy of wellbeing', co-created by a multi-stakeholder coalition [43]. One of the major subsector of bioeconomy is forest based. It emphasises on the use and reuse of forest based materials for production of goods and services. Woods can be a very advantageous raw material for the bioeconomy as they are versatile and renewable. Woods can become a substitute for the fossil based, non-renewable products. The dominating steel and concrete in the industrial sector can be replaced with the Cross Laminate Timber (CLT) and synthetic fibers like polyester in the textile industry can be replaced with wood based textiles. Nanocellulose is one of the revolutionary innovations which is five times stronger than steel and five times lighter. This change will reduce the carbon footprint drastically and promote a greener economy. A circular bioeconomy will also become a major source of job opportunities as according to World Economic Forum's New Nature Economy Report II on "The Future of Nature and Business" , the sustainable management of forests can create $230 billion in business opportunities and 16 million jobs by the year 2030 [44].

Telemedicine

Telemedicine is the term used to refer to the use of electronic technologies to communicate information to provide and support healthcare when distance separates the participants [45]. According to the World Health Organization (WHO), Telemedicine is "The delivery of healthcare services, where distance is a critical factor, by all healthcare professionals using information and communication technologies for the exchange of valid information for diagnosis, treatment and prevention of disease and injuries, research and evaluation and for the continuing education of healthcare providers, all in the interests of advancing the health of individuals and their communities. " Telemedicine will function with merging the sectors of IT and healthcare. After the threat of home quarantine caused by the COVID pandemic, telemedicine can prove to be of much use and benefit. It will not only promote easy access of medical help and treatment in remote areas but also reduce transportation time and cost. In developing countries such as India, where even primary medical care is not available in all rural areas, the use of telemedicine can save lives. It can also be used to monitor the patient, disease surveillance, as well as second opinion for the treatment. It can also provide for surgery using tele-monitored hand robots. Students who have been unable to continue their education due to the long distance between their homes and the classrooms can be guided using this technology. Clinical trials and research in the remote areas will also be made possible with the telemedicine. The use of telemedicine will highly benefit the healthcare system by detection and treatment of diseases in the rural and remote areas, the economy by creation of different jobs, equipment's etc, as well as save countless lives [46].

Social Acceptance

Although vaccines and other diagnostics did a great work in combating the pandemic, the skepticism of people regarding them also rose. People, all over the world, were lacking the belief in vaccines and the healthcare system to eradicate the disease, although there was a slight increase in their trust after the visible success of the vaccines. In a survey conducted in 23 countries among 23, 000 respondents, vaccine acceptance in the year 2022 was 79.1 percent, up from 75.2 percent in 2021. Vaccine hesitancy depended on different factors in different countries such as less than the median income in the United States, not having a university degree in France, Poland, South Africa, Sweden and United States, etc. Misinformation and misrepresentation of the vaccines especially in developing countries also led to increase in vaccine hesitancy [47].

The eradication of the mistrust is also crucial for the development of the biotech sector as it depends on the participation of society. The biotech companies require funding and support from investors and people. The reaction of people to the innovations and advancements in biotechnology becomes crucial for it's future. The trust of the public in science and scientists have to be rebuilt through propagating the crucial information about the advancements through campaigns, proper education and increase in literacy, and engaging the general public through interactive means.

2. Conclusion

The world and the biotech sector were shaken when the COVID-19 pandemic hit the world. It caused a worldwide crisis which affected everyone and everything. Yet the churning of the biotech sector, made the butter of growth. It marked the end of an era for biotech and the creation of a better one. From creation of new vaccines and diagnostics to their proper dispersal and usage, we witnessed it all. It also marked the boom of biotech startups and the increase in investment of capitals in the biotech industry. Although much work for the complete development of bioeconomy and biotechnology is still due, the foundations have already been laid. Now is the time to act for the betterment and sustenance of life on earth.

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