



ISSN : 3108-2017(Online)  
3108-1304(Print)

Vol.-1; Issue-2 (Oct.-Dec.) 2025

Page No.- 42-53

©2025 IJSTE

<https://ijste.gyanvidya.com>

**Author's :**

### 1. Anjali Kumari

Department of Zoology, Nitishwar Mahavidyalaya (A constituent unit of B.R.A. Bihar University), Muzaffarpur-842002-India.

### 2. Kriti Milan

Laboratory of Bioactive Material Synthesis, University Department of Chemistry, B.R.A. Bihar University, Muzaffarpur-842001-India.

### 3. Abhay Nanda Srivastava

Laboratory of Bioactive Material Synthesis, University Department of Chemistry, B.R.A. Bihar University, Muzaffarpur-842001-India.

Corresponding Author :

### Abhay Nanda Srivastava

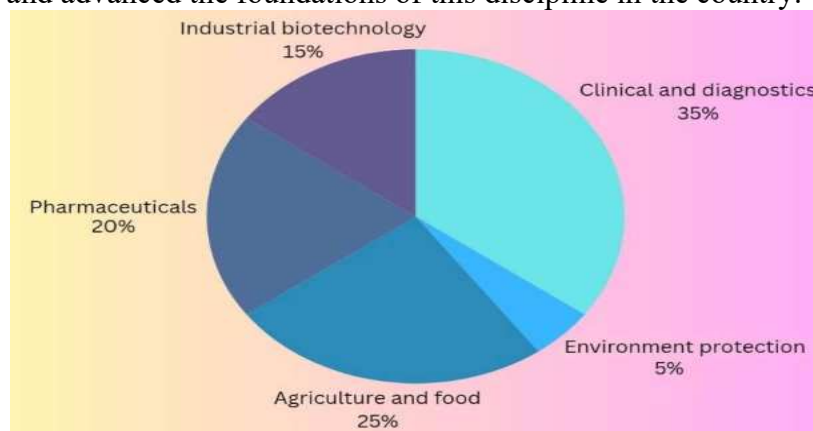
Laboratory of Bioactive Material Synthesis, University Department of Chemistry, B.R.A. Bihar University, Muzaffarpur-842001-India.

## Contribution of Indian Scientists in Elevation of Biochemistry

**Abstract :** This article reviews major contributions of Indian Scientists in structural biology and molecular biochemistry. In this article, we will examine the contribution of Scientists along with their efforts and experiments, highlight the names of present-day Scientists and Indian institutes, and explore the challenges and opportunities in India. We will also discuss the available infrastructure, research funding. We will also examine the legacy of Indian Scientist in biochemistry as well as the inspiration it provides to future generation.

**1. Introduction :** Biochemistry is the bridge between biology and chemistry. It helps in understanding life processes and diseases at the molecular level. Biochemistry mainly focuses on biomolecules such as proteins, nucleic acids, carbohydrates, and lipids, and how these molecules interact to maintain cellular structure and function. Through the study of metabolic pathways, enzymes, and genetic mechanisms, biochemistry helps explain how living cells grow, reproduce, and respond to environmental changes. This field also plays an important role in medicine, biotechnology, and agriculture by providing insights into disease mechanisms and the development of new treatment. [1] It helps in improve crop yield, disease resistance also helps in making biofertilizers, pest control and genetically improved seeds. This pie chart shown as Figure 1, illustrates the distribution of the major applications of biochemistry within India. The data highlights that Clinical and diagnostics is the leading application, accounting for the largest share at 35%, followed by Agriculture and food at 25%. Pharmaceuticals and Industrial biotechnology follow with 20% and 15% respectively, while Environment protection represents the smallest application at 5%. Collectively, these sectors underscore the critical and diverse role biochemistry plays in supporting key pillars of

the Indian economy and public health. This article aims to examine the contribution of eminent Indian Scientists to the field of biochemistry, highlighting the pioneering efforts through which they established and advanced the foundations of this discipline in the country.



**Figure 1:** Graphical representation of major applications of biochemistry in India

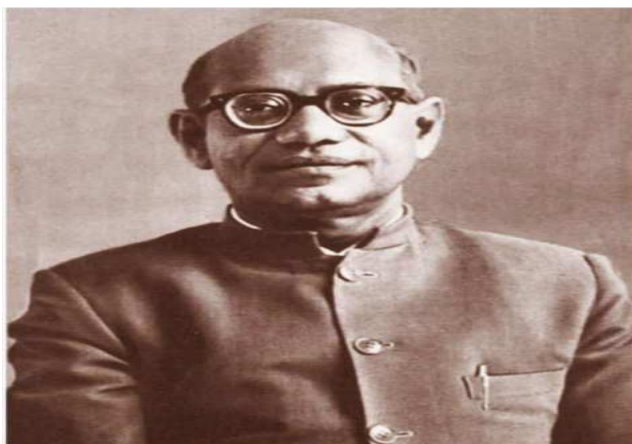
## 2. Early pioneers in Biochemistry

**Meghnad Saha (1893–1956)**– Saha himself was not a biochemist, but he encouraged the growth of biochemistry. Though a physicist he encouraged molecular and biochemical research in India. Saha applied the principles of thermodynamics and quantum theory to chemical molecules. The ionization of elements in stellar atmospheres depends mainly on temperature and pressure. Higher temperatures increase the degree of ionization of atoms in gases. [2] This relationship helps scientists understand the spectra and chemical composition of stars. [2]



**Figure 2:** Image of Meghnad Saha

**B.C. Guha (1904–1962)** – Often referred to as father of modern biochemistry in India [3]. His research focused on vitamin C biosynthesis, nutrition, and waste management. His contribution led to formation of Guha Research Conference (GRC) in 1960. His research was primarily centered on vitamins, nutritional biochemistry, and the practical application of science to solve hunger and malnutrition. Guha was not just a researcher but a builder of scientific infrastructure in India. His study examined how this vitamin is present in different food materials and biological tissues. The research also discussed the chemical nature and stability of Vitamin B<sub>2</sub> under various conditions. [4] These investigations helped scientists better understand the nutritional importance of riboflavin. Guha's work contributed significantly to the development of nutritional biochemistry and vitamin research.



**Figure 3: B.C. Guha**

**Asima Chatterjee (1917–2006)** – First woman in India to receive a Doctorate of Science. Her extensive research focused on natural products like Vinca alkaloids and anti-malarial drugs. She is most famous for her work on Vinca alkaloids used in cancer chemotherapy and for developing Ayush-56 (anti-epileptic) and Ayush-64 (anti-malarial) treatments. The research by Asima Chatterjee focused on the structure and stereochemistry of ajmalicine, an indole alkaloid obtained from medicinal plants.[5] Her study analyzed the chemical transformations of this compound and helped clarify its molecular structure.



**Figure 4: Asima Chatterjee**

**Kamala Sohonie (1911–1998)** – First woman Ph.D. in Science. She worked on staple diets and neera. She discovered that Cytochrome C, [6] an enzyme essential for energy production (the electron transport chain), was present in every cell of plant tissues. Her work led to the use of Neera as an inexpensive dietary supplement to combat malnutrition among tribal children and pregnant women, for which she received the Rashtrapati Award. In her research published in the Biochemical Journal, she studied the enzyme cytochrome c and its role in cellular respiration.



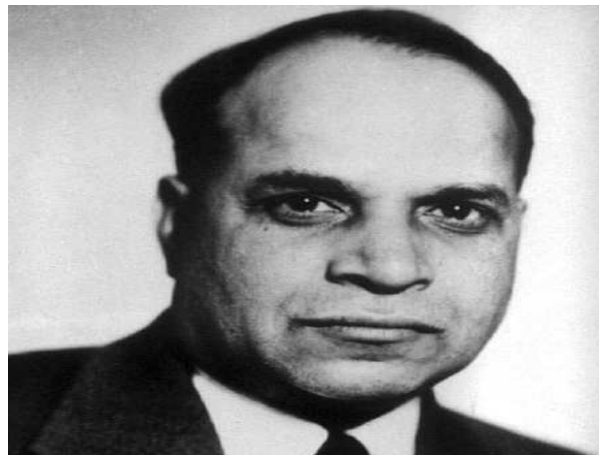
**Figure 5: Kamala Sohonie**

**G.N. Ramachandran (1922–2001)** – Developed the Ramachandran Plot, essential for understanding protein structures. By treating atoms as hard spheres, he calculated which rotation angles ( $\phi$  and  $\psi$ ) around the alpha-carbon of an amino acid were physically possible without atoms colliding (steric hindrance). He introduced the Ramachandran plot, which explains the allowed conformations of peptide bonds in protein structures.[7] This discovery became a fundamental tool for studying protein structure and understanding molecular biology. His research greatly advanced the field of biochemistry and structural biology.



**Figure 6: G.N. Ramachandran**

**Yellapragada Subbarow (1895–1948)** – He discovered the role of ATP as the cellular energy currency. He discovered Diethylcarbamazine (DEC),[8] essential for treating filariasis. Along with Cyrus Fiske, he developed a colorimetric method for the estimation of phosphorus in biological fluids (Bharti & Marfatia, 2017). Published in 1925, it remains one of the most cited papers in scientific history (Bharti & Marfatia, 2017).



**Figure 7: Dr. Yellapragada Subbarow**

### 3. Advancement of Biochemistry in India

#### *Early foundations (1920s–1950s)*

B.C. Guha established the Guha Research Conference in 1960.[9] The Department of Biochemistry at the Indian Institute of Science (IISc), Bengaluru, founded in 1921.[10] Its fundamental aim is to provide for advanced instruction and to conduct original investigations in all branches of knowledge.

\* Excellence in Research: To push the boundaries of knowledge in basic sciences (Physics, Chemistry, Biology, and Mathematics) and Engineering.

\* High-Level Education: To offer world-class postgraduate (Masters and PhD) and undergraduate programs that train the next generation of scientific leaders.

\* Innovation and Translation: To bridge the gap between academic research and industrial application through the Society for Innovation and Development (SID) and the Interdisciplinary Centre for Water Research (ICWaR).

\* National Problem Solving: To address India's specific challenges in sectors like aerospace, sustainable energy, healthcare (through the Centre for Brain Research), and climate change.

The Society of Biological Chemists (India), in 1930s, [11] encouraged collaboration among Indian researchers (Nature, 1932).

***Institutions building (1950s–1980s)*** : The CSIR – Indian Institute of Chemical Biology (IICB), Kolkata, emerged as a hub for biomedical biochemistry. [12] Its core aim is to conduct multidisciplinary research at the interface of chemistry and biology to address diseases of national and global importance.

#### *Core Aims and Objectives*

Multidisciplinary Disease Research: To conduct basic and applied research on infectious diseases (specifically Cholera and Leishmaniasis/Kala-azar), cancer, neurobiology, and metabolic disorders.[13]

Drug Discovery and Development: To develop novel therapeutic strategies, including herbal products, vaccines, and synthetic drugs. Notable successes include the development of an oral cholera vaccine and treatments for gastric ulcers and vitiligo.

Technological Innovation: To create diagnostic kits for malignancy, hormonal disorders, and other health conditions using state-of-the-art technology.

Human Resource Development: To generate highly trained scientific manpower in specialized fields such as molecular genetics, structural biology, and bioinformatics.

Industry-Institute Liaison: To bridge the gap between laboratory research and commercial application through technology transfers and consultancy services.[14]

***Modern Developments (1990s–2010s)*** : Increased funding from DBT, CSIR, and ICMR supported infrastructure.[15]

According to CSIR Annual reports, India advanced in biotechnology and genetic engineering.

#### **4. Present-day innovations**

IIT BHU developed a device for early detection of bone cancer.[16]

CSIR-CCMB Hyderabad discovered how protein flexibility enables multitasking in plants.[17]

DBT and BIRAC launched high-performance biomanufacturing.[18]

IIT Madras – Danish collaboration revealed how genetic variants activate hidden metabolic pathways.[19]

The CSIR-Centre for Cellular and Molecular Biology (CCMB) in Hyderabad stands as India's premier hub for genomic and molecular research. Since its inception, the institute has bridged the gap between fundamental laboratory science and national-scale applications, ranging from criminal justice to public health.

The most iconic contribution came from Dr. Lalji Singh, who developed indigenous DNA fingerprinting technology.[20] By isolating unique "Bkm" probes, he revolutionized the Indian judicial system, making India a world leader in forensic science. In the realm of human history, Dr. K. Thangaraj pioneered population genetics, mapping the ancestry of over a billion people. His work revealed that modern Indians descend from two ancient lineages—Ancestral

North Indians (ANI) and Ancestral South Indians (ASI)—a discovery vital for understanding hereditary disease patterns across ethnic groups. [21]

Beyond human health, CCMB has left a significant mark on agriculture. The development of Improved Samba Mahsuri rice, a variety resistant to bacterial blight with a low Glycemic Index, has benefited millions of farmers and diabetic patients alike.[22] Today, scientists like Dr. R. Sankaranarayanan continue to push boundaries in structural biology, uncovering "proofreading" mechanisms that ensure the accuracy of life-sustaining protein synthesis.[23]

### 5. Biochemists contributing from Indian origins

**Ruchi Ram Sahni (1863–1948)** – A pioneering figure of modern science in India. He carried indirect research in biochemistry, teaching of chemistry, introduction of laboratory culture, and advocacy for science. His indirect contribution was important for the later growth of biochemistry in India.

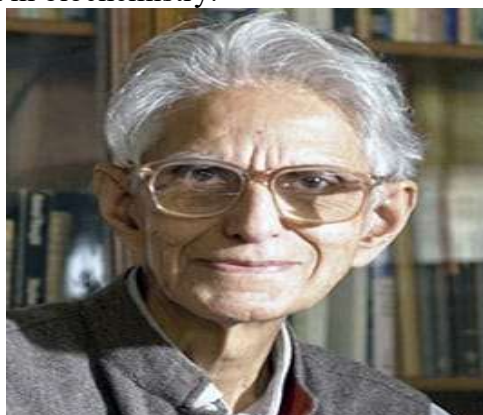
**Yellapragada Subbarow (1895–1948)** – Discovered ATP's role in energy transfer and tetracycline. Also developed chemotherapy drugs. His team developed Diethylcarbamazine (DEC), the first effective drug against filariasis.

**Sambhu Nath De (1915–1985)** – Discovered the cholera toxin secreted by *Vibrio cholerae*. [24] De developed a model which became foundation for studying other bacterial enterotoxins. His contributions helped in development of modern cholera vaccines and the scientific basis for Oral Rehydration Therapy (ORT).



**Figure 8: Sambhu Nath De**

**Obaid Siddiqi (1932–2013)** – Researched in the molecular biology of protein synthesis. His team explored how genes influence sensory systems. As a founding member of Tata Institute of Fundamental Research (TIFR) and later founding director of NCBS, [25] he created India's most advanced centres for research in biochemistry.





**Figure 9: Obaid Siddiqi**

There are many such scientists like Modadugu Vijay Gupta, Chandrima Shaha, Jagannathan Vijaya, V.R. Lalithambika who have made significant contributions in different fields. It is on the basis of their work that India continues to progress today, not only in the medical field but also in many other areas of science and technology.

**Har Gobind Khorana (1922–2011)** – Helped in cracking the genetic code. He showed that the genetic code is made of triplets (codons).[26] This discovery is a cornerstone of modern biochemistry and molecular biology. He was the first to synthesize a gene in the laboratory (1972).[27]



**Figure 10: Har Gobind Khorana**

These discoveries laid the foundation for genetic engineering, biotechnology, and synthetic biology. He shared the Nobel Prize in 1968 with Marshall Nirenberg and Robert Holley for interpreting the genetic code.



**Figure 11: Featuring Nobel Laureate Har Gobind Khorana**

His discoveries form the basis of genetic engineering, biopharmaceuticals, genomic medicine, and DNA sequencing technologies. His legacy continues in opening the door to the genetic revolution that defines modern life sciences.

**6. Present-day Scientist :** Number of researches are ongoing to bolster the area of biochemistry to improve the area of human wellness. The synergistic approach of scientists of this era elevates the development of scientific discoveries with the help of biochemical research. Among many, some pioneer researchers are briefed as below-

**(i). Dipankar Chatterjee (1951)- Indian institute of science :** Dipankar Chatterji is a molecular biochemist known for his work on bacterial transcription and stress-response mechanisms. His research has helped explain how bacteria regulate gene expression during environmental stress and antibiotic exposure.[28] These studies are important for understanding microbial survival and drug resistance.

**(ii). Manju Bansal (1949)- Indian institute of science :** Manju Bansal is a pioneer in computational structural biology in India. Her research focuses on DNA and protein structures and how molecular conformation influences biological function. She developed computational tools to analyze nucleic acid structures and molecular interactions.[29]

**(iii). Sandhya S. Visweswariah (1963)- Indian institute of science :** Sandhya S. Visweswariah studies cyclic-nucleotide signaling pathways and their role in cell regulation.[30] Her research investigates guanylyl cyclases and how cyclic GMP influences cellular signaling in health and disease.

**(iv). Satyajit Mayor(1964)- National centre for biological sciences :** Satyajit Mayor is a leading cell biologist studying membrane organization and endocytosis.[31] His work has explained how lipid organization influences cell signaling and membrane trafficking.

**(v). Hemalatha Balaram (1955)- Jawaharlal Nehru centre for Advanced scientific research :** Hemalatha Balaram studies biochemical pathways of malaria parasites. Her work focuses on enzymes involved in parasite metabolism[32] and the development of potential antimalarial drug targets.

**(vi). Ashok K. Vaid (1952)- University of Delhi :** Ashok K. Vaid works in protein biochemistry and enzyme regulation. His research explores metabolic enzyme mechanisms and their role in metabolic disorders.[33]

**(vii). Amitabha Chattopadhyay (1960)- JNU :** Amitabha Chattopadhyay is an Indian biochemist and membrane biophysicist known for his work on cell membrane organization and lipid-protein interactions. His research focuses on how cholesterol and other lipids regulate membrane proteins and receptors. He has made important contributions to understanding G-protein-coupled receptor function.[34] His studies help explain how membrane structure influences cell signaling pathways. These discoveries have implications for drug design and neurological diseases. His work is widely cited in membrane biochemistry research.

**(viii). Umesh Varshney (1957)- JNU :** Umesh Varshney is a molecular biologist whose research focuses on protein synthesis and translation mechanisms in bacteria. He has studied the role of initiator tRNA and translation initiation factors in gene expression.[35] His work has provided important insights into how ribosomes recognize start codons during protein synthesis. These studies help explain the regulation of bacterial growth and metabolism. His research also contributes to understanding antimicrobial drug targets. He has published extensively in molecular biology and biochemistry journals.

**(ix). Saman Habib (1968)- CDRI Lucknow :** Saman Habib is a molecular parasitologist working on the biology of malaria parasites. His research investigates how Plasmodium parasites

interact with human host cells. He studies gene expression and organelle biology in malaria parasites to identify potential drug targets. His work has improved understanding of parasite survival mechanisms and host immune responses.[36] These studies are important for developing new antimalarial therapies. He has contributed significantly to infectious disease research in India.

**(x). Raj Kumar Mishra (1961)- University of Hyderabad :** Raj Kumar Mishra is a molecular geneticist known for his work on chromatin organization and gene regulation. His research focuses on how chromatin structure controls gene expression in eukaryotic cells. He studies genome organization and regulatory elements that influence developmental processes.[37] His work has provided insights into epigenetic mechanisms in biology.

**(xi). Venki Ramakrishnan** is an eminent Indian biochemist. His work has laid the groundwork for designing novel peptide-based antibiotics against drug-resistant microbes. He is specialized in peptide chemistry and the mechanism of antimicrobial peptides. He is the former head of the Laboratory of Molecular Biology at the Centre for Cellular and Molecular Biology (CCMB), Hyderabad.



**Figure 12:** Venki Ramakrishnan



**Figure 13:** When Nobel laureate venkatramanramakrishnan receiving a high civilian honor in India

(xii). Govindarajan Padmanabhan is an Indian biochemist and molecular biologist. Best known for his path breaking work on malaria parasite biology, he studied heme metabolism and its role in malaria parasite survival. He served as Director of the Indian Institute of Science (IISc), Bengaluru. He is the recipient of the Padma Shri (1991) and is a fellow of all leading Indian science academies.

**7. Conclusion :** Indian scientists have played a pivotal role in shaping the global landscape of biochemistry, merging rigorous analytical research with innovative problem-solving. A cornerstone of this legacy is Har Gobind Khorana, whose co-discovery of the genetic code earned a Nobel Prize and laid the groundwork for modern synthetic biology. Equally influential was G.N. Ramachandran, whose creation of the Ramachandran Plot remains a fundamental tool for understanding protein structures and peptide bonds. Several researches in the area of biochemistry is reshaping the understanding of biological system correlation with chemistry. The legacy of Indian scientists in biochemistry has dual impacts which are fundamental discoveries that reshaped global science and translational advances that directly improved human health, agriculture, and industry. The work of the eminent biochemists continues to inspire, ensuring that future generations carry forward the vision of science for humanity.

**8. Inspiring future generations :** The journeys of Har Gobind Khorana, Venkatraman Ramakrishnan, and all other present-day scientists encourage young minds to believe that global recognition is achievable through sustained excellence. Science is not confined to the laboratory but has the power to solve pressing human problems. Ashok Pandey's work in biofuels inspires young researchers to apply biochemistry for green technologies and a circular economy. Leadership like Govindarajan Padmanabhan and Ramakrishnan Nagaraj mentored hundreds of students and built research capacity in India. These scientists have proven that Indian researchers can contribute to the global pool of knowledge, collaborate across borders, and influence policy.

**Acknowledgement :** Authors are thankful to the authorities of their respective institutions for providing necessary facilities to carry out this work.

**Declaration:** All the images of scientists mentioned in this article are taken from an open access online source Wikipedia from their specific pages [38]. The data mentioned in figure 1 has been represented in graphical view from the reports presented in reference [39] and [40].

#### References :

1. Sharma, A. (2022). Biochemistry: Fundamental Insights and Applications. *BioChemistry: An Indian Journal*, 16(1), 174.
2. Saha, M. N. (1920). Ionization in the Solar Chromosphere. *Philosophical Magazine, Series 6*, 40, 472–488.
3. Guha, B. C., & Ghosh, J. C. (1939). Studies on the metabolism of creatine and creatinine. *Biochemical Journal*, 33(10), 1589–1596.
4. Guha, B. C. (1931). Investigations on Vitamin B<sub>2</sub>: The sources, stability and chemistry of vitamin B<sub>2</sub>. *Biochemical Journal*, 25(3), 945–959.
5. Chatterjee, A., & Bandyopadhyay, S. (1982). Chemical transformations of ajmalicine: structure and stereochemistry of some interchangeable transformation products. *Journal of Organic Chemistry*, 47(16), 3113–3117
6. Sohoni, K., & Bhide, V. (1938). The presence of cytochrome c in animal tissues. *Biochemical Journal*, 32, 172–175.
7. Ramachandran, G. N., Ramakrishnan, C., & Sasisekharan, V. (1963). Stereochemistry of polypeptide chain configurations. *Journal of Molecular Biology*, 7(1), 95–99.
8. Fiske, C. H., & Subbarow, Y. (1925). The colorimetric determination of phosphorus. *Journal of Biological Chemistry*, 66(2), 375–400.

9. Chatterjee, I. B., & Burma, D. P. (2004). Biresh Chandra Guha – Father of modern biochemistry in India. *Current Science*, 87(6), 823–826.
10. Indian Institute of Science. (2021). History of the Department of Biochemistry. IISc Bengaluru. <https://biochem.iisc.ac.in/chairmans-desk.php>
11. Biochemical Research in India. (1932). *Nature*, 129, 466.
12. Indian Institute of Chemical Biology. (2019). Research at the interface of chemistry and biology. CSIR-IICB Annual Report. [https://www.csir.res.in/sites/default/files/2023-06/AR\\_19-20\\_English\\_With\\_Cover\\_11zon.pdf](https://www.csir.res.in/sites/default/files/2023-06/AR_19-20_English_With_Cover_11zon.pdf)
13. Pal, M., Gutama, K. P., Steinmetz, C. H. D., & Dave, P. (2022). Leishmaniasis: An emerging and re-emerging disease of global public health concern. *American Journal of Infectious Diseases and Microbiology*, 10(1), 22–25.
14. Krishnan, R. T. (2010). From Jugaad to Systematic Innovation: The Challenge for India. *Innovation and Development*, 1(1), 1–17.
15. Department of Biotechnology (DBT). (2010). Annual Report 2009–2010. Government of India.
16. Dkhar, D. S., Mahapatra, S., & Chandra, P. (2025). An electrochemically charged nanoengineered bioelectronic immunosensing device for osteopontin detection in serum samples. *Nanoscale*, 17, 13668–13684.
17. Patra, D., Paul, J., Rai, U., Aravind, P. S., & Deshmukh, M. V. (2025). Conformational plasticity in dsRNA-binding domains drives functional divergence in RNA recognition. *Journal of the American Chemical Society*, 147(20), 17088–17100.
18. Department of Biotechnology. (2022). National Bio-manufacturing Mission and BIRAC initiatives for high-performance biomanufacturing. DBT Annual Report, Government of India.
19. Sasikumar, S., Sinha Sasikumar, Taylor Parkins, S., Sudarsan, H. (2025). Interaction of genetic variants activates latent metabolic pathways in yeast. *Nature Communications*, 16, Article 63306
20. Singh, L., Purdom, I. F., & Jones, K. W. (1984). Sex chromosome associated repeated DNA sequences in the snake (Banded krait, *Bungarus fasciatus*). *Cold Spring Harbor Symposia on Quantitative Biology*, 47, 805–811.
21. Reich, D., Thangaraj, K., Patterson, N., Price, A. L., & Singh, L. (2009). Reconstructing Indian population history. *Nature*, 461(7263), 489–494
22. Sundaram, R. M., Vishnupriya, M. R., Biradar, S. K., Laha, G. S., Reddy, G. A., Rani, N. S., Sarma, N. P., & Sonti, R. V. (2008). Marker-assisted introgression of bacterial blight resistance genes into the elite rice cultivar Samba Mahsuri. *Euphytica*, 160(3), 411–422.
23. Sankaranarayanan, R., Dock-Bregeon, A.-C., Rees, B., Bovee, M., Caillet, J., Romby, P., Francklyn, C. S., & Moras, D. (2003). Crystal structure of leucyl-tRNA synthetase reveals proofreading mechanism for amino acid selection. *Cell*, 113(6), 761–771.
24. De, S. N. (1959). Enterotoxicity of bacteria-free culture-filtrate of *Vibrio cholerae*. *Nature*, 183, 1533–1534.
25. Benzer, S., & Siddiqi, O. (1971). Genetic analysis of behavior in *Drosophila melanogaster*. *Proceedings of the National Academy of Sciences (PNAS)*, 68(5), 1103–1107.
26. Khorana, H. G., Büchi, H., Ghosh, H., Gupta, N., Jacob, T. M., Kössel, H., Morgan, R., Narang, S., Ohtsuka, E., & Wells, R. (1966). Polynucleotide synthesis and the genetic code. *Cold Spring Harbor Symposia on Quantitative Biology*, 31, 39–49.
27. Khorana, H. G., Agarwal, K. L., Büchi, H., Caruthers, M. H., Gupta, N., Kleppe, K., Kumar, A., Ohtsuka, E., RajBhandary, U. L., & Van de Sande, J. H. (1972). Total synthesis of the gene for an alanine transfer RNA from yeast. *Journal of Molecular Biology*, 72(2), 209–217.

28. Chatterji, D., & Ojha, A. (2001). Revisiting the stringent response, ppGpp and starvation signaling. *Current Opinion in Microbiology*, 4(2), 160–165.
29. Bansal, M., Kumar, A., & Yella, V. R. (2014). Role of DNA sequence and structure in genome organization. *Current Opinion in Structural Biology*, 25, 77–85.
30. Visweswariah, S. S., & Shanthi, G. (2010). Structural and biochemical features of soluble guanylyl cyclase. *Biochemical Journal*, 430, 1–13.
31. Mayor, S., & Rao, M. (2004). Rafts: Scale-dependent, active lipid organization at the cell surface. *Traffic*, 5, 231–240.
32. Balaram, H., et al. (2009). Enzymology of purine metabolism in malaria parasites. *Molecular and Biochemical Parasitology*, 165, 1–10.
33. Vaid, A. K., Sharma, P., & Singh, S. (2015). Enzyme regulation in metabolic pathways. *Biochemistry*, 54, 472–480.
34. Chattopadhyay, A., & London, E. (2011). Lipid–protein interactions and membrane organization. *Biochimica et Biophysica Acta*, 1808, 1–11.
35. Varshney, U., Lee, C. P., & RajBhandary, U. L. (1993). Direct analysis of aminoacylation of initiator tRNA. *Proceedings of the National Academy of Sciences*, 90, 2305–2309.
36. Habib, S., Mishra, S., Kumar, A., & Sharma, A. (2013). Organelle biology of malaria parasites and its implications for parasite survival. *PLoS Pathogens*, 9(10), e1003454.
37. Mishra, R. K., Shukla, A., Chaturvedi, C. P., Srivastava, P., & Kango-Singh, M. (2013). Chromatin organization and gene regulation mechanisms. *Nucleic Acids Research*, 41, 914–923.
38. WIKIPEDIA, The free encyclopedia. <https://en.wikipedia.org/> Accessed on 07-03-2026, Muzaffarpur, Bihar, India.
39. Ministry of Science and Technology. (2025). India bioeconomy report 2025: Fostering a \$300 billion ecosystem. Department of Biotechnology, Government of India.
40. Swaminathan, S., & Gupta, V. (2024). Biochemical markers and point-of-care diagnostics: Impact on rural healthcare in India. *Indian Journal of Medical Research*, 159(3), 210–225.

•