Dr. Suman Adhikari is currently an Associate Professor in the Department of Chemistry at Govt. Degree College, Dharmanagar, Tripura, India. He earned his M.Sc. in Chemistry from the University of Kalyani, West Bengal, India, followed by a Ph.D. from the same institution. Afterwards, he spent a year as a Postdoctoral Research Fellow at Kangwon National University, Chunchon, South Korea, focusing on Supramolecular Chemistry. His research interests include Supramolecular Chemistry, Coordination Chemistry, and Metal-based anticancer drugs. Dr. Adhikari has published many papers in high-impact, peer-reviewed International Journals. Dr. Adhikari has also been granted two Indian patents for his work on the synthesis and biological activities of novel metal-based complexes. Dr. Adhikari serves as a Guest editor for 'Frontiers in Chemistry' and as an editorial board member for 'International Journal Of Experimental Research And Review (IJERR)'.

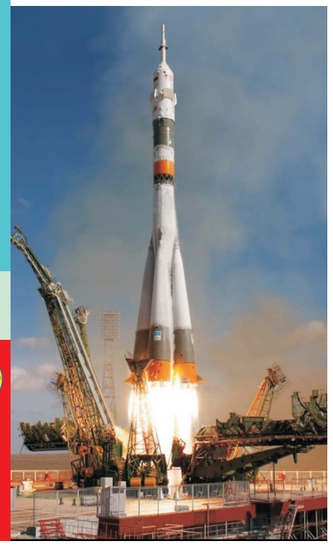
Dr. Manik Bhattacharya holds the position of Assistant Professor at the Department of Economics, Government Degree College, Dharmanagar, North Tripura, India. He earned his Doctorate Degree in Economics from Visva-Bharati, Santiniketan, West Bengal. His scholarly pursuits revolve around decentralization, participatory rural development, social capital, and the political economy of agrarian change. Dr. Bhattacharya has contributed significantly to academia with numerous research papers published in esteemed peer-reviewed journals, and authored books focusing on participatory rural development. He further enhances the academic landscape as a reviewer for reputable foreign journals.

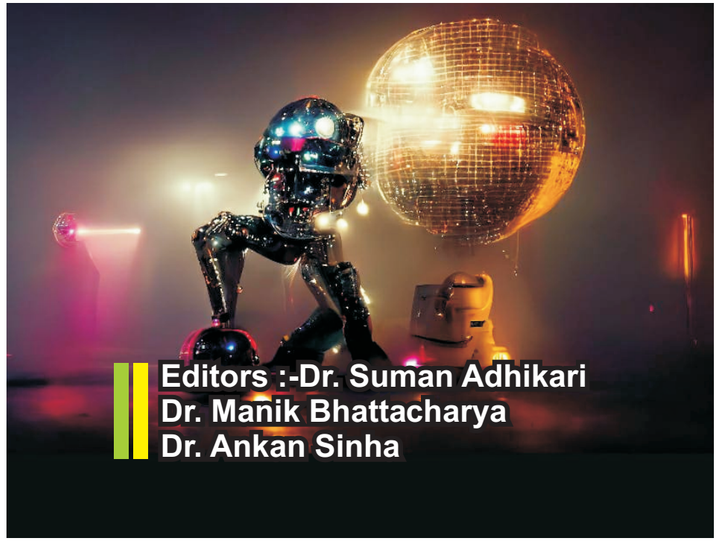
Dr. Ankan Sinha is an Assistant Professor at Government Degree College in Dharmanagar, North Tripura, India. He holds a PhD, M.Phil, M.P.Ed, and B.P.Ed from LNIPE, Gwalior, India, and has been awarded a Junior Research Fellowship (JRF). Dr. Sinha has diversified his expertise with certificate courses in Yoga and Food & Nutrition from Kaivalyadhama, Lonawala, and IGNOU, respectively, and an appreciation course in Environmental Studies from IGNOU. He served as a technical official in Weightlifting and Para powerlifting during the Delhi Commonwealth Games in 2010. Specializing in Exercise Physiology and Weightlifting, he has authored nine research papers, two textbooks, and a fundamental drill book, published in over 30 esteemed national and international journals. Dr. Sinha has also been a prolific presenter, delivering over 18 papers at various national and international conferences.

ISBN 9788196982843

A Basic Handbook of Science, Technology and Innovation for Inclusive Development

A Basic Handbook of Science, Technology and Innovation for Inclusive Development





Editors :-Dr. Suman Adhikari
Dr. Manik Bhattacharya
Dr. Ankan Sinha

A Basic Handbook of Science, Technology and Innovation for Inclusive Development
[Volume: 1]

International Academic Publishing House (IAPH)

A Basic Handbook of Science, Technology and Innovation for Inclusive Development [Volume: 1]

Edited by:

Dr. Suman Adhikari, Dr. Manik Bhattacharya and

Dr. Ankan Sinha

A Basic Handbook of Science, Technology and Innovation for Inclusive Development
Editors: Dr. Suman Adhikari, Dr. Manik Bhattacharya and Dr. Ankan Sinha

First published: June 08, 2024
ISBN: 978-81-969828-4-3

Published by:
Manoranjan Madhu
International Academic Publishing House (IAPH)

Address:

NATIONAL OFFICE:
Nivedita Park, Sarada Sarani,
Kolkata-700131, West Bengal, India
Contact No.: +91-9733697736
E-mail: iaphjournal@gmail.com
Website: www.iaph.co.in

INTERNATIONAL OFFICE:
91 Victoria Road, Swindon
SN13BD, ENGLAND
E-mail: publisher@iaph.co.in
Website: www.iaph.co.in

Type setting and printed by:
International Academic Publishing House (IAPH), Kolkata, India

Firstly, for creating a welcoming environment for intellectual exploration and scholarly endeavours, we are incredibly grateful to Sri Gautam Das, Principal, Government Degree College, Dharmanagar, North Tripura, India.

We are deeply indebted to the faculty members of the Government Degree College, Dharmanagar, North Tripura, for their unwavering encouragement throughout the preparation of the book "A Basic Handbook of Science, Technology, and Innovation for Inclusive Development." Their relentless dedication to advancing scientific knowledge and fostering inclusive development has served as a catalyst for our endeavour.

We are also extremely grateful to the staff of Government Degree College, Dharmanagar, North Tripura, for their moral support for the publication of this book.

Our heartfelt appreciation goes to the esteemed authors and contributors whose expertise and insights have enriched the content of this book. Their diverse perspectives and scholarly contributions have contributed to the creation of a comprehensive resource on science, technology, and innovation for inclusive development.

Furthermore, we express our gratitude to Dr. Nithar Ranjan Madhu and other officials of the International Academic Publishing House (IAPH), for their professionalism, expertise, and support during the publication process. Their commitment to academic excellence and dissemination of knowledge has played a pivotal role in the success of this endeavour.

Lastly, we extend our thanks to all those who have supported and encouraged us throughout this journey. Their invaluable input and encouragement have been instrumental in bringing this book to fruition. Without their unwavering support, this endeavour would not have been possible.

Dr. Suman Adhikari,
Dr. Manik Bhattacharya
and
Dr. Ankan Sinha

About the Book

"A Basic Handbook of Science, Technology, and Innovation for Inclusive Development" is aimed at a broad audience committed to advancing equitable and sustainable development outcomes through the transformative power of science, technology, and innovation, as well as serving as a knowledge beacon in the ever-changing global development landscape. These landmark studies, written by well-known scholars and researchers, delve extensively into the complex interplay of science, technology, and innovation, highlighting their critical role in supporting equitable growth and sustainable development. At its core, the book tries to untangle the complexity of incorporating science and technology into development goals, with a particular emphasis on ensuring that the benefits are dispersed equally throughout society. Drawing on a rich tapestry of theoretical frameworks, empirical research, and real-world case studies, it presents a comprehensive view of how technological breakthroughs can be utilized to uplift marginalized populations, bridge socioeconomic disparities, and promote social inclusion. The handbook provides a comprehensive roadmap for policymakers, practitioners, and scholars, covering everything from the transformative potential of emerging technologies like artificial intelligence and biotechnology to the importance of multi-stakeholder collaboration and policy coherence. The book, with its clear explanations and actionable insights, not only serves as a valuable resource for understanding the dynamics of inclusive development but also inspires a collective vision for harnessing the power of science, technology, and innovation to create a more equitable and sustainable future for all. An honest attempt has been made through this book to provide quality, user-friendly information to the subject concerns. We would also like to request that our readers provide us with helpful recommendations and comments to help us enhance this work. Such valuable recommendations and themes will be incorporated into our upcoming edition.

Dr. Suman Adhikari,
Dr. Manik Bhattacharya
and Dr. Ankan Sinha

DOI:https://doi.org/10.52756/ bhstiid.2024.e01.001

Chapter- 1

The Genetics of Alzheimer's Disease and the role of non-long coding RNAs in disease pathogenesis

Sreekanya Roy[1,2], Sima Biswas[1], Dipanjan Guha[2], Rakhi Dasgupta[1,*], Angshuman Bagchi[1,2,*]

Keywords: Alzheimer's disease, Amyloid plaque hypothesis, Tau pathology hypothesis, genes involved, non-coding RNAs.

Abstract:

The advancements in medical research and public health have led to a recent relative increase in the global population of elderly persons that is leading to an increase in age-related, non-communicable neurological diseases. Neurodegenerative diseases cause progressive loss of neuron function that tends to the rapid death of neurons. One such neurodegenerative condition is Alzheimer's disease (AD), which is a result of accumulation of misfolded proteins. AD is distinguished into two forms Sporadic Alzheimer's Disease (sAD) and Familial Alzheimer's Disease (fAD). sAD is marked by late onset of the disease, whereas, fAD is characterized as the early onset with Mendellian inheritance. A number of hypotheses were proposed to explain the disease. The widely accepted ones are: Amyloid plaque Hypothesis and Tau pathology Hypothesis. Amyloid plaque hypothesis states that amyloid β (Aβ) peptide accumulates and deposits in the brain, either as oligomers or fibrils, and thus regarded as the main cause of Alzheimer's disease (AD); whereas Tau pathology hypothesis states that the main factor causing neurodegeneration in AD is tau phosphorylation and aggregation. The most significant genes include APP, APOE, PSEN1, PSEN2, etc. The clinical hallmarks are amyloid plaques and neurofibrilary tangles (NFTs). In the recent decade scientists have also seen significant relation between non-coding RNAs and Alzheimer's disease (AD).

Sreekanya Roy[1,2]
[1]Department of Biochemistry and Biophysics, University of Kalyani, Kalyani, Nadia, West Bengal, India
[2]BIF Centre, University of Kalyani, Kalyani, Nadia, West Bengal, India
E-mail: sreekanyabcbp23@klyuniv.ac.in; Orcid iD: https://orcid.org/0009-0009-2944-3976
Sima Biswas[1]
[1]Department of Biochemistry and Biophysics, University of Kalyani, Kalyani, Nadia, West Bengal, India
Dipanjan Guha[2]
[2]BIF Centre, University of Kalyani, Kalyani, Nadia, West Bengal, India
Rakhi Dasgupta[1,*]
[1]Department of Biochemistry and Biophysics, University of Kalyani, Kalyani, Nadia, West Bengal, India
E-mail: rdgadg@gmail.com
Angshuman Bagchi[1,2,*]
[1]Department of Biochemistry and Biophysics, University of Kalyani, Kalyani, Nadia, West Bengal, India
[2]BIF Centre, University of Kalyani, Kalyani, Nadia, West Bengal, India
E-mail: angshu@klyuniv.ac.in
*__Corresponding Author__: rdgadg@gmail.com; angshu@klyuniv.ac.in

Dr. Suman Adhikari, Dr. Manik Bhattacharya and Dr. Ankan Sinha, A Basic Handbook of Science, Technology and Innovation for Inclusive Development [Volume: 1]. ISBN: 978-81-969828-4-3; pp. 01-12; Published online: 27th May, 2024

Introduction:

In the recent decade, neurodegenerative diseases have affected the human population widely. With the advancement of medical science and public health, the older global population has increased comparatively in recent times. Coincident with this aging population, age-related, non-communicable neurodegenerative diseases are very common to encounter (Johnson, 2015; Haloi et al., 2023; Biswas et al., 2024; Madhu et al., 2024)). Dr. Alois Alzheimer first reported Alzheimer's Disease (AD) on November 3, 1906. He observed a patient having psychosis, progressive sleep and memory problems, violence, and disorientation symptoms until her passing. Five years later, Dr. Alzheimer found distinctive plaques and neurofibrillary tangles in the brain histology. Later on, he communicated three further cases in 1909 and a "plaque-only" variation in 1911. A 1993 reexamination of the original specimens revealed that the "plaque-only" variety was a distinct stage of the same process (Hippius & Neundörfer, 2003)

In the second decade of studying this disease, scientists were engaged in knowing about the molecular mechanism(s) of the onset of this disease and further characterizing the disease. Differentiating AD became relevant due to the reported mutant variants in several human sub-populations, where individuals were suffering from dementia at a very early stage of life; similarly, some of the variants had no senile plaque deposition in their brains. Thus, AD is distinguished into two forms Sporadic Alzheimer's Disease (sAD) and Familial Alzheimer's Disease (fAD) (Bertram & Tanzi, 2012; Barber, 2012)

sAD is marked by the late onset of the disease, whereas fAD is characterized as the early onset with Mendelian inheritance. fAD is also marked by the presence of mutations in amyloid Precursor Protein (APP), which is considered as the origin of amyloid beta (Aβ) (Barber, 2012). Further fAD has also been classified according to human sub-population and also the particular mutations responsible have also been identified. fAD is of utmost importance as to know about a disease it is always necessary to study about the mutants of the disease. Similarly, fAD has also given various insights about AD pathology (Vélez et al., 2020). Several hypotheses were put forward to explain the disease. The widely accepted ones are: Amyloid plaque Hypothesis and Tau pathology Hypothesis.

Amyloid plaque hypothesis:

This hypothesis is one the most effective explanations of AD pathogenesis. The amyloid beta plaque contains the miss-folded Aβ and the AD is marked by the accumulation of amyloid plaques made of majorly 42-40 amino acid residue peptides called amyloid Beta 42(Aβ42) and amyloid Beta 40(Aβ40). This phenomenon takes place when the rate of accumulation of Aβ is more than the rate of utilization. Aβ is regarded as the clinical hallmark of AD pathogenesis (Shin et al., 2008; Paroni et al., 2019) thus understanding the source of Aβ is of utmost importance. Aβ helps in detection of AD in an individual. It is formed when proteolytic cleavage occurs to Amyloid Precursor Protein (APP) (O'brien & Wong, 2011). APP is an atypical transmembrane protein that undergoes proteolytic cleavage similar to the Delta-Notch

pathway (Kwak et al., 2011). The only difference lies in the fact that, for APP, this cleavage can occur in two separate pathways, giving rise to different cleavage products. The pathways are namely: Non-amylogenic pathway and Amylogenic pathway (O'brien & Wong, 2011). So, it is evident that only a single pathway gives rise to AD pathogenesis in an individual. But to understand AD, both pathways should be taken into consideration. APP, being a transmembrane protein, is susceptible to S2 cleavage at the extracellular domain, giving rise to a small extracellular stump. This stump is very critical; rather the length of stump determines the formation of the type of cleavage product, which will either tend to be harmless or very harmful for an individual. Now, this S2 cleavage can be done by two secretases: Alpha secretase (AS) and Beta secretase (BS). When AS cleaves APP it forms an extracellular stump of 12-amino acid residue, while on the other hand, if BS cleaves APP it forms an extracellular stump of 28-26 amino acid residues. The initial secretase is a part of the non-amylogenic pathway, and the latter one is a part of the amylogenic pathway. From here, both the pathways are similar. Gamma secretase (GS) causes S3 cleavage in the transmembrane domain by identifying the extracellular stump. The S3 cleavage generates a 14 amino acid extra residue linked with the extracellular stump; thus, freeing the cytosolic domain of APP. For the non-amylogenic pathway a 26 amino acid (12+14) residue long partially membrane embed peptide is produced which is not harmful; on the other hand for amylogenic pathway a 42-40 amino acid residue long peptide called Aβ42-40 is produced (Liu et al., 2021; Chow et al., 2010). These Aβ peptides rapidly oligomerize and that lead to accumulation of large amyloid plaques as found in AD. These plaques get deposited in the neurons that eventually cause the cell to disrupt, causing a phenomenon of neurodegeneration. Hence, AAP, the source protein for Aβ in AD undergoes through two cleavage phenomenon in both the pathways; the only difference is caused by the length of the extracellular stump produced by the S2 cleavage of BS, which in turn is a very vulnerable point for the progression of AD pathology.

Although this hypothesis has evolved and changed much through the years, the Aβ oligomers (AβOs) hypothesis represents the modern version of this theory. Basically, it can be said that the hypothesis has stream-lined, as AβOs were long detected in the human brain parenchyma and vasculature and reported while the original amyloid plaque hypothesis was being developed, but was only considered as a mere intermediate in the process of generation of amyloid plaques, which were believed to be the pathogenic form of Aβ (Cline et al., 2018; Walsh & Selkoe, 2007). The clear evidence of considering AβOs as the most toxic and pathogenic form of Aβ came by studying cases of fAD. Particularly one such example is the Osaka fAD mutation of Aβ (APP E693del) (Julia & Goate, 2017), which was marked by very low prevalence of senile plaques that were initially conserved most important. Instead this variant showed very elevated levels of AβOs in the cerebrospinal fluid (CSF) causing severe cognitive impairment. While traditionally AD has been defined as dementia with amyloid plaques, replacing plaques with AβOs is a much closer approach towards defining the disease pathology. Thus it can also be said that AβOs are the building blocks of the amyloid plaques

that are considered as the biological hallmark of AD. Moreover, scientists are trying to define AβOs as a biomarker of AD for early detection of the disease that in turn will help in preventing the disease pathology to spread from the source itself (Delaby et al., 2023).

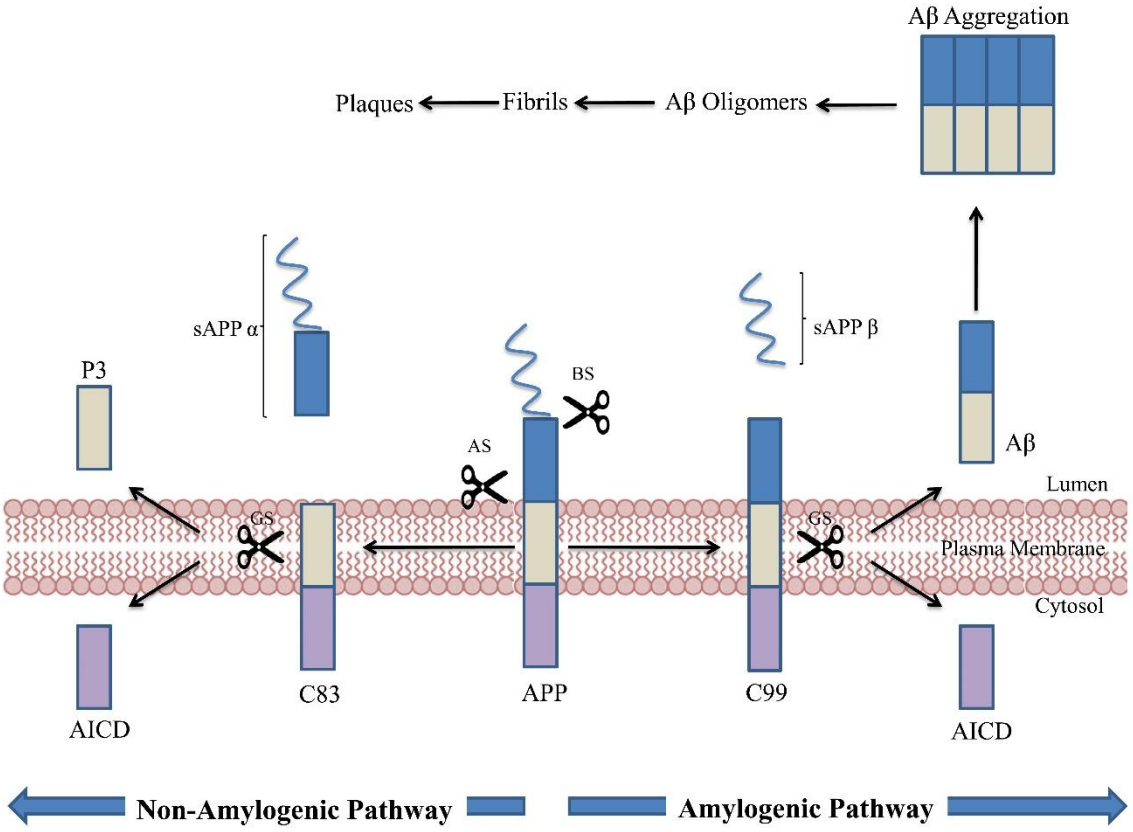


Figure 1. Schematic diagram of APP processing through amylogenic and non-amylogenic pathway. APP is initially subjected to S2 cleavage by either AS or BS and then to S3 cleavage by GS. Aβ is flanked out as a cleavage product in the amylogenic pathway, which in turn forms Aβ oligomers to fibrils and ultimately plaques

Tau pathology hypothesis:

According to the tau hypothesis, excessive or aberrant tau phosphorylation causes normal adult tau to change into paired helical filament Tau (pTau) and Neuro Fibrillary Tangles (NFTs) (Shin et al., 2008; Arnsten et al., 2021). Tau protein is a microtubule-associated protein (MAP) that is very soluble. It interacts with tubulin through its isoforms and phosphorylation to stabilize microtubule assembly. Six isoforms of the tau protein family, with amino acid ranges of 352-441, make up this family (Goedert et al., 2024). In contrast to the smallest isoform, which has three repeats (R1, R3, and R4) and no insert (352 amino acids total), the longest isoform in the CNS contains four repeats (R1 to R4) and two inserts. In paired helical filaments

from AD, all six tau isoforms are present and frequently in a hyperphosphorylated condition. Tau isoform expression and function mutations result in hyperphosphorylation. Without mutations, the exact mechanism by which tau aggregates is unknown, however it may be caused by an increase in phosphorylation, protease activity, or exposure to polyanions such glycosaminoglycans. Microtubules are disassembled by hyperphosphorylated tau, which binds to normal tau, MAP1 (microtubule associated protein 1), MAP2, and ubiquitin to form Paired Helical Filament tangles. This irreversible structure impairs cytoplasmic processes and hinders axonal transport; both can result in cell death and eventually lead towards dementia (Maccioni et al., 2010).

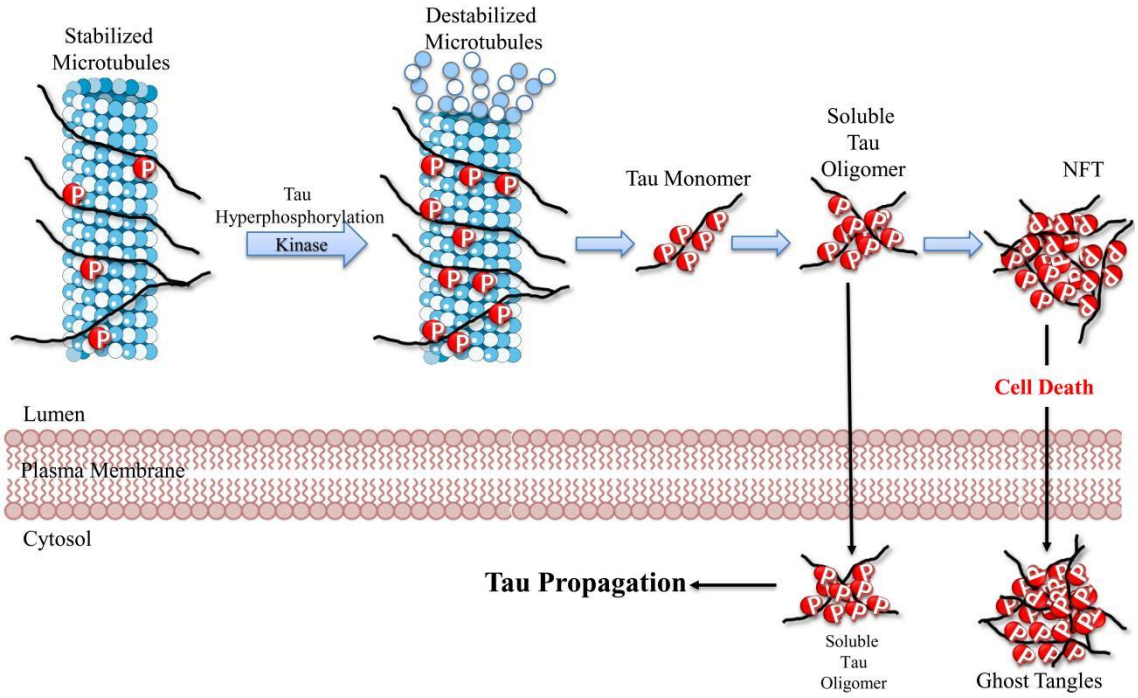


Figure 2. Schematic representation of Tau propagation, where the black thread with red bead (representing phosphate) represents the phosphorylated Tau protein stabilizing the microtubules. When subjected to hyperphosphorylation more red beads get added causing destabilization of the microtubules. The tau monomers then aggregate one upon other forming Tau oligomers and eventually NFTs

Later, it was marked that pTau also induces Aβ formation creating a brutal cycle where both pTau and Aβ induces each other's production. For example, in sAD, cell biology alterations in the ageing association cortex (such as calcium dysregulation) might worsen early-stage tau pathology, which in turn causes endosomes to become trapped in aggregated pTau, leading to a cleavage. Because "endosomal traffic jams" promote the cleavage of APP to Aβ in endosomes,

genetic changes in retromersignaling (such as SORL1) may make sAD risk worse (Garbuz et al., 2021). Contrarily, in fAD, basic genetic changes in amyloid signaling (such as APP duplications) might start the degenerative process, which then causes Tau hyperphosphorylation to rise. In either scenario, a vicious cycle regulated by Fyn Kinase an Src family kinase, that eventually results in amyloid plaques and neurofibrillary tangles would be set in motion (Nygaard et al., 2014).

The neuropathological indicators of Alzheimer's Disease (AD) include extracellular Aβ plaque buildup and formation of neurofibrillary tangles (NFTs), making both hypotheses crucial for understanding AD's origin.

Genes involved in AD:

The first-degree relatives of AD patients exhibit an increased risk of dementia, despite difficulties in investigations of early hereditary cases. Early-onset cases provide insight into familial inherited neuropathology and identify the underlying genes regulating pathology, thus leading to the identification of potential risk factors and regulatory genes of AD.

APP

Strong evidence between some rare forms of fAD and particular genetic factors were first surfaced in the early 1990s, APP gene alterations were observed. Many amyloid peptides are produced when APP is cleaved; the most prevalent one is Aβ42, while the more soluble Aβ40 is also linked to cerebral micro-vessels and may appear later in the disease. Furthermore, Aβ38 may be deposited in vascular walls as a result of APP mutations in the amyloid coding region, particularly in patients with severe cerebral amyloid angiopathy (CAA). Depending on the kind of mutation, early soluble peptide oligomers may potentially be involved, offering a genetic foundation for variances in fAD pathogenesis. Genome-wide association studies (GWAS), have identified a significant number of genes that have a functional effect on APP, including at least 832 genes that have the ability to modulate APP metabolism, eight of which are located within regions known to be prone to AD. Among these genes is the "fermitin family homolog 2 gene" (FERMT2), a co-activator of β-3-integrin that is strongly correlated with changes in Aβ in cerebrospinal fluid (CSF). Down regulation of this gene may elevate Aβ by raising the level of mature APP and facilitating its recycling at the cell surface. In addition, ATP-binding cassette transporter A1 (ABCA1) gene may also have a role in Aβ deposition and clearance, which is associated with many variants of AD. It can easily concluded that APP gene processes the stretch of Aβ within it which is easily the most important clinicopathological evidence of the disease, thus categorizing APP as one of the chief regulatory gene of AD (Lanoiselée et al., 2017; Chouraki & Seshadri, 2014).

PSEN1/2

PSEN is a nine trans-membrane protein located in the endoplasmic reticulum which is endoproteolytically cleaved, assembled into an Gamma Secretase (GS) complex, and then

transported to the cell surface, where it may have an impact on the processing of APP. Researchers reported that one of the most prevalent types of fAD is linked to PSEN1/2 gene alterations. Mutant PSEN1 interacts with APP by promoting normal APP's 42-specific-GS cleavage, which would boost Aβ deposition. PSEN generally functions as the following:

Firstly, it could be influenced by decreasing the activity of GS. Secondly, the PSEN1 gene could have a role in cell differentiation as it could be connected to Delta-Notch signalling. Thirdly, PSEN1/2 may be engaged in interactions with the transcriptional coactivator cAMP-response element binding (CREB-binding) protein, which is essential for controlling gene expression, or in disruption of the calcium homeostasis within the cell. Hence, a decrease in all these kinds of protection may be connected to AD (Lanoiselée et al., 2017; De Strooper, 2007; Kelleher & Shen; 2017).

APOE

Numerous research works have highlighted the significance of genes related to cholesterol transfer as risk factors for AD. These genes include clusterin apolipoprotein J (APOJ), apolipoprotein E (APOE), and apolipoprotein C1 (APOC1), all of which have a significant role in breakdown of cholesterol homeostasis. Further study shows a significant risk factor for sAD is allelic variation in the APOE gene, as persons with AD have an elevation of 2-3 times the frequency of allele ε4 in comparison to healthy control cases. Moreover, ε4 may have a direct impact on cognitive function as it has been linked to lower test results on memory and learning skills for adults. As allele ε4 may hasten the ageing brain's development of AD pathology, it is frequently linked to an earlier onset of the illness. Additionally, most studies show that people who express ε4 have higher levels of Aβ deposition. Furthermore, peripheral inflammation, APOE, and Aβ may combine to cause cerebrovascular dysfunction and cognitive decline, and in transgenic mice, ε4 significantly promotes age-dependent CAA. Moreover, APOE also act as a regulatory gene for the various types of cancer induction. From the above discussion it is thus evident that APOE is a key gene in establishing the sAD pathology as well as to investigate any relation of AD with other harmful diseases (Lanoiselée et al., 2017; Kim et al., 2009).

Other genes

Less than 5% of AD cases are caused by the combination of the APP and PSEN1/2 genes (Giau et al., 2019). Thus, to identify other genes linked to AD, GWAS was performed which revealed the association of AD-associated genes on chromosomes 6, 9, 10, 11, 12, 14, 18, and 19 (Bertram & Tanzi, 2009). To mention some of the significant ones: the vitamin D receptor (VDR) gene is located at 12q13 on chromosome 12, which is where the gene on chromosome 12 was located. Since this gene is a key modulator of vitamin D activity, AD may be associated with vitamin D deficiency (Ghahremani et al., 2023). Furthermore, a 9p21.3 gene variation may influence Caucasian susceptibility to AD. A more recent GWAS finds 26 unique risk factor genes that are involved in many processes such as immune response, endocytic trafficking, and cholesterol and lipid metabolism. Additional genes that have been linked to risk include

glyceraldehyde-3-phosphate dehydrogenase (GAPDH), genetic variations in the estrogen receptor (ESR) gene, polymorphisms in the clusterin gene, the transferrin (Tf) gene, and a rare variant of the triggering receptor expressed on myeloid cells 2 (TREM2) gene, where upregulation of the TREM2 gene has been observed in the frontal cortex of sAD patients (Armstrong, 2019).

Non-Coding Genome and AD:

There is growing evidence that the majority of the human genome is actively being translated into non-coding RNAs. Many of these non-coding RNAs have been found to be novel regulators of gene expression at different levels while not having evident protein-coding potential. Among these, circular RNAs (circRNAs) are a novel class of non-coding RNAs that form continuous loops by covalent bonding and lack the typical 5′ caps and 3′ poly-A tails. circRNAs are extensively expressed in mammalian brains in comparison to other organs, and they have functionality in synaptic activity and neurological development, which are important in neuropsychiatric illnesses. With a longer half-life than linear RNAs and no free hydroxyl endings that provide resistance to exonucleases, circRNAs are incredibly stable and tend to accumulate during brain ageing. Hence is an excellent candidate for biomarker (Patrick et al., 2020; Akhter & Rumana,2018).

Similarly, long non-coding RNAs (lncRNAs) that are typically longer than 200 nucleotides have been demonstrated to have a role in brain development and function, and the dysregulation of their expression has been linked to a variety of neurological illnesses. The majority of cases of AD are categorized as sAD, when there is no known genetic basis and when symptoms typically appear beyond the age of 65. Instead, autosomal mutations in three genes (APP, PSEN1, and PSEN2) involved in the APP amylogenic pathway, which result in the generation and aggregation of lethal Aβ peptides, cause uncommon monogenic forms of fAD to be inherited. However, twin-based genetic studies of dementia have suggested that 60–80% of instances of sAD are heritable; indicating that genetics play a significant role in disease progression. As mentioned earlier a significant portion of this heritability is explained by the alleles of the APOE gene, which codes for the APOE, notably the APOE epsilon 4 (ε4) allele. Even yet, the aetiology of sAD is complicated and oligogenic, and numerous genome-wide association studies (GWAS) have shown risk mutations for sAD in more than 40 loci. However, due to linkage disequilibrium, several of these genetic variations or single nucleotide polymorphisms (SNPs) are frequently inherited collectively. Furthermore, a number of these SNPs are found in non-coding areas of the genome, predominantly in the lncRNAs. Classical AD diagnosis depends on clinical manifestation of the disease, considering these identified lncRNAs as biomarkers will lead the way towards establishing a definition of AD based on biomarkers that reflect such biological alterations at early stages of the disease. A number of disease-associated variations have also been found to map to non-coding regions of the genome, including genomic locations that include lncRNA genes, as a result of recent advancements in AD GWAS. Finally, these lncRNAs may also open up new and creative

biomarker approaches or therapy options for AD (Patrick et al., 2020; Li et al., 2021; Lan et al., 2022).

Micro RNAs (miRNAs) are about 19-25 nucleotides long RNA. The majority of miRNAs are produced by converting DNA sequences into primary miRNAs, or pri-miRNAs, which are then processed into mature miRNAs and precursor miRNAs, or pre-miRNAs. In AD, miRNA regulates in various processes of the disease pathology for instance miR-101, miR-17 etc negatively regulate APP. miR-125b has been seen to influence hyperphosphorylation of Tau protein. Other than these various miRNAs have been recorded in influencing the neuronal function, inflammation and oxidative stress to nerve cells. Lastly, many miRNAs have been found in the cerebro spinal fluid (CSF) of AD patients leading its way towards recognizing miRNAs as a potential biomarker of AD (Patrick et al., 2020; Wang et al., 2019).

Conclusion and future prospective:

AD is accounted as the most prevalent of all the neurodegenerative diseases. Although several hypotheses are present; but, significant among them are amyloid plaque Hypothesis and Tau pathology Hypothesis. Similarly, the genes like APP, PSEN1/2, APOE, etc are also important for AD induction. In spite of all the advancements in the last three decades scientists have encountered an abysmal failure in targeting AD with any drug, which is concerning. The recent findings of involvement of non-coding genome in AD pathogenesis and the relation between the two hypotheses has been rewarding in better understanding of the disease. Moreover, AD has also been linked with various other diseases like cancer, diabetes, etc; paving its way towards finding any relation between the said diseases and also repurposing drugs already in use.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

All the authors approved the final version of the manuscript for publication.

Availability of data and material

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Funding

This work was supported through the funding from DBT, Govt. of India project reference number BT/PR40162/BTIS/137/48/2022, dated 31.10.2022.

Authors' contributions:

SR executed all review works. SB, DG helped SR in writing the manuscript. RDG and AB conceptualized, supervised and finalized the manuscript.

Acknowledgements

The authors are thankful to the BIF Centre, University of Kalyani for proving the infrastructure. The authors are also thankful to the University of Kalyani for providing a plagiarism-checking facility. SR and DG was supported with salary from DBT, Govt. of India.

References:

Akhter, R. (2018). Circular RNA and Alzheimer's disease. *Circular RNAs: Biogenesis and Functions*, 239-243.

Armstrong, R. A. (2019). Risk factors for Alzheimer's disease. *Folia neuropathologica*, *57*(2), 87-105.

Arnsten, A. F., Datta, D., Del Tredici, K., & Braak, H. (2021). Hypothesis: Tau pathology is an initiating factor in sporadic Alzheimer's disease. *Alzheimer's & Dementia*, *17*(1), 115-124.

Barber, R. C. (2012). The genetics of Alzheimer's disease. *Scientifica*, *2012*.

Bertram, L., & Tanzi, R. E. (2009). Genome-wide association studies in Alzheimer's disease. *Human molecular genetics*, *18*(R2), R137-R145.

Bertram, L., & Tanzi, R. E. (2012). The genetics of Alzheimer's disease. *Progress in Molecular biology and Translational Science*, *107*, 79-100.

Biswas, G., Madhu, N.R., Sarkar, B., Paul, S., Erfani, H., Alam, Q. (2024). Rare Genetic Disorders: Unraveling the Pathophysiology, Gene Mutations, and Therapeutic Advances in Fabry Disease and Marfan Syndrome. In: Umair, M., Rafeeq, M., Alam, Q. (eds) Rare Genetic Disorders. Springer, Singapore. pp. 199-219. https://doi.org/10.1007/978-981-99-9323-9_7

Chouraki, V., & Seshadri, S. (2014). Genetics of Alzheimer's disease. *Advances in genetics*, *87*, 245-294.

Chow, V. W., Mattson, M. P., Wong, P. C., & Gleichmann, M. (2010). An overview of APP processing enzymes and products. *Neuromolecular medicine*, *12*, 1-12.

Cline, E. N., Bicca, M. A., Viola, K. L., & Klein, W. L. (2018). The amyloid-β oligomer hypothesis: beginning of the third decade. *Journal of Alzheimer's Disease*, *64*(s1), S567-S610.

De Strooper, B. (2007). Loss- of- function presenilin mutations in Alzheimer disease: Talking Point on the role of presenilin mutations in Alzheimer disease. *EMBO reports*, *8*(2), 141-146.

Delaby, C., Hirtz, C., & Lehmann, S. (2023). Overview of the blood biomarkers in Alzheimer's disease: promises and challenges. *Revue Neurologique*, *179*(3), 161-172.

Garbuz, D. G., Zatsepina, O. G., & Evgen'ev, M. B. (2021). Beta amyloid, tau protein, and neuroinflammation: an attempt to integrate different hypotheses of Alzheimer's disease pathogenesis. *Molecular Biology*, *55*, 670-682.

Ghahremani, M., Smith, E. E., Chen, H. Y., Creese, B., Goodarzi, Z., & Ismail, Z. (2023). Vitamin D supplementation and incident dementia: Effects of sex, APOE, and baseline

cognitive status. *Alzheimer's & Dementia: Diagnosis, Assessment & Disease Monitoring*, *15*(1), e12404.

Giau, V. V., Bagyinszky, E., Yang, Y. S., Youn, Y. C., An, S. S. A., & Kim, S. Y. (2019). Genetic analyses of early-onset Alzheimer's disease using next generation sequencing. *Scientific reports*, *9*(1), 8368.

Goedert, M., Crowther, R. A., Scheres, S. H., & Spillantini, M. G. (2024). Tau and neurodegeneration. *Cytoskeleton*, *81*(1), 95-102.

Haloi, R., Chanda, D., Hazarika, J., & Barman, A. (2023). Statistical feature-based EEG signals classification using ANN and SVM classifiers for Parkinson's disease detection. *Int. J. Exp. Res. Rev.*, 31(Spl Volume), 141-149. https://doi.org/10.52756/10.52756/ijerr.2023.v31spl.014

Hippius, H., & Neundörfer, G. (2003). The discovery of Alzheimer's disease. *Dialogues in clinical neuroscience*, *5*(1), 101-108.

Johnson, I. P. (2015). Age-related neurodegenerative disease research needs aging models. *Frontiers in aging neuroscience*, *7*, 168.

Julia, T. C. W., & Goate, A. M. (2017). Genetics of β-amyloid precursor protein in Alzheimer's disease. *Cold Spring Harbor perspectives in medicine*, *7*(6), a024539.

Kelleher III, R. J., & Shen, J. (2017). Presenilin-1 mutations and Alzheimer's disease. *Proceedings of the National Academy of Sciences*, *114*(4), 629-631.

Kim, J., Basak, J. M., & Holtzman, D. M. (2009). The role of apolipoprotein E in Alzheimer's disease. *Neuron*, *63*(3), 287-303.

Kwak, Y. D., Marutle, A., Dantuma, E., Merchant, S., Bushnev, S., & Sugaya, K. (2011). Involvement of notch signaling pathway in amyloid precursor protein induced glial differentiation. *European journal of pharmacology*, *650*(1), 18-27.

Lan, Z., Chen, Y., Jin, J., Xu, Y., & Zhu, X. (2022). Long non-coding RNA: insight into mechanisms of Alzheimer's disease. *Frontiers in Molecular Neuroscience*, *14*, 821002.

Lanoiselée, H. M., Nicolas, G., Wallon, D., Rovelet-Lecrux, A., Lacour, M., Rousseau, S., ... & collaborators of the CNR-MAJ project. (2017). APP, PSEN1, and PSEN2 mutations in early-onset Alzheimer disease: A genetic screening study of familial and sporadic cases. *PLoS medicine*, *14*(3), e1002270.

Li, D., Zhang, J., Li, X., Chen, Y., Yu, F., & Liu, Q. (2021). Insights into lncRNAs in Alzheimer's disease mechanisms. *RNA biology*, *18*(7), 1037-1047.

Liu, X., Liu, Y., & Ji, S. (2021). Secretases related to amyloid precursor protein processing. *Membranes*, *11*(12), 983.

Maccioni, R. B., Farías, G., Morales, I., & Navarrete, L. (2010). The revitalized tau hypothesis on Alzheimer's disease. *Archives of medical research*, *41*(3), 226-231.

Madhu, N.R., Biswas, G., Paul, S., Adhikari, S., Sarkar, B., Rafeeq, M.M., & Umair, M. (2024). Challenges and Future Opportunities in Rare Genetic Disorders: A Comprehensive Review. In: Umair, M., Rafeeq, M., Alam, Q. (eds) Rare Genetic

Disorders. Springer, Singapore. pp. 251-275. https://doi.org/10.1007/978-981-99-9323-9_9

Nygaard, H. B., van Dyck, C. H., & Strittmatter, S. M. (2014). Fyn kinase inhibition as a novel therapy for Alzheimer's disease. *Alzheimer's research & therapy*, *6*, 1-8.

O'brien, R. J., & Wong, P. C. (2011). Amyloid precursor protein processing and Alzheimer's disease. *Annual review of neuroscience*, *34*, 185-204.

Paroni, G., Bisceglia, P., & Seripa, D. (2019). Understanding the amyloid hypothesis in Alzheimer's disease. *Journal of Alzheimer's Disease*, *68*(2), 493-510.

Patrick, E., Rajagopal, S., Wong, H. K. A., McCabe, C., Xu, J., Tang, A., ... & De Jager, P. L. (2020). The role of non-coding RNAs in Alzheimer's disease.

Shin, J., Lee, S. Y., Kim, S. H., Kim, Y. B., & Cho, S. J. (2008). Multitracer PET imaging of amyloid plaques and neurofibrillary tangles in Alzheimer's disease. *Neuroimage*, *43*(2), 236-244.

Vélez, J. I., Lopera, F., Silva, C. T., Villegas, A., Espinosa, L. G., Vidal, O. M., ... & Arcos-Burgos, M. (2020). Familial Alzheimer's disease and recessive modifiers. *Molecular Neurobiology*, *57*(2), 1035-1043.

Walsh, D. M., &Selkoe, D. J. (2007). Aβ oligomers–a decade of discovery. Journal of neurochemistry, 101(5), 1172-1184..

Wang, M., Qin, L., & Tang, B. (2019). MicroRNAs in Alzheimer's disease. *Frontiers in genetics*, *10*, 434919.

HOW TO CITE

Sreekanya Roy, Sima Biswas,Dipanjan Guha, Rakhi Dasgupta, Angshuman Bagchi (2024). The Genetics of Alzheimer's Disease and the role of non-long coding RNAs in disease pathogenesis. © International Academic Publishing House (IAPH), Dr. Suman Adhikari, Dr. Manik Bhattacharya and Dr. Ankan Sinha, *A Basic Handbook of Science, Technology and Innovation for Inclusive Development [Volume: 1]*, pp. 01-12. ISBN: 978-81-969828-4-3 DOI:https://doi.org/10.52756/ bhstiid.2024.e01.001

OPEN ACCESS PEER REVIEW
DOI: https://doi.org/10.52756/ bhstiid.2024.e01.002
Chapter- 2

The Biological Activity and Synthesis of Orally Active COVID-19 (SARS-CoV-2) Antiviral Drug Molnupiravir

Tanmoy Sahoo[a,b], Priyanka Shrivastava[c], Anirban Chandra[d], Swapan Kumar Biswas[d]* and B. V. Subba Reddy[a]*

Keywords: SARS-CoV-2, Antiviral, Cytidine, Uridine, D-Ribose Molnupiravir, Ribonucleoside.

Abstract:

In the midst of the COVID-19 pandemic, a multitude of potential drugs have emerged, among them molnupiravir (MK-4482 and EIDD-2801), an innovative oral antiviral designed to combat COVID-19. Currently undergoing final clinical trials, molnupiravir has displayed encouraging results in boosting the replication process of viral RNA mutations in both animal and human subjects. With the urgent demand for its production, it became an urgent need for the society to establish an efficient and feasible synthetic pathway from basic materials. This research delves into the molecular docking analysis of molnupiravir, shedding light on its mechanism of action (MOA) while outlining the most recent synthetic processes. Such insights are poised to benefit various disciplines, including medicinal chemistry, organic chemistry, biochemistry, and pharmacology. Marketed under the brand name Lagevrio, molnupiravir stands out as a simple yet potent orally active antiviral medication. Initially developed for treating influenza, its application has expanded to combat severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). It has an exceptional potency as the first oral, direct-acting antiviral medication against SARS-CoV-2. This review explores different synthetic strategies/routes employed in the synthesis of molnupiravir, with the aim of facilitating the development of novel routes for its further enhancement.

Introduction:

The COVID-19 pandemic, stemming from the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), a novel coronavirus, has presented a significant global health challenge. As of

Tanmoy Sahoo[a,b]
[a]Fluoro-Agrochemicals, CSIR-Indian Institute of Chemical Technology, Hyderabad-500 007, India
[b]Academy of Scientific and Innovative Research (AcSIR), Ghaziabad, 201002, India
Orcid iD: https://orcid.org/0009-0008-5483-7136
Priyanka Shrivastava[c]
[c]Holy Cross School, Durjoynagar, Airport Road, Agartala,799006, Tripura(West), India
Orcid iD: https://orcid.org/0009-0009-5545-6084
Anirban Chandra[d]
Department of Chemistry, Tripura University, Suryamaninagar, 799022, Tripura(West), India
Orcid iD: https://orcid.org/0009-0009-8943-9530
Swapan Kumar Biswas[d]*
[d]Department of Chemistry, Tripura University, Suryamaninagar, 799022, Tripura(West), India
E-mail: swapankumarbiswas@tripurauniv.ac.in; Orcid iD: https://orcid.org/0000-0002-2757-7702
B. V. Subba Reddy[a]*
[a]Fluoro-Agrochemicals, CSIR-Indian Institute of Chemical Technology, Hyderabad-500 007, India
E-mail: basireddy@iict.res.in; Orcid iD: https://orcid.org/0000-0003-0814-583X
***Corresponding Author**: swapankumarbiswas@tripurauniv.ac.in & basireddy@iict.res.in

Dr. Suman Adhikari, Dr. Manik Bhattacharya and Dr. Ankan Sinha, A Basic Handbook of Science, Technology and Innovation for Inclusive Development [Volume: 1]. ISBN: 978-81-969828-4-3; pp- 13-39; Published online: 27th May, 2024

March 8th, 2021, over 115 million individuals had been infected, with nearly 2.5 million fatalities worldwide (Aleccia et.al, 2021; Roychoudhury et.al, 2021; Kalal & Charola, 2021; Vashist et. al, 2023). In the midst of this crisis, molnupiravir emerges as a promising treatment option. Originally conceived as an antiviral medication for influenza, this prodrug features a nucleoside scaffold of N4-hydroxycytidine (Halford et.al, 2020, Hu et.al, 2021). Initially developed at Emory University in collaboration with the university's drug innovation ventures at Emroy, it is now being advanced by Merck as a novel oral antiviral agent for combating COVID-19 (Chavda et.al, 2023). Animal studies have showcased molnupiravir's effectiveness in preventing viral transmission and inhibiting SARS-CoV-2 (Chavda et.al, 2022). Operating as an oral antiviral ribonucleoside analog, molnupiravir is regarded as a 5′-isobutyrate prodrug of the direct-acting antiviral ribonucleoside analog, EIDD-1931, or β-D-N4-hydroxycytidine. Upon entry into the bloodstream, molnupiravir undergoes cleavage to release EIDD-1931. Within cells, EIDD-1931 undergoes phosphorylation by host kinases to form its active antiviral form, the corresponding 5′-triphosphate (Bian et.al, 2022, Maurya et.al, 2022)

Biological Activity

In animal models infected with various coronaviruses, influenza virus, and the Ebola virus, EIDD-1931 has demonstrated successful inhibition of replication across multiple RNA viruses (Akkiz et.al, 2021, Abu-Zaied et.al, 2021). This orally administered drug exhibits high potency against SARS-CoV-2 infection, with a favorable safety profile (Sezer et.al, 2022). Phase 1 clinical trials have shown that molnupiravir, as a novel oral antiviral medication, is well tolerated and safe for healthy volunteers (Gil et.al, 2020). In Phase 2 trials involving patients with mild to moderate COVID-19, the drug was administered twice daily for five days in a placebo-controlled, double-blind, randomized, multicenter trial. Results indicated a reduction in SARS-CoV-2 transcription process, cleansing of infectious virus, prevention of COVID-19 progression, and successful inhibition of SARS-CoV-2 replication (Sezer et.al, 2022, Gil et.al, 2020, Sharma et.al, 2021). Findings from the Phase 2/3 trial were presented at the European Congress of Clinical Microbiology and Infection Disease (ECCMID), demonstrating promising outcomes for non-hospitalized COVID-19 patients (Khan et.al, 2020). Merck and Ridgeback Bio are collaborating to develop a new antiviral compound, EIDD-2801. This review mainly focuses on the drug’s action mechanism and the new synthetic pathway of molnupiravir as an antiviral agent, aiming to illuminate the rational synthesis of more effective molnupiravir variants as potential antiviral candidates.

Molnupiravir was developed by Emory University as part of an antiviral drug screening project funded by the Defense Threat Reduction Agency (DTRE). This initiative aimed to combat the Venezuelan equine encephalitis virus (VEEV) (Aleccia et.al, 2021). Specifically, EIDD-2801 is a prodrug effective against different RNA viruses like influenza, Ebola, chikungunya, and various coronaviruses. In 2019, the National Institute of Allergy and Infectious Diseases (NIAID) sanctioned molnupiravir for Phase I clinical trials targeting influenza (Halford et.al, 2020).

Subsequently, amidst the COVID-19 pandemic in 2020, Ridgeback Biotherapeutics acquired the drug in collaboration with Merck & Co., USA. During the COVID-19 pandemic, human health and the social economy were severely affected worldwide. Globally, more than 767 million COVID-19 cases have been reported according to the WHO. Structural changes through mutation of SARS-CoV-2 have affected its transmissibility, therapeutic agent effectiveness, disease severity, and ultimately human health (Abu-Zaied et.al, 2021). Due to the high mutation rate of SARS-CoV-2 virus, any type of therapy against this virus as become challenging, leading to the repurposing of several antiviral agents to treat COVID-19 patients (Fischer et.al, 2022). Among these developments, orally active molnupiravir has demonstrated robust anti-SARS-CoV-2 activity in both in vitro and in vivo trials (Teli et.al, 2023). Importantly, it has also shown efficacy against the Omicron variant of SARS-CoV-2 (Rautio et.al, 2018).

Molnupiravir is an isopropyl pro-drug of N-hydroxycytidine. Prodrugs are biologically inactive substances that are biotransformed by the body into pharmacologically active compounds (Hacker et.al, 2009, Jornada et.al, 2016). They play an important role in designing and discovery of new drug in medicinal chemistry (Markovic et.al, 2020, Painter et.al, 2021). In many cases, scientists engineered the prodrugs to improve the bioavailability of the drug, and molnupiravir has been specifically formulated to address the low bioavailability of N-hydroxycytidine (Toots et.al, 2019, Yoon et.al, 2028, *Int. J. Stroke* 2018). Research has investigated the uptake and distribution of N-hydroxycytidine in mice (Kabinger et.al, 2021). Molnupiravir, on the other hand, has been observed to impede the transcription and replication of the viral RNA genome of coronaviruses by targeting the RNA-dependent RNA polymerase (RdRp), thereby inducing copying errors (Gordon et.al, 2021, Yip et.al, 2022, Toots et.al, 2020). Initially, the prodrug molnupiravir undergoes activation by the host cell enzyme (carboxyl esterase) to generate the N-hydroxycytidine compound, which is biologically active one (Painter et.al, 2019, Wang et.al, 2022), which is then subsequently converted to N4-hydroxycytidine triphosphate by host cell kinases (Painter et.al, 2019). Thenafter it targets the RdRp, which is virally encoded, and the RdRp uses the NHC triphosphate as a substrate instead of cytidine and uridine triphosphates, inhibiting viral replication (**Fig 1**). Due to its significant benefits, this drug has attracted immense interest among scientists to develop an efficient, sustainable and cost-effective synthetic route for its production. This chapter of the book comprehensively outlines various synthetic methodologies for the synthesis of molnupiravir, elucidating the strengths and limitations of each approach.

Molnupiravir Metabolism:

Originally developed for influenza treatment in 2019, molnupiravir acts as an oral prodrug of N6-hydroxycytidine. However, with the emergence of SARS-CoV-2, molnupiravir has exhibited strong anti-SARS-CoV-2 activity both in vitro and in animal models. Numerous nucleosides and analog nucleotides have been identified as potential target and selective antiviral inhibitors of coronaviruses, including SARS-CoV-2, showcasing a wide spectrum range of antiviral activity.

Some of these compounds have swiftly progressed into clinical trials for COVID-19 treatment (**Fig. 2)**. Unlike other COVID-19 drugs granted emergency use authorization (EUA), molnupiravir can be produced on a larger scale.

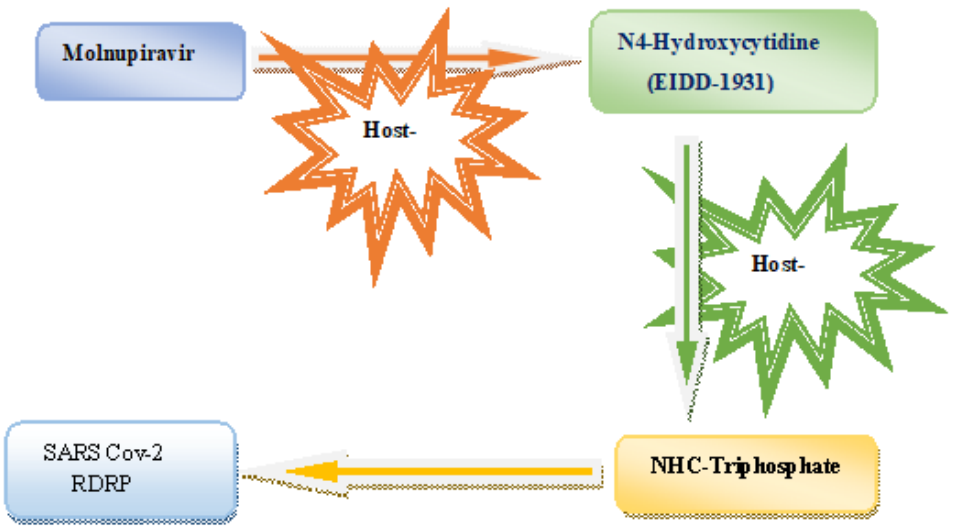


Fig.1 Schematic diagram of N4-hydroxycytidine triphosphate

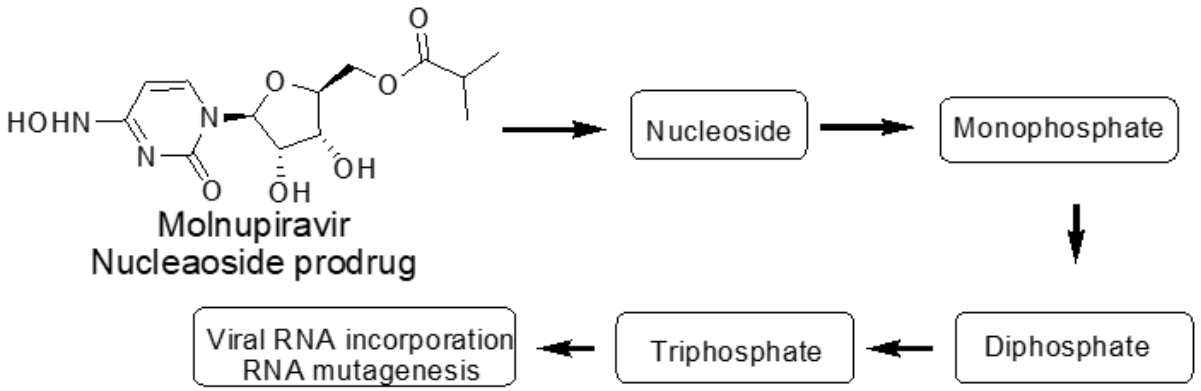


Fig. 2 Structure of nucleoside analog of molnupiravir and its metabolic activation.

Furthermore, this drug does not necessitate in-hospital settings or cold transportation for administration. Evidence from phase 1, 2, and 3 clinical trials has indicated that molnupiravir is better tolerated and safer in the short term, without any significant side effects (Teli et.al, 2023).

Mechanism of action of molnupiravir

Since the coronavirus pandemic began, a number of research projects have been initiated to investigate ways to combat the new novel virus. Researchers have been diligently developing various vaccines and drug moieties, each with differing degrees of success. Molnupiravir,

initially designed to combat influenza, emerged as another potential candidate for antiviral treatment. Understanding the molecular mechanistic pathway of molnupiravir is crucial for advancing the development of antiviral drugs.

Upon metabolism within the body, molnupiravir becomes an RNA-like component once it enters the cell. Initially, RNA polymerase (the viral copy machine) incorporates these components into the RNA genome of the virus. Subsequently, RNA-like components pair with viral genetic material components. As viral RNA multiplies to generate new viruses, it accumulates several mutations, thereby impeding pathogen reproduction. This antiviral drug induces mutations in other RNA viruses, thereby halting their expansion.

Molnupiravir, the promising drug, currently undergoing phase 3 studies, exhibits a unique mechanism of action. Once inside the cell, molnupiravir is converted into its active form, N-hydroxycytidine hydrate (NHC triphosphate or MTP). Interestingly, the RNA-dependent RNA polymerase (RdRp) of SARS-CoV-2 can replace MTP with cytidine triphosphate (CTP) or uridine triphosphate (UTP) (Fig. 2A). Particularly during the synthesis of sub-genomic RNA and negative-strand genomic RNA using positive-strand genomic RNA as a template, RdRp consistently substitutes M for U or C. Subsequently, +gRNA or +sgmRNA (positive-strand sub-genomic mRNA) can be derived from RNA containing M as a template. As a result of this process, mutations occur in the positive-stranded genomic RNA products, stemming from the incorporation of M in negative-strand genomic RNA (Fig. 2B). Consequently, this impedes the formation of new viable viruses. In conclusion, this two-step mechanism illustrates how molnupiravir and its activated form induce RNA mutations through the polymerases of other viruses (**Fig. 3**).

Previous studies have shown that molnupiravir-induced lethal mutagenesis is facilitated by the relatively high selectivity of N-hydroxycytidine triphosphate (MTP) for incorporation as a cytidine triphosphate (CTP) analog. Moreover, the indiscriminate incorporation of either adenosine triphosphate (ATP) or guanosine triphosphate (GTP) takes place when molnupiravir monophosphate (MNP) is concentrated in the template strand, indicating at least a two-step mechanism. The initiation of Cytosine to uracil mutations could occur downstream of the erroneously incorporated AMP (Adenosine Monophosphate) and uridine triphosphate (UTP) incorporation could subsequently occur. The replication fidelity necessary for viability is delineated by the accumulation of mutations that exceed the viral replication "error threshold." In conclusion, molnupiravir exhibits favorable pharmacokinetic characteristics, making it highly suitable for oral delivery (Painter et.al, 2021).

Dose and safety of molnupiravir in patients infected with the coronavirus

Agile is a Phase Ib/IIa platform designed for the swift evaluation of COVID-19 therapies. In a study led by Khoo, Saye H., *et al*. [16] (registered as NCT04746183), the safety and optimal dosage of molnupiravir in combating primary SARS-CoV-2 infection were assessed. Participants were randomly assigned to receive oral doses of 300 mg, 600 mg, or 800 mg of molnupiravir

twice daily for five consecutive days. If the likelihood of dose-limiting toxicity exceeding 30% was greater than 25%, it was deemed unsafe. Secondary outcomes included clinical improvement, safety, virological responses, and pharmacokinetics. From July 17th to October 30th, 2020, a study enrolled eighteen participants out of 103 screened. The results demonstrated that molnupiravir was well-tolerated at doses of 300 mg, 600 mg, and 800 mg, with no severe adverse effects observed. Overall, molnupiravir demonstrated safety and good tolerability in the second phase of assessment, leading to the recommendation of administering a dose of 800 mg twice daily for five consecutive days.

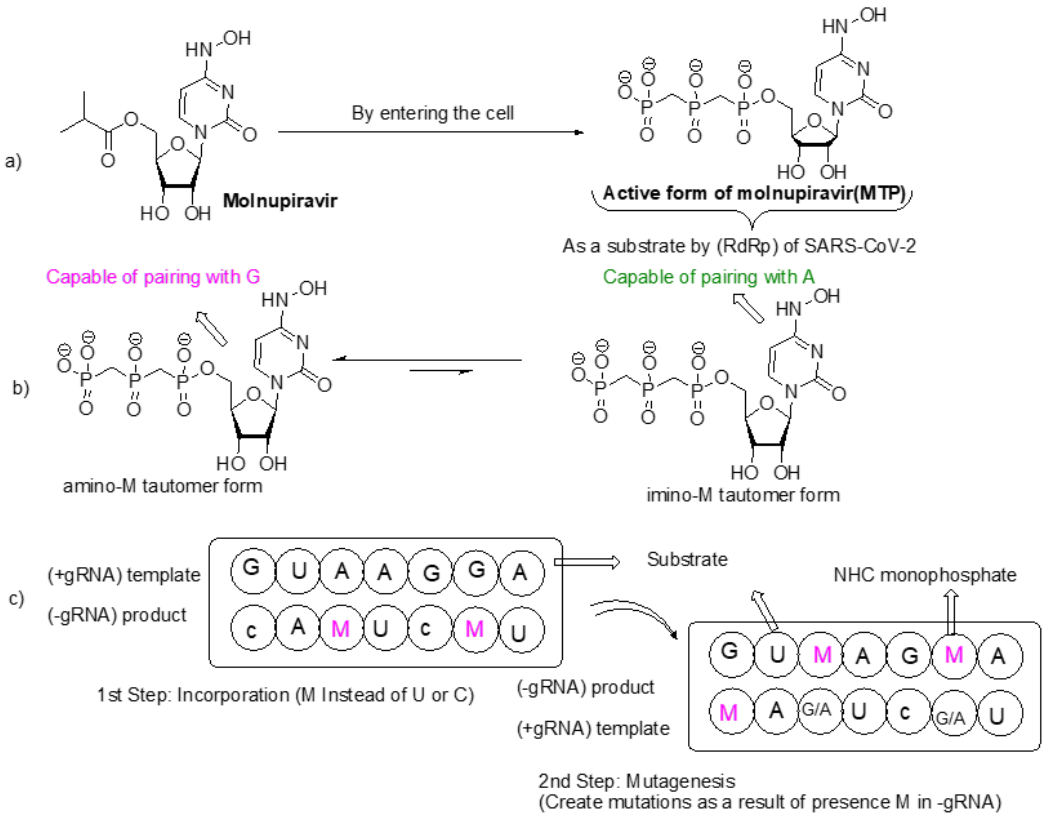


Fig. 3 Mechanism of action of molnupiravir.

The conversion of molnupiravir drug to its active form in the cell involves several steps. Initially, molnupiravir is metabolized to N-hydroxycytidine (NHC) within the cell. Subsequently, NHC undergoes phosphorylation by host cell kinases to form NHC monophosphate (MNP). Further phosphorylation of MNP yields NHC diphosphate (MNP), which finally gets converted to NHC triphosphate (MTP), the active form of molnupiravir, capable of inhibiting viral RNA replication.

NHC triphosphate (MTP) can exist in different tautomeric forms, including the hydroxylamine form (2) and the oxime form (3). The hydroxylamine form allows MTP to pair with guanosine

(G) and function similarly to cytidine (C). On the other hand, the oxime form enables MTP to pair with adenosine (A) and function like uridine (U).

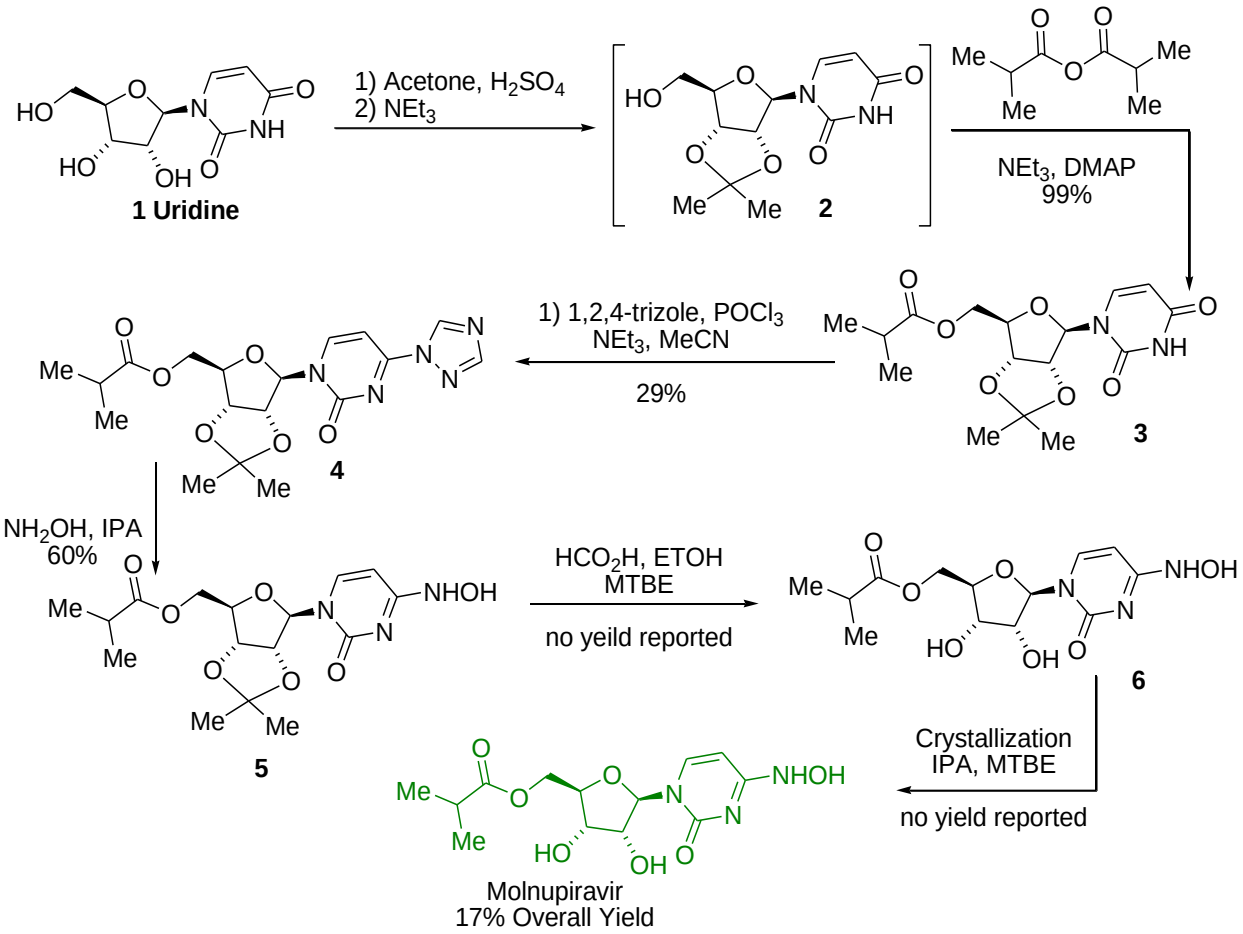
A two-step model is used to explain Molnupiravir-induced RNA mutagenesis. In the first step, the RNA-dependent RNA polymerase (RdRp) substitutes NHC (M) for uridine (U) or cytidine (C) during RNA synthesis from positive-strand genomic RNA (+gRNA). In the subsequent stage, mutations arise in positive-stranded genomic RNA products as a result of the presence of NHC (M) in negative-strand genomic RNA, thereby impeding viral replication.

SYNTHETIC ROUTES TO ACCESS THE MOLNUPIRAVIR:

Emory University unveiled the primary synthesis route for molnupiravir (Yoon et.al, 2018). Following this pathway, molnupiravir undergoes five sequential steps, initiating from uridine (4). While the yield of the final two steps remains unreported in this study, the overall synthetic process attains a maximum yield of 17%. Initially, the vicinal diol undergoes protection using acetone and sulfuric acid at room temperature for 18 h to yield acetonide (5). After purification by trimethylamine, 4-(N, N-dimethylamino) pyridine (DMAP), and triethylamine (Et3N), the reaction mixture is cooled to 0 °C, followed by gradual addition of isobutyric acid anhydride (6) and subsequent warming to room temperature.

Acetonitrile solution of compound (3) is then added to the reaction mixture containing triethylamine and 1,2,4-triazole. Upon cooling, phosphoryl chloride ($POCl_3$) is introduced, and the solution is warmed to room temperature, yielding the corresponding triazole (4). Compound (5) is obtained by treating 2-Propanol (2-PrOH) solution of compound (4) with hydroxylamine (NH_2OH) at r.t, yielding 60%. Using neat formic acid, deprotection is performed at room temperature, yielding molnupiravir (10), which is finally crystallized and recrystallized using 2-PrOH/MTBE (**Scheme 1)**.

Vasudevan, N. (Vasudevan et.al, 2020) group proposed a very short pathway for molnupiravir synthesis, which involve esterification, followed by hydroxamination of cytidine. This approach achieves a yield of 75%, a substantial upliftment over the previously reported 17%. The number of steps is also reduced from five to two, and the expensive uridine is replaced by cytidine. With minor modifications to the reaction conditions, N(4)-hydroxycytidine (NHC) is synthesized with a yield of 70%. Notably, pure NHC is obtained directly from the reaction mixture with a 50% isolated yield through simple crystallization after concentration, thus circumventing dihydroxamination with $NH_2OH\_H_2SO_4$ in ^{i}PrOH when investigating transamination of cytidine isobutyryl ester. The synthesis of molnupiravir achieves a high yield from the compound, highlighting the feasibility of direct hydroxamination from both cytidine reaction pathways, which drops to 37% when hydroxyamination is performed **(Scheme 2**).



Scheme 1: Synthetic pathway revealed from molnupiravir by Emory University in 2019.

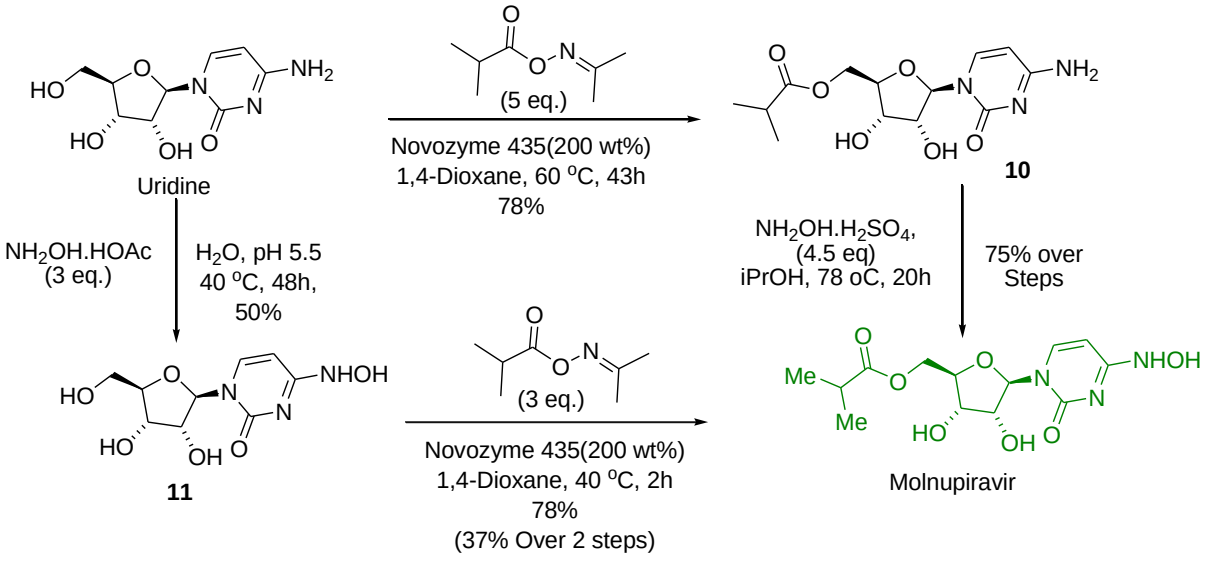
Synthesizing Molnupiravir is quite challenging, particularly its purification, despite being it's structural simplicity, a prodrug composed of N-hydroxycytidine and ribose. In the last couple of years, various research teams globally have devised multiple synthetic pathways using uridine, cytidine, or ribose as the primary starting materials.

Synthesis from Uridine (a natural nucleoside):

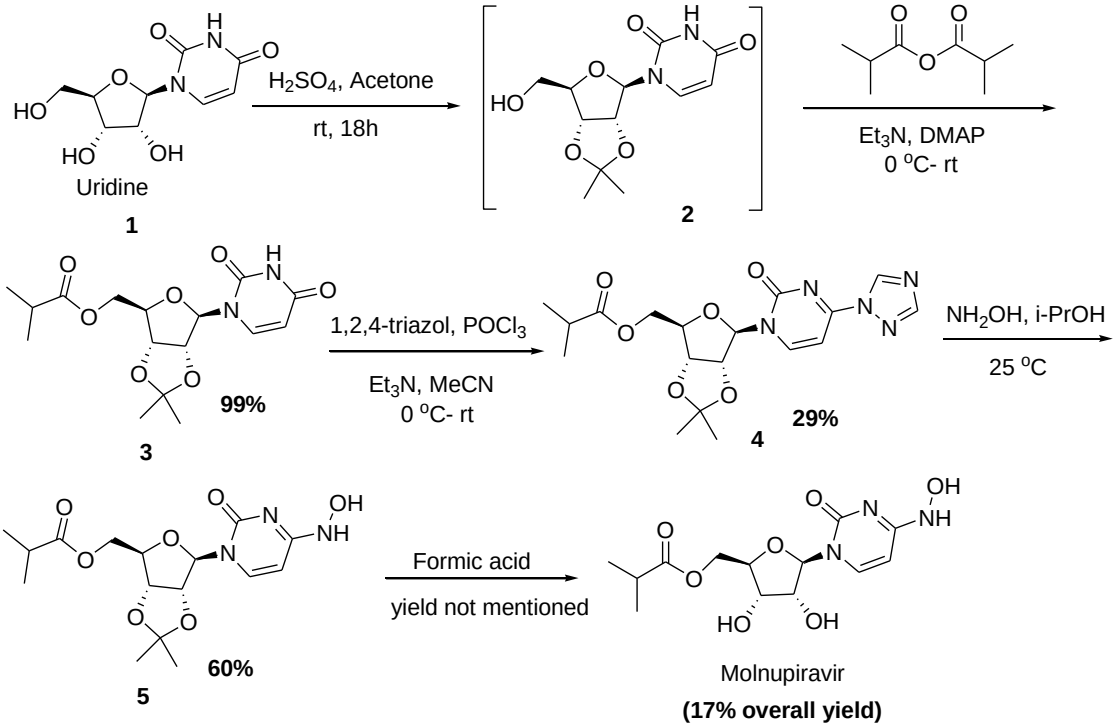
Amarante *et al*. reported the synthesis of Molnupiravir, with the first synthetic route disclosed by Emory University in 2019. This route involves five synthetic transformations starting from uridine, yielding Molnupiravir in 17% yield (Amarante et. al 2022). (**Scheme 3**).

The initial step in this process involves the formation of the isobutyl ester **3** protection of uridine as its acetonide, followed by esterification using isobutyric anhydride in the presence of triethylamine, with almost cent present yield. Following this, compound 3 undergoes treatment with excess 1,2,4-triazole and phosphorus oxychloride in the presence of a base (Et_3N:), resulting in the triazole derivative **4** with a yield of 29%. Subsequently, the nucleophilic substitution of **4** by hydroxylamine hydrochloride in isopropanol yields the N-hydroxycytidine derivative **5** with

moderate yield (~60%). This compound **5** is then subjected to the deprotection of the acetonide using formic acid to produce Molnupiravir.



Scheme 2: Synthesis pathway of molnupiravir from cytidine.

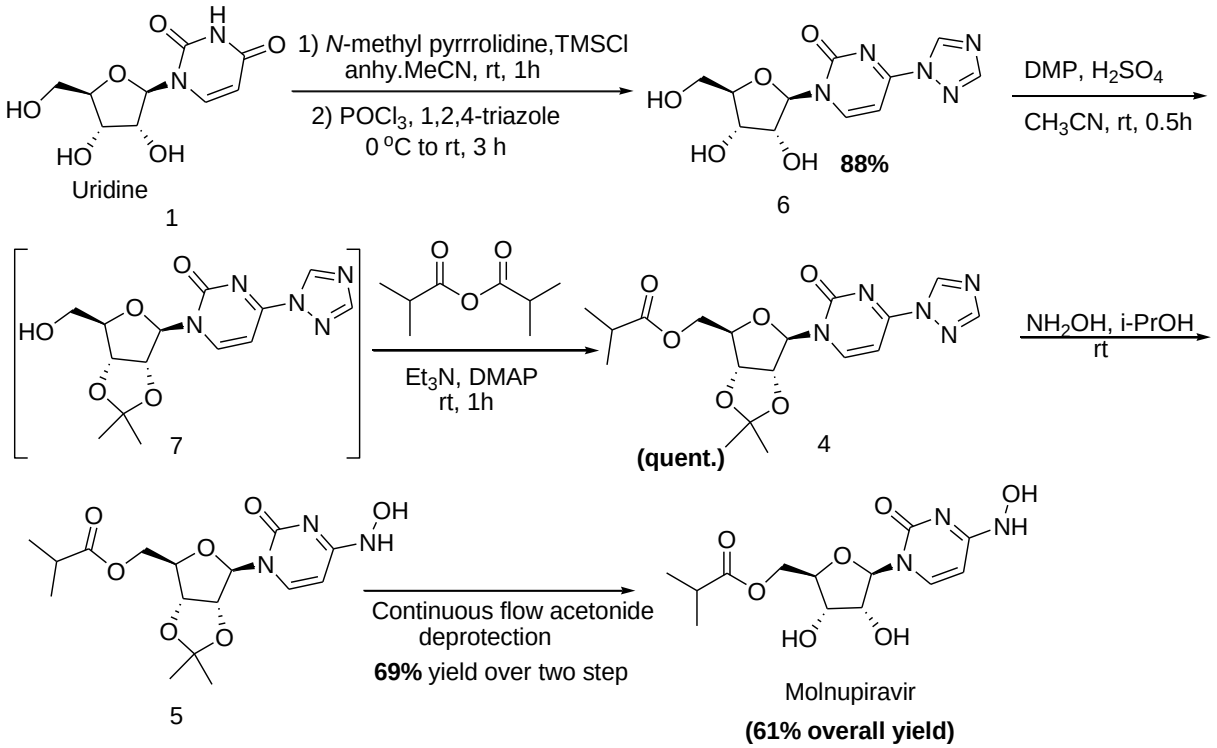


Scheme 3: Amarante et. al synthesis of Molnupiravir

However, this method suffers from a low overall yield after five consecutive steps (17%) and requires excess triazole. These factors limit its applicability in large-scale synthesis.

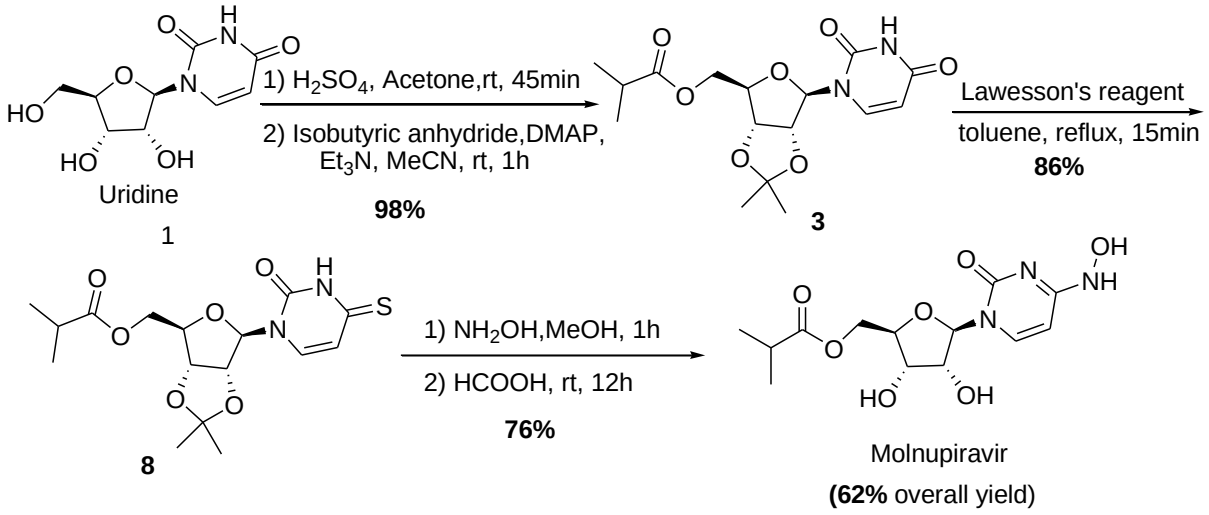
In 2020, Kappe *et al*. (Steiner at al. 2020) introduced an enhanced synthetic route for Molnupiravir (**Scheme 4**). Initially, triazolation of uridine was conducted, yielding an 88% yield, followed by acetonide protection/esterification, resulting in the formation of triazolyl uridine **4**

in quantitative yield. Subsequently, hydroxyamination and acetonide deprotection of compound **4** were carried out under continuous flow conditions, leading to the production of the final compound Molnupiravir with a 69% yield. Despite the overall yield improvement from 17% to 61%, one drawback of this process is the requirement for excess triazole.



Scheme 4: Improved synthetic route by Kappe *et al*.

In 2021, Das *et al*. (Dey et al. 2021) introduced a novel pathway for Molnupiravir synthesis (**Scheme 5**) [33]. This method entails a one-pot synthesis: acetonide protection followed by uridine esterification, yielding compound **3** in a 98% yield. Subsequently, it is converted into thiouridine 8, a key intermediate in this process, with an 86% yield in the presence of Lawesson's reagent. Thiouridine 8 is then transformed into the final compound Molnupiravir through a one-pot synthetic process, hydroxyamination followed by acetonide deprotection and the route delivers the product with a 62% overall yield and >99% purity, although it necessitates a stoichiometric quantity of Lawesson's reagent.



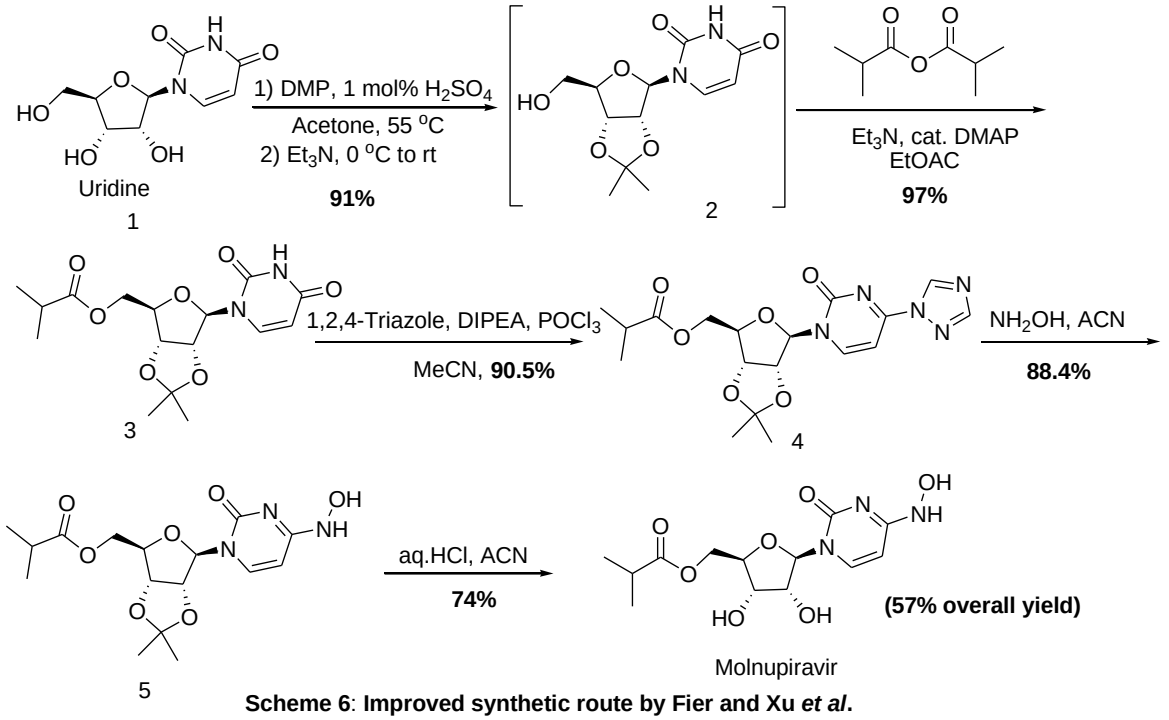
Scheme 5: Novel synthetic route of molnupiravir through thiouridineintermediate

In 2021, Fier *et al*. (Fier at al. 2021) presented an enhanced synthetic process for Molnupiravir (**Scheme 6**). They achieved a 1.6-fold increase in overall yield by enhancing the yield in each synthetic step of the original synthetic route as disclosed by Emory University. The synthesis was started with the protection of uridine under the condition of 1 mol% of H_2SO_4/DMP in acetone at 55°C. Quenching the reaction mixture with Et_3N yielded compound 2, with the yield better by 1.3-fold compared to the original process.

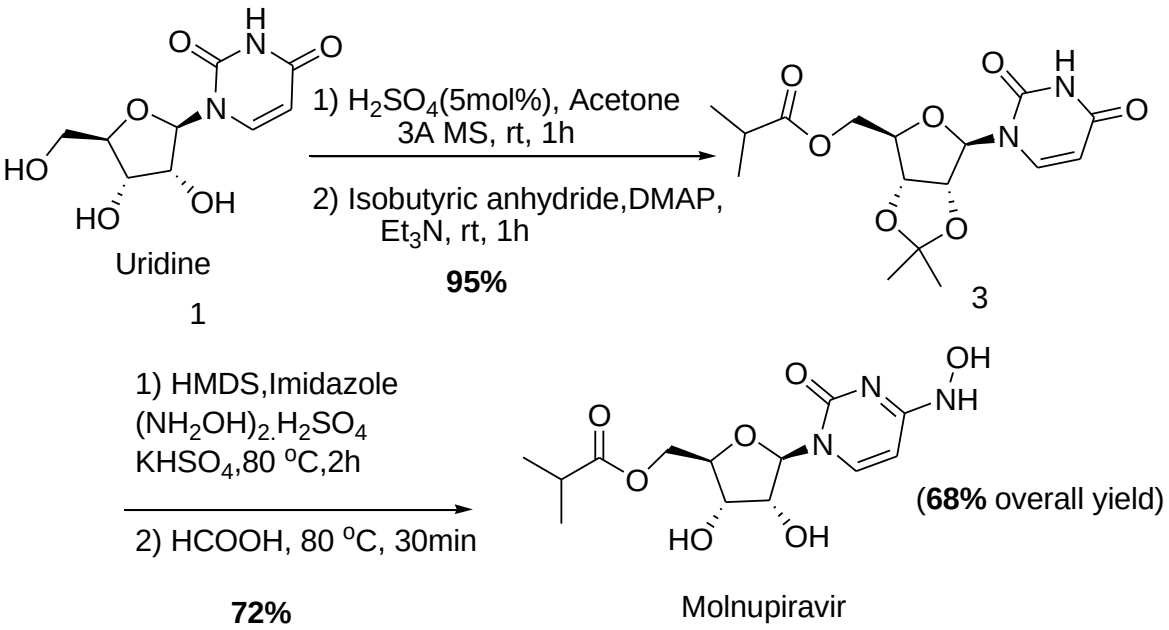
Subsequently, treatment of compound **2** with isobutyric anhydride, Et_3N, and catalytic DMAP in ethyl acetate, providing compound **3** in a 97% yield. Triazolization of compound **3** was achieved with a 90.5% yield by treating it with 1,2,4-triazole, DIPEA, and $POCl_3$ in acetonitrile. Hydroxylamination was then carried out using NH_2OH (50 wt% in H_2O) in acetonitrile, followed by acetonide deprotection in the presence of aqueous HCl to yield Molnupiravir with a 57% overall yield.

In 2022, De Souza *et al*. (Pereira et al. 2022) devised a concise two-step synthetic route for Molnupiravir (**Scheme 7**). Regarded as one of the most efficient synthetic processes, this method employed product purification through pH-controlled extraction, followed by crystallization. A one-pot synthesis initiated with acetonide protection and esterification of uridine under established reaction conditions, with subsequent purification achieved through pH-controlled extraction, yielding a 95% yield.

The subsequent step involved the hydroxylamination of compound **3**, accomplished by treating hydroxylamine sulfate with HMDS in the presence of imidazole and $KHSO_4$. Acetonide deprotection was then achieved using formic acid at 80°C, resulting in the production of Molnupiravir with a 68% overall yield.



Scheme 6: **Improved synthetic route by Fier and Xu *et al*.**



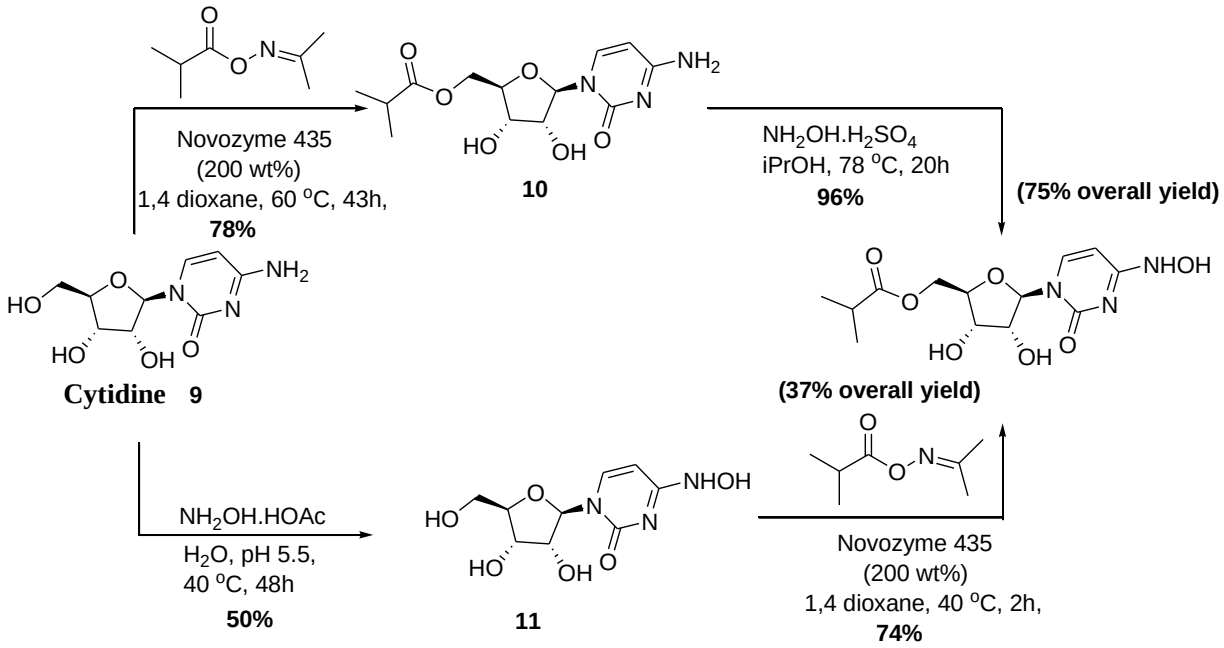
Scheme 7: Concise synthetic route for molnupiravir by De Souza *et al*.

Synthesis of Molnupiravir using Cytidine as the starting material:

Various research groups have documented the synthesis of Molnupiravir using uridine as a primary starting material. However, scientists have also explored an alternative approach by synthesizing Molnupiravir from a more readily available and cheap starting material, cytidine.

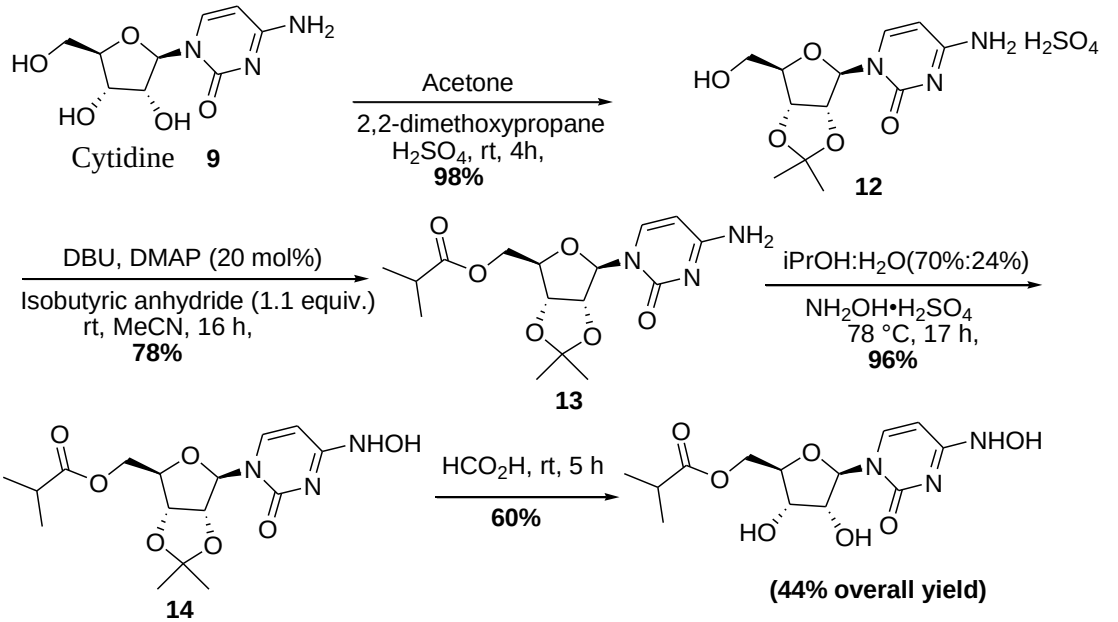
In 2020, Gopalsamuthiram *et al*. introduced a novel and succinct route for synthesizing Molnupiravir from cytidine (**Scheme 8**) (Gopalsamuthiram et al. 2020), employing two distinct synthetic pathways.

In the first route, Novaenzyme-435 (200 wt%) facilitated the cytidine's selective esterification, yielding the mono-ester **10** with an impressive 78% yield. Subsequently, hydroxyamination of compound **10** was done in the presence of hydroxylamine sulfate, resulting in the formation of Molnupiravir with an outstanding 96% yield, thus achieving a 75% overall yield. Conversely, in the second route, hydroxyamination was conducted as the initial step, followed by esterification, yielding Molnupiravir with a 37% overall yield. This method offers a significant advancement by substituting the expensive uridine starting material with the more cost-effective and readily available cytidine.

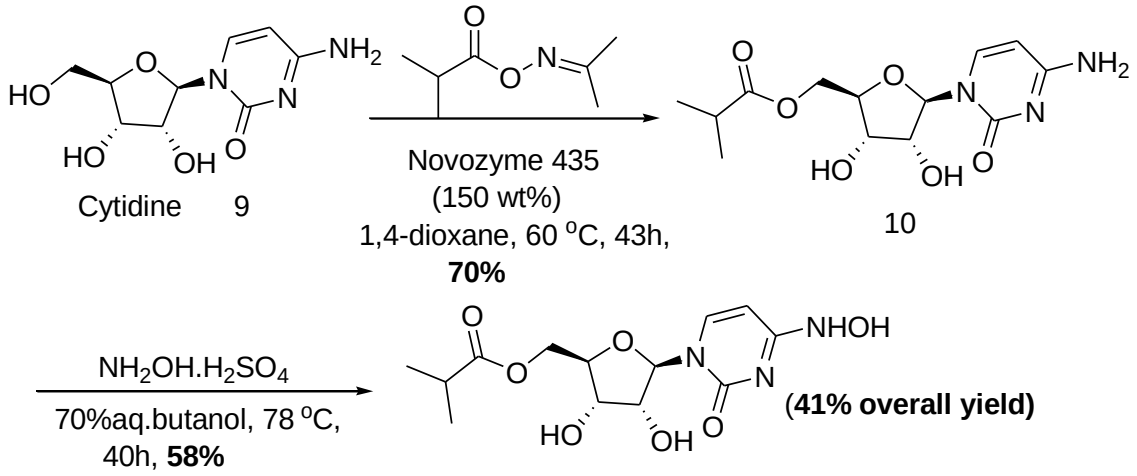


Scheme 8: Novel concise method for molnupiravir by Snead *et al*.

In the same year, Jamison *et al*. developed a non-enzymatic synthetic route for Molnupiravir from cytidine. The protection of dihydroxyl group of cytidines was carried out in the presence of 2,2-dimethoxypropane and catalytic sulfuric acid in acetone, yielding a 98% yield. Subsequently, non-enzymatic acylation with isobutyric anhydride, DBU, and catalytic DMAP is performed. Hydroxyamination and deprotection of the acetonide are performed under formic acid condition, resulting in the formation of Molnupiravir (**Scheme 9**) (Ahlqvist *et al*. 2021). Utilizing low-cost reagents, the overall process was conducted to produce Molnupiravir, achieving an overall yield of 44%.



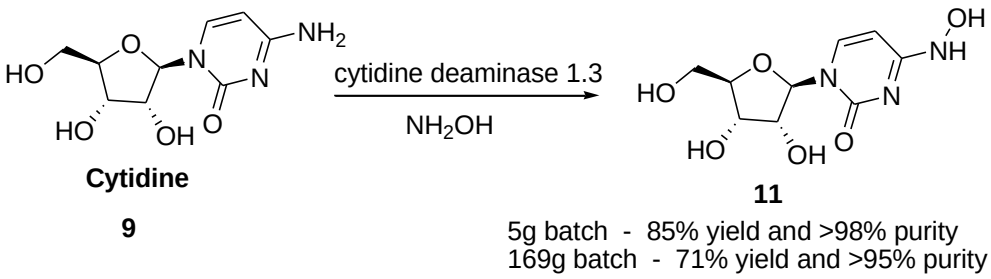
Scheme 9: Chemical synthetic route for molnupiravir from cytidine



Scheme 10: Large scale improve synthetic route by Jamison *et al*.

Bruke *et al*. designed a two-step synthetic approach for synthesizing Molnupiravir on a large scale from cytidine (**Scheme 10**) (Bruke et al. 2022). This method involves enzymatic acylation of cytidine with Novozyme 435 (150 wt%) to yield the desired product in 78% yield. Subsequently, hydroxyamination is carried out in the presence of hydroxylamine sulfate, resulting in a 58% yield. Notably, column purification is not necessary at any point in the process. Despite the relatively low overall yield of around 41%, this method offers a significant advantage for large-scale synthesis (up to 200g) due to the absence of column purification, streamlining the manufacturing process.

Turner et al. introduced a method for the biocatalytic production of a crucial intermediate **11**, of Molnupiravir (**Scheme 11**) (Hu et al. 2022). In this process, the synthetic conversion from cytidine to N-hydroxy cytidine was facilitated by an engineered variant of cytidine deaminase (CD1.3) enzyme. This variant exhibits a preference for hydroxyaminolysis over the hydrolysis of cytidine. Notably, the desired product is produced with good yield and excellent purity through this innovative enzymatic process, even at high substrate concentrations. Furthermore, the product underwent purification via crystallization. Consequently, this method shows significant potential as a cost-effective approach for the synthesis of Molnupiravir.

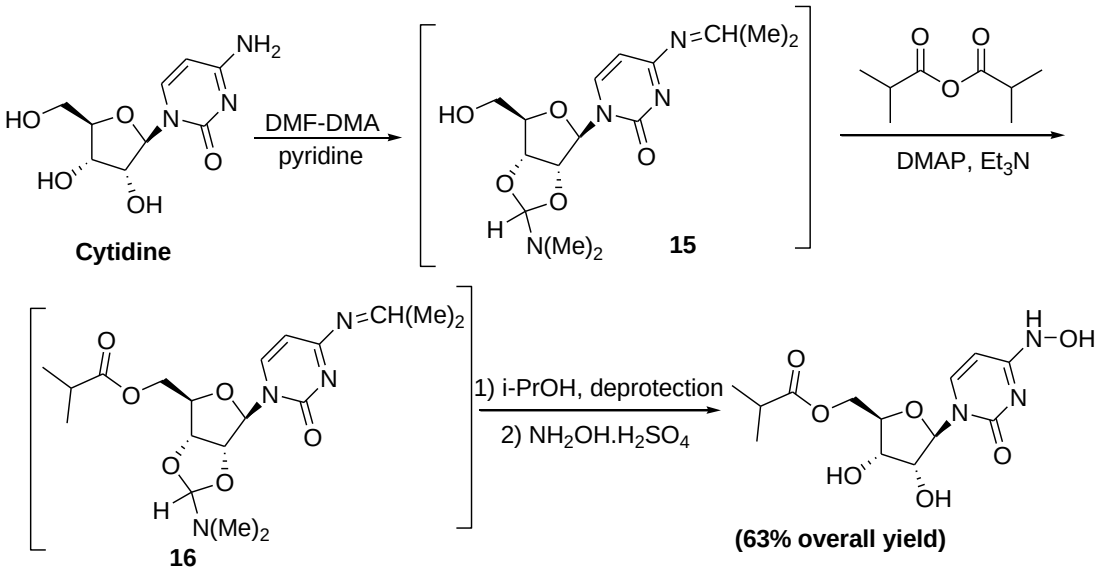


Scheme 11: Enzymetic synthesis of *N*-hydroxy cytidine key intermediate by Turner *et al*.

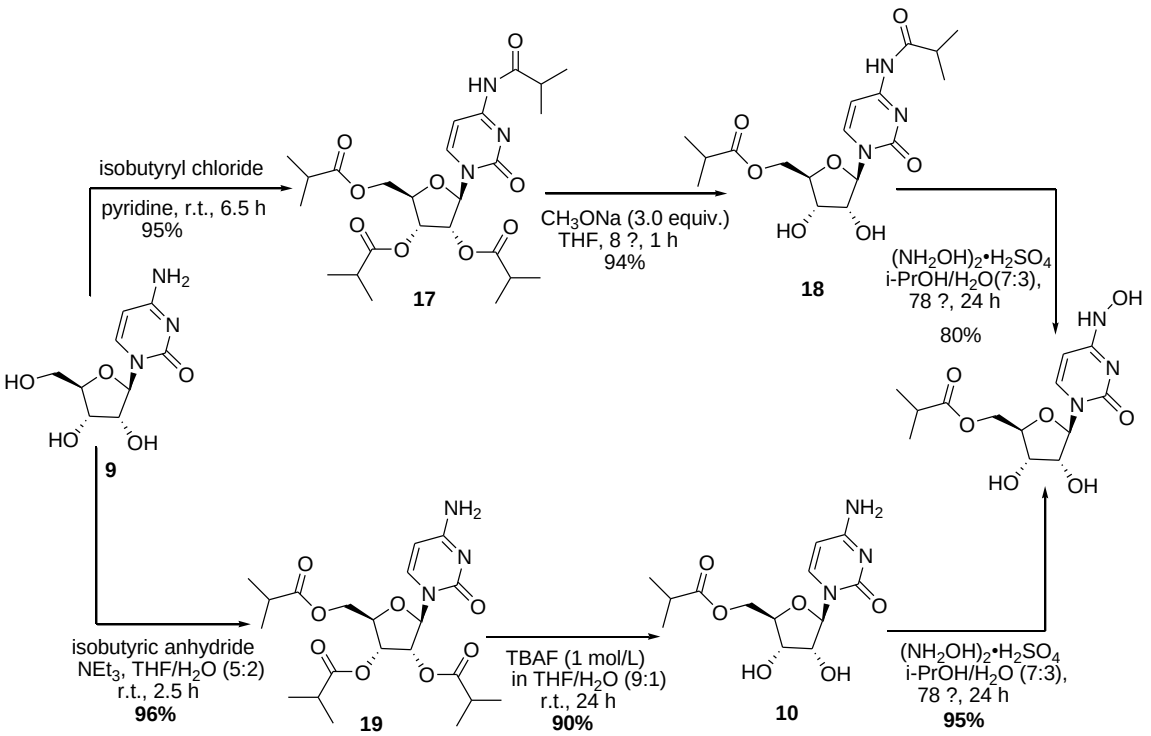
Aisa *et al*. devised a streamlined one-pot synthetic process to produce Molnupiravir from cytidine, achieving an impressive yield of 70% (Scheme 12) [40]. The synthesis initiates with the protection of cytidine's 2^{o} OH group and 1^{o} amine group utilizing DMF-DMA reagent in the presence of 10 equivalents of pyridine in THF solvent, yielding crude compound 15. Subsequently, this compound is subjected to a series of transformations: treatment with isobutyric anhydride, Et_3N, and catalytic DMAP in DCM solvent at room temperature, resulting in the formation of ester 16. Following this, ester 16 undergoes further reaction with ^{i}PrOH and a mixture of 70% ^{i}PrOH/water, along with hydroxylamine sulfate, under heating conditions at 78°C for 18 hours. Upon cooling to room temperature, the organic layer is concentrated to dryness, and the crude Molnupiravir is then crystallized from 2-methyltetrahydrofuran, followed by re-slurry in 2-PrOAc. This comprehensive process yields Molnupiravir with an overall yield of 63%. Notably, the method's single-step isolation and utilization of a highly labile protecting group contribute significantly to minimizing yield loss. These features render Aisa *et al*.'s method highly efficient and promising for large-scale Molnupiravir synthesis.

Liu *et al*. proposed a three-step non-enzymatic synthetic method for accessing Molnupiravir (**Scheme 13**) (Liu et al. 2022*)*. The synthesis of Molnupiravir initiates with cytidine, which undergoes conversion into compound **17** with a remarkable yield of 95% using isobutyric anhydride. Following this, selective deprotection of compound **17** employing sodium methoxide furnishes compound 18 in a high yield of 94%. Subsequently, hydroxylamination of compound **18** yields the target Molnupiravir with an impressive yield of 80%. Overall, this synthetic pathway achieves a remarkable 71% overall yield, underscoring its efficiency and potential for large-scale production. In an alternative approach, they have been capable of growth the general

yield to 82% via tri-acylation in place of tetra-acylation of cytidine (**19**), followed by selective deprotection and hydroxylamination.



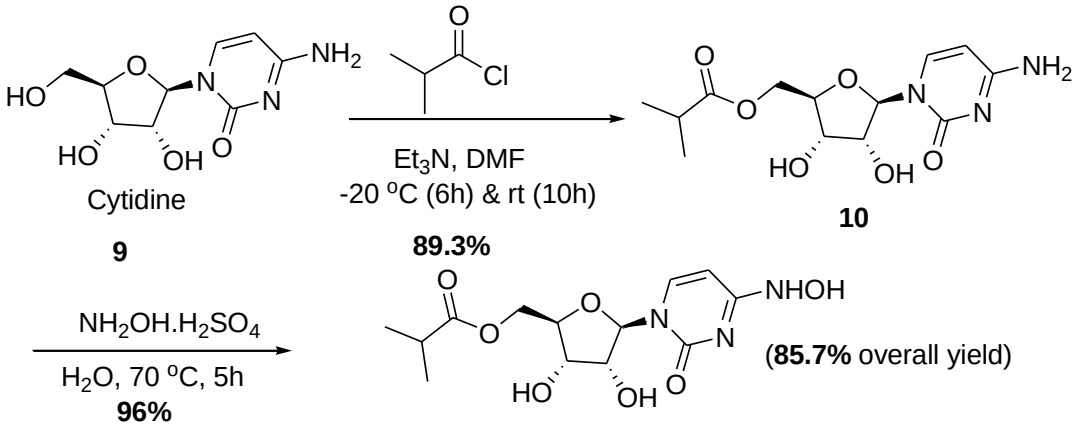
Scheme 12: One-pot synthetic route to molnupiravir by Aisa *et al*.



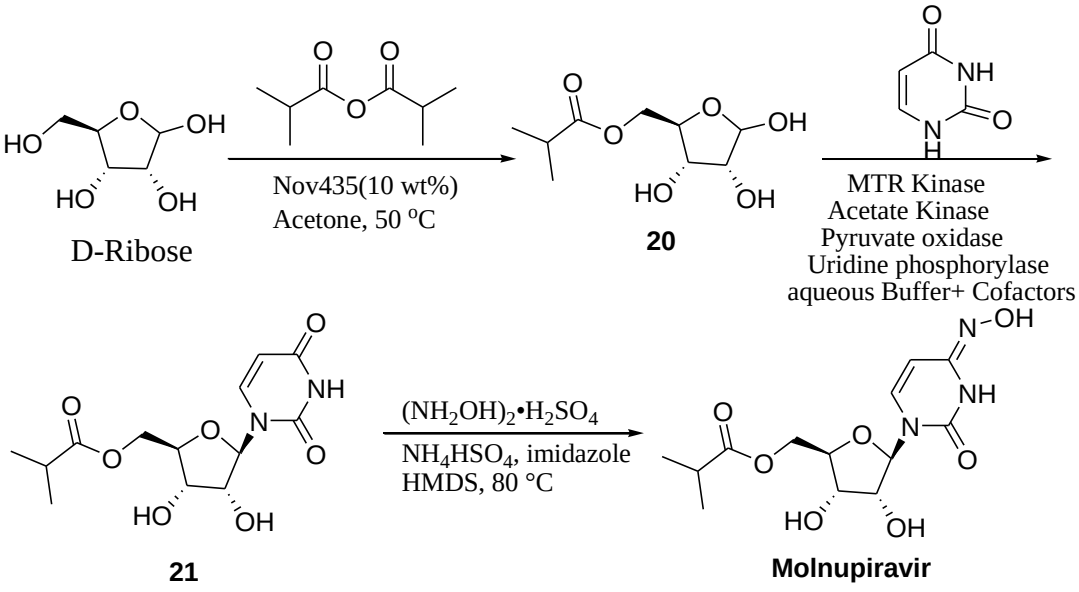
Scheme 13: Three steps synthetic route by F. Liu *et al*.

A two-step chemical synthesis has been carried out by Venkatanarayana *et al.* 2023, group using cytidine as the starting material which is commercially available and inexpensive (**Scheme 14**). The first step contains selective Acylation of Cytidine without Enzyme in DMF with

Isobutyryl Chloride and Et_3N, yielding compound **10** with 89.3% yield. This step is considered one of the novel key steps in this process. Subsequently, compound **10** is treated with hydroxylamine sulfate in H_2O at 70°C for 5 hours to obtain the final compound Molnupiravir in a remarkable 96% yield. This approach utilizes low cost commercially available supplies and concise steps, offering potential for exploring the synthesis of Molnupiravir on a larger scale.



Scheme 14: Two steps syntyhetic route by P. Venkatanarayana *et al*.

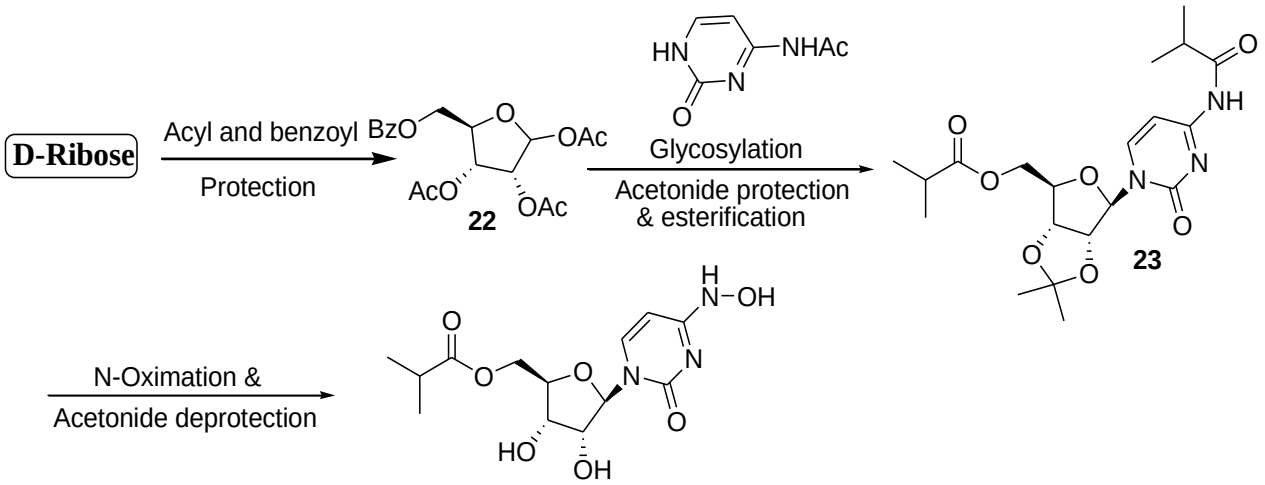


Scheme 15: Enzymatic synthesis of Molnupiravir from Ribose

Synthesis from D-Ribose:

Ribose emerges as one of the most economical key starting materials when compared to cytidine and uridine. However, only a handful of methods have been documented for synthesizing Molnupiravir using D-Ribose as the starting material. In 2020, Benkovics *et al*. presented an efficient three-step enzymatic route for Molnupiravir synthesis (**Scheme 15**). The initial step of this process entails the selective esterification of D-ribose utilizing the Novazyme-435

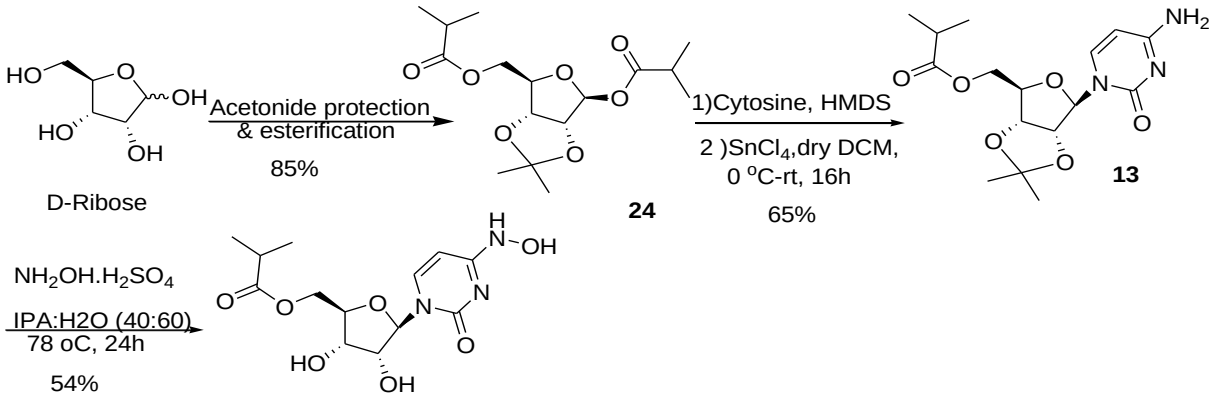
biocatalyst, resulting in an impressive yield of 94%. Subsequently, 1-phosphorylation followed by coupling with uracil using acetate kinase leads to the formation of compound **21**. Compound **21** is then converted into Molnupiravir by hydroxyamination in the presence of HMDS. Despite starting from commodity chemicals like ribose and uracil, the major limitation of this process lies in the non-commercial availability of the enzymes used.



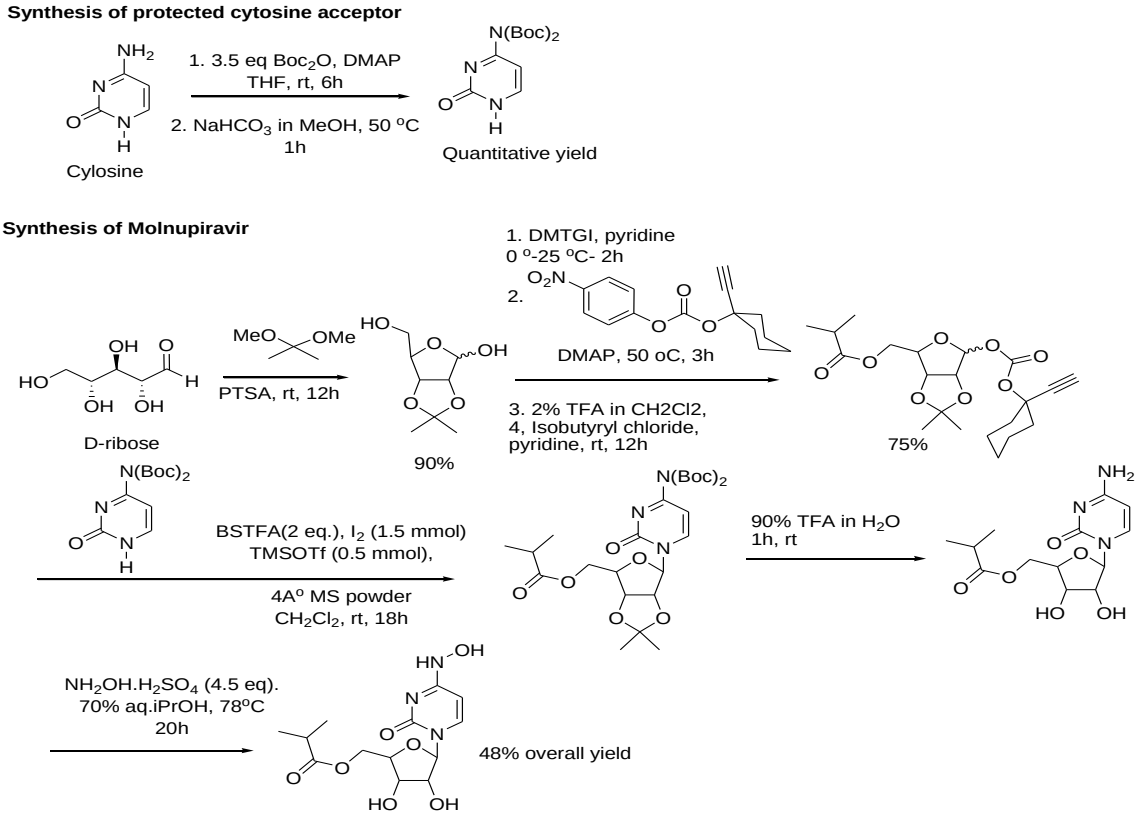
Scheme 16: A convenient synthetic approach to Molnupiravir (EIDD-2801) from Ribose

An appropriate/suitable synthesis method for Molnupiravir was provided by Mukherjee *et al.* by the conversion of N-acyl amidines to amidoximes (**Scheme 16**) (Ahmed et al. 2021). The synthesis initiates with the protection of ribose to yield acetate **22**, followed by coupling with N-acetyl cytosine. Subsequent acetonide protection and esterification result in the formation of nucleoside **23**. Hydroxylamination followed by acetonide deprotection of compound 23 yields Molnupiravir in a 62% overall yield. While this methodology yields satisfactory overall results, it necessitates numerous chemical transformations such as protection and deprotection during the process, adding complexity to the synthesis.

In 2022, Reddy's research group innovated a concise three-step chemical process aimed at accessing Molnupiravir from readily available D-Ribose (Sahoo at al. 2022)]. This strategic approach aimed to streamline the synthesis while ensuring efficiency and scalability. The process commenced with the selective esterification of D-Ribose, leveraging optimized reaction conditions to achieve a high yield. Subsequently, the intermediate underwent a series of carefully orchestrated transformations, each designed to introduce key functional groups essential for Molnupiravir synthesis. Finally, purification steps were implemented to enhance the purity of the final product, ensuring compliance with rigorous quality standards. This innovative methodology not only offers a more efficient route to Molnupiravir but also holds promise for large-scale production, contributing to the accessibility and affordability of this crucial antiviral drug.



Scheme 17: Concise three steps chemical process to access the Molnupiravir

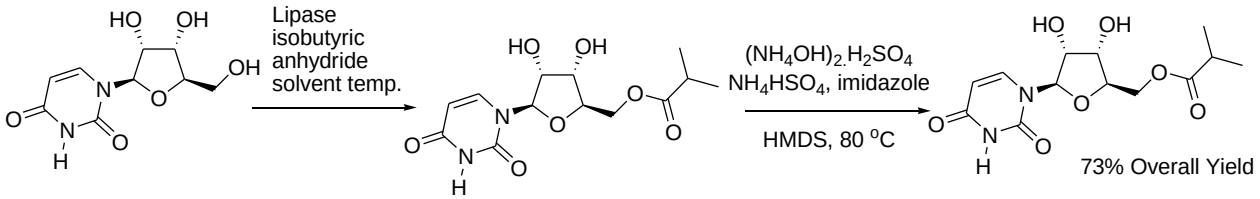


Scheme 18: Synthesis of Molnupiravir from D-Ribose and Cytosine

Chakraborty *et al*. 2024, synthesized glycosyl donor 5 from D-ribose (**Scheme 18)** [46], initially attempting anomeric allyl protection but shifting to acetonide group protection due to yield loss from ribopyranoside formation. Ribofuranoside 7 was obtained in 90% yield. Donor 5 was synthesized in 75% overall yield after three sequential reactions, including primary hydroxyl group protection, conversion to ethynyl cyclohexyl propargyl donor, DMT group cleavage, and esterification with isobutyryl chloride. Cytosine's amine group was protected with bis-Boc group. N-glycosylation reactions with donor 5 resulted in mainly O-glycosidic product formation, with less than 20% N-glycosidic product. Optimization revealed AgOTf as the cocatalyst and TMSOTf as the additive, yielding up to 90% glycosylation yield. Using I2 and TMSOTf, the

nucleosidation reaction produced the desired β isomer 8 in 90% yield, with gram-scale compatibility. After removing Boc and acetonide groups, hydroxylamination at the N4 position yielded Molnupiravir.

Bade *et al.* presented a synthesis pathway for Molnupiravir (**Scheme 19**) [47], starting with intermediate synthesized from uridine under optimized conditions using lipase Addzyme 011 (TLL) and isobutyric anhydride in THF at 40 °C for 96 hours, demonstrating excellent regioselectivity at the primary alcohol. Subsequently, the amidic carbonyl of uracil in intermediate 2 was converted to an oxime using cost-effective hexamethyldisilazane (HMDS) as the solvent and mild dehydrating agent, with imidazole serving as a catalyst to enhance conversion rates via TMS-imidazole formation. This approach contrasts with Merck and Co.'s enzymatic process utilizing ribose, achieving a 69% overall yield, and Hu et al. and Ahlqvist et al.'s one-pot chemical synthesis from cytidine, yielding 63% overall. These methods involved protection and deprotection steps or a chemo-enzymatic process utilizing Novozyme 435, resulting in a 41% overall yield, albeit limited by expensive substrates and relatively poor yields. In order to overcome these obstacles, Bade et al.'s research target was to use inexpensive uridine and reducing the number of steps, while achieving good overall yields in the synthesis of molecular Molnupiravir.

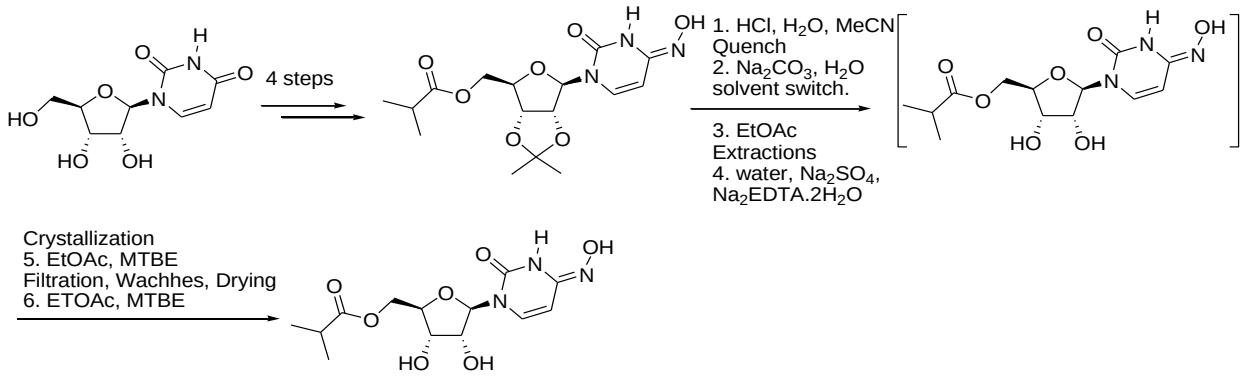


Scheme 19: Chemo-Enzymatic Synthesis of Molnupiravir via Lipase

Rachel *et al*. conducted stability studies on molnupiravir Forms 1 and 2, (**Scheme 20)** [48] both as drug substance and in formulated capsules. They found no significant changes in impurity profile or physical attributes over 6 months at accelerated conditions, indicating stability at intended storage conditions. Drug product stability tests showed consistent crystal forms and no significant changes in key properties like chemical stability and dissolution. No hydrate formation was observed. Both forms exhibited stability over 3 months in bottles and open dish conditions at elevated humidity and temperature. XRPD confirmed no change in crystal form, demonstrating similarity and suitability for pharmaceutical use.

Furthermore, stability assessments of the drug product were performed to assess the influence of crystal form on various attributes, including chemical stability and dissolution. Following the formulation of Molnupiravir Form 1 and Form 2 into capsules via a high-shear wet granulation process, it was observed that the original crystal form persisted consistently in the final product. As Molnupiravir does not form hydrates, hydrate formation was not considered a concern during the drug production process or in stability testing under elevated relative humidity.

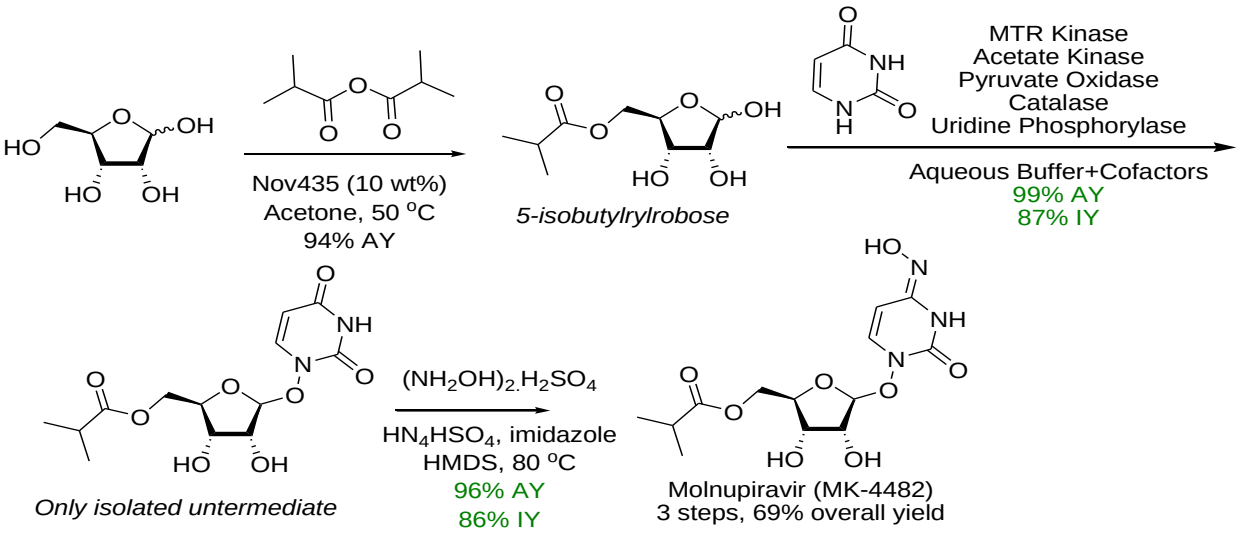
Drug product capsules containing either Form 1 or predominantly Form 2 drug substances were subjected to accelerated stability conditions (40°C/75% RH) for up to 3 months, both in bottles and in open dish conditions. The resulting stability data for both Form 1 and Form 2 indicated no notable changes observed in key drug product properties, including chemical stability and dissolution profile. Additionally, X-ray powder diffraction (XRPD) analysis confirmed the retention of Molnupiravir's crystal form throughout the drug product stability testing.



Scheme 20: Schematic of the abbreviated manufacturing process for molnupiravir.

At the same time, we focused on making a reliable manufacturing process to always make the Active Pharmaceutical Ingredient (API) of the same quality. At first, we isolated the API using distillative crystallization. In this process, a solution with API, EtOAc, MeCN, and water is distilled, and dry EtOAc is added to make the water content lower, which makes the API form crystals because it's very soluble in water. We improved this method to have better control over when crystals start forming and how quickly they grow. This made the API more consistent in quality across different batches and scales. Even though this updated process was a bit more complex to run, we chose it because it was more reliable, especially with tight project deadlines and concerns about regulatory approval for any changes in the Particle Size Distribution (PSD) or crystal form.

In 2021, the McIntosh *et al*. (**Scheme 21**) group emphasized Molnupiravir (MK-4482) as a promising investigational antiviral agent for treating COVID-19. Recognizing the likely high demand and urgent need for this compound, it became imperative to establish a concise and sustainable synthesis route using readily available raw materials to expedite the manufacturing and distribution of Molnupiravir. The approach presented in their study relies on a groundbreaking biocatalytic cascade, featuring an engineered ribosyl-1-kinase and uridine phosphorylase. These engineered enzymes are coupled with a phosphate recycling strategy enabled by pyruvate oxidase. In comparison to the initial synthetic route, this new method for producing Molnupiravir is 70% shorter and yields around seven times higher. Looking ahead, the biocatalytic tactic outlined for Molnupiravir synthesis is expected to find widespread use in simplifying the production of nucleosides across various applications.



Scheme 21: Ribosyl-1-Kinase Enables Concise Synthesis of Molnupiravir

In summary, various approaches have been explored for the synthesis of Molnupiravir from its three primary starting materials (*e.g.* uridine, cytidine and ribose), offering potential avenues for discovering new routes for large-scale production at an affordable price. While numerous research groups have dedicated considerable time and effort to investigating the synthesis of this drug, a comparative analysis reveals that only a few routes exist for synthesizing Molnupiravir from ribose. Moreover, the enzymatic pathway for obtaining Molnupiravir from ribose is not the most favoured option due to the lack of commercially available enzymes. Nevertheless, we believe that this review could serve as a valuable resource for the scientific community, particularly in furthering the development of Molnupiravir from ribose, given its natural availability and cost-effectiveness as a precursor.

Acknowledgments

T. Sahoo thanks to CSIR, New Delhi, India, for the award of a fellowship and Indian Institute of Chemical Technology-Hyderabad (CSIR-IICT) and Dr. A. Chandra and Dr. S K. Biswas thanks to VC Tripura University and HOD Chemistry, Tripura University and Tripura University.

References:

Abu-Zaied, M. A.; Elgemeie, G. H.; Mahmoud, N. M. Anti-covid-19 drug analogues: synthesis of novel pyrimidine thioglycosides as antiviral agents against SARS-COV-2 and avian influenza H5N1 viruses. *ACS Omega* **2021**, *6*(26), 16890–16904. doi.org/10.1021/acsomega.1c01501.

Ahlqvist, G. P.; McGeough, C. P.; Senanayake, C.; Armstrong, J. D.; Yadaw, A.; Roy, S.; Ahmad, S.; Snead, D. R.; Jamison, T. F. Progress Toward a Large-Scale Synthesis of Molnupiravir (MK-4482, EIDD-2801) from Cytidine. *ACS Omega* **2021**, *6*, 10396-10402. doi.org/10.1021/acsomega.1c00772.

Ahmed, A.; Ahmed, Q. N.; Mukherjee, D. Conversion of *N*-acyl amidines to amidoximes: a convenient synthetic approach to molnupiravir (EIDD-2801) from ribose. *RSC Adv.* **2021**, *11*, 36143-36147. doi.org/10.1039/D1RA06912H.

Akkiz, H. Implications of the Novel Mutations in the SARS-CoV-2 Genome for Transmission, Disease Severity and the Vaccine Development. J. Transl. Sci. 2021, 7, 636532. DOI: 10.3389/fmed.2021.636532.

Aleccia, J. (29 September 2021). "A Daily pill to treat COVID could be just months away". *ABC News*. Kaiser Health News. Archived from the original on 29 September 2021.

Bade, R., Bothe, J. R., Sirota, E., Brunskill, A. P. J.; Newman, J. A., Zhang, Y., Tan, M., Zheng, M., Brito, G., Poirier, M., Fier, P. S., Xu, Y., Ward, M. D., Stone, K., Lee, I. H., Gmitter, A. J., Bernardoni, F., Zompa, M. A., Luo, H. Patel., S. K., Masiuk, T., Mora, J., Ni, T., O., G. A.; Tarabokija, J., Liu, J., Lowinger, M. B.; Mahmood, T., Polymorphs, Particle Size, and a Pandemic: Development of a Scalable Crystallization Process for Molnupiravir , an Antiviral for the Treatment of COVID-19, Org. Process Res. Dev. 2023, 27, 11, 2100–2110. doi.org/10.1021/acs.oprd.3c00268.

Benkovics, T.; McIntosh, J.; Silverman, S.; Kong, J.; Maligres, P.; Itoh, T.; Yang, H.; Huffman, M.; Verma, D.; Pan, W.; Ho, H.I.; Vroom, J.; Knight, A.; Hurtak, J.; Morris, W.; Strotman, N.; Murphy, G.; Maloney, K.; Fier, P. Evolving to an ideal synthesis of Molnupiravir, an investigational treatment for COVID-19. *ChemRxiv.* **2020**. 10.26434/chemrxiv.13472373.v1.

Bian, L.; Gao, F.; Zhang, J.; He, Q.; Mao, Q.; Xu, M.; Liang, Z. Effects of SARS-CoV-2, Variants on Vaccine Efficacy and Response Strategies. *Expert Rev. Vaccines* **2021**, *20*, 365–373. DOI: 10.1080/14760584.2021.1903879.

Burke, A. J.; Birmingham, W. R.; Zhuo, Y.; Thorpe, T. W.; da Costa, B. Z.; Crawshaw, R.; Rowles, I.; Finnigan, J. D.; Young, C.; Holgate, G. M.; Muldowney, M. P.; Charnock, S. J.; Lovelock, S. L.; Turner, N. J.; Green, A. P. An Engineered Cytidine Deaminase for Biocatalytic Production of a Key Intermediate of the Covid-19 Antiviral Molnupiravir. *J. Am. Chem. Soc*. **2022**, *144*, 3761−3765. DOI: 10.1021/jacs.1c11048

Chakraborty S, Sutar Y, Prasad K, Rajput J, Hotha S. Expedient Synthesis of Antiviral Drug Molnupiravir from D-Ribose and Cytosine. ChemRxiv. 2024; doi:10.26434/chemrxiv-2024-gd0tn.

Chavda, V.P.; Balar, P.; Vaghela, D.; Solanki, H.K.; Vaishnav, A.; Hala, V.; Vora, L. Omicron Variant of SARS-CoV-2: An Indian Perspective of Vaccination and Management. Vaccines 2023, 11, 160.Pati, B.; Banerjee, S."Quinazolines: an illustrated review, *J. Adv. Pharm. Edu. Res.*, **2013**, *3*, 136–151. doi.org/10.3390/vaccines11010160.

Chavda, V.P.; Yao, Q.; Vora, L.K.; Apostolopoulos, V.; Patel, C.A.; Bezbaruah, R.; Patel, A.B.; Chen, Z.-S. Fast-Track Development of Vaccines for SARS-CoV-2: The Shots That Saved the World. *Front. Immunol*. **2022**, *13*, 961198., WHO Coronavirus (COVID-19) Dashboard, https:// covid19.who.int/, accessed 2023. DOI: 10.3389/fimmu.2022.961198.

Dey, R.; Nayak, S.; Das, P.; Yadav, S. Short Synthesis of Molnupiravir (EIDD-2801) via a Thionated Uridine Intermediate. *ACS Omega* **2021**, **6**, 28366–28372. DOI: 10.1021/acsomega.1c04550.

Fier, P. S.; Xu, Y.; Poirier, M.; Brito, G.; Zheng, M.; Bade, R.; Sirota, E.; Stone, K.; Tan, L.; Humphrey, G. R.; Chang, D.; Bothe, J.; Zhang, Y.; Bernardoni, F.; Castro, S.; Zompa, M. A.; Taylor, J.; Sirk, K. M.; Diaz-Santana, A.; Diribe, I.; Emerson, K. M.; Krishnamurthi, B.; Zhao, R.; Ward, M.; Xiao, C.; Ouyand, H.; Zhan, J.; Morris, W. J. Development of a Robust Manufacturing Route for Molnupiravir, an Antiviral for the Treatment of COVID-19. *Org. Process Res. Dev.* **2021**, *25*, 2806–2815. doi.org/10.1021/acs.oprd.1c00400.

Fischer, W.A.; Eron, J.J.; Holman, W.; Cohen, M.S.; Fang, L.; Szewczyk, L. J.; Sheahan, T.P.; Baric, R.; Mollan, K.R.; Wolfe, C.R. A Phase 2a Clinical Trial of Molnupiravir in Patients with COVID-19 Shows Accelerated SARS-CoV-2 RNA Clearance and Elimination of Infectious Virus. *Sci. Transl. Med*. **2022**, *14*, eabl7430. DOI: 10.1126/scitranslmed.abl7430.

Gil, C.; Ginex, T.; Maestro, I.; Nozal, V.; Barrado-Gil, L.; Cuesta-Geijo, M. A.; COVID-19: drug targets and potential treatments. *J. Med. Chem.* **2020**, *63*, 12359–12386. DOI: 10.1021/acs.jmedchem.0c00606.

Gopalsamuthiram, V.; Williams, C.; Noble, J.; Jamison, T. F.; Gupton, B. F., Snead, D. R.; A. Concise Route to MK-4482 (EIDD-2801) from Cytidine: Part 2. *Synlett* **2020**, *32*, 326– 328. DOI:10.1055/a-1275-2848

Gordon, C.J.; Tchesnokov, E.P.; Schinazi, R.F.; Gotte, M. Molnupiravir promotes € SARS-CoV-2 mutagenesis via the RNA template. *J Biol Chem* **2021**, *297*, 100770. DOI: 10.1016/j.jbc.2021.100770.

Hacker, M.; Messer, W.S.; Bachmann, K.A. "Chapter 10.5: Elimination (Metabolism and Excretion)". *Pharmacology: Principles and Practice*. *Academic Press*. **2009**, 216–217. ISBN: 0080919227, 9780080919225

Halford, B. "An emerging antiviral takes aim at COVID-19". *C&EN*. Archived from the original on 2 August 2020.

Hu, B.; Guo, H.; Zhou, P.; Shi, Z.L. Characteristics of SARS-CoV-2 and COVID-19. *Nat. Rev. Microbiol.* **2021**, *19*, 141–154. doi: 10.1038/s41579-020-00459-7.

Hu, T.; Xie, Y.; Liu, Y.; Xue, H.; Zhu, F.; Aisa, H. A.; Shen, J. "One-Pot" Synthesis of Molnupiravir from Cytidine. *Org. Process Res. Dev.* **2022**, *26*, 2, 358–364. DOI: 10.1055/s-0041-1738031.

Jornada, D.H.; Dos Santos Fernandes, G.F.; Chiba, D.E.; De Melo, T.R.F.; Dos Santos, J.L.; Chung, M.C. The Prodrug Approach: A Successful Tool for Improving Drug Solubility. *Molecules* **2016**, *21*, 42. DOI: 10.3390/molecules21010042.

Kabinger, F.; Stiller, C.; Schmitzova, J. Mechanism of molnupiravir-induced SARS-CoV-2 mutagenesis. *Nat Struct Mol Biol* **2021** *28*, 740e6. DOI: 10.1038/s41594-021-00651-0.

Kalal, C.; & Charola, S. An alarming public health concern over variability in herbal compositions of marketed immunity booster products during COVID-19: A botanical survey-based study. *Int. J. Exp. Res. Rev.* **2021**, *24*, 40-50. https://doi.org/10.52756/ijerr.2021.v24.005

Khan, Z.; Karataş, Y.; Rahman, H. Anti COVID-19 drugs: need for more clinical evidence and global action. *Adv. Ther.* **2020**, *37*(6), 2575–2579. DOI: 10.1007/s13337-021-00684-5.

Liu, Z.; Yang, J.; Liu, F. New Routes to Antiviral Molnupiravir against SARS-CoV-2 Infection. *Chin. J. Org. Chem.* **2022**, *42*, 2988-2993. DOI:10.6023/cjoc202203044

Markovic, M.; Ben-Shabat, S.; Dahan, A. Prodrugs for Improved Drug Delivery: Lessons Learned from Recently Developed and Marketed Products. *Pharmaceutics* **2020**, *12*, 1031. doi.org/10.3390/pharmaceutics12111031.

Maurya, R.; Mishra, P.; Swaminathan, A.; Ravi, V.; Saifi, S.; Kanakan, A.; Mehta, P.; Devi, P.; Praveen, S.; Budhiraja, S.; SARS-CoV-2 Mutations and COVID-19 Clinical Outcome: Mutation Global Frequency Dynamics and Structural Modulation Hold the Key. *Front. Cell. Infect. Microbiol*. **2022**, *12*, 868414. doi: 10.3389/fcimb.2022.868414.

McIntosh, J. A., Benkovics, T., Silverman, S. M., Huffman, M. A., Kong, J., Maligres, P. E., Itoh, T., Yang, H., Verma, D., Pan, W., Ho, H., Vroom, J., Knight, A. M., Hurtak, J. A., Klapars, A.,

Fryszkowska, A., Morris, W., Strotman, N. A., Murphy, G. S., Maloney, K. M., and Fier, P. S., Engineered Ribosyl-1-Kinase Enables Concise Synthesis of Molnupiravir, an Antiviral for COVID-19, ACS Cent. Sci. 2021, 7, 12, 1980–1985, doi.org/10.1021/acscentsci.1c00608.

Multisociety Consensus Quality Improvement Revised Consensus Statement for Endovascular Therapy of Acute Ischemic Stroke. *Int. J. Stroke* **2018**, *13*, 612–632. DOI: 10.1016/j.jvir.2017.11.026

Painter, G. R.; Bluemling, G. R.; Natchus, M. G.; Guthrie, D. WO pat., WO2019113462, 2019.

Painter, G.R.; Bowen, R.A.; Bluemling, G.R.; DeBergh, J.; Edpuganti, V.; Gruddanti, P.R.; Guthrie, D.B.; Hager, M.; Kuiper, D.L.; Lockwood, M.A. The Prophylactic and Therapeutic Activity of a Broadly Active Ribonucleoside Analog in a Murine Model of Intranasal Venezuelan Equine Encephalitis Virus Infection. *Antivir. Res.* **2019**, *171*, 104597. DOI: 10.1016/j.antiviral.2019.104597.

Painter, W.P.; Holman, W.; Bush, J.A.; Almazedi, F.; Malik, H.; Eraut, N.C.J.E.; Morin, M.J.; Szewczyk, L.J.; Painter, G.R. Human Safety, Tolerability, and Pharmacokinetics of Molnupiravir, a Novel Broad-Spectrum Oral Antiviral Agent with Activity Against SARS-CoV-2. *Antimicrob. Agents Chemother* **2021**, *65*, e02428-20.

Pereira, V. R. D.; Bezerra, M. A. M.; Gomez, M. R. B. P.; Martins, G. M.; da Silva, A. D.; de Oliveira, K. T.; de Souza, R. O. M. A.; Amarante, G. W. Concise two-step chemical synthesis of molnupiravir. *RSC Adv.* **2022**, *12*, 30120-30124. doi.org/10.1039/D2RA05064A.

Rautio, J.; Meanwell, N.A.; Di, L.; Hageman, M.J. "The expanding role of prodrugs in contemporary drug design and development". *Nature Reviews. Drug Discovery*. **2018**, *17* (8): 559–587. doi.org/10.1038/nrd.2018.46.

Rosangzuala, K., Patlolla, R. R., Shaikh, A., Naik, K. A. P., Raveena, G., Nemali, M., Mudiam M. K. R.*, and Banoth, L., * Streamlined Chemo-Enzymatic Synthesis of Molnupiravir via Lipase Catalyst, ACS Omega 2024, 9, 4, 4423–4428, doi.org/10.1021/acsomega.3c06872.

Roychoudhury, S.; Das, A.; Jha, N.K.; Kesari, K.K.; Roychoudhury, S.; Jha, S.K.; Kosgi, R.; Choudhury, A.P.; Lukac, N.; Madhu, N.R.; Kumar, D.; & Slama, P. Viral pathogenesis of SARS-CoV-2 infection and male reproductive health. *Open Biology* (The Royal Society Publishing, UK), **2021**, *11*, 200347 (Page 1- 11). https://doi.org/10.1098/rsob.200347.

Sahoo, T.; Reddy, B.V.S. Concise synthesis of antiviral drug, molnupiravir by direct coupling of fully protected D-ribose with cytosine. *Tetrahedron Lett.* **2022**, *97*, 153783. doi.org/10.1016/j.tetlet.2022.153783.

Sezer, A.; HalilovićAlihodžić, M.; Vanwieren, A.R.; Smajkan, A.; Karić, A.; Djedović, H.; Šutković, J. A review on drug repurposing in COVID-19: from antiviral drugs to herbal alternatives. J. Genet. Eng. Biotechnol. 2022, 20, 78. DOI: 10.1186/s43141-022-00353-0.

Sharma, A.; Ahmed, S.; Kaur, J.; Chawla, R.; Rejeeth, C. Exploring status of emergency drugs and vaccine development in Covid-19 pandemic: an update. *VirusDisease* **2021**, *32*, 198–210.

Steiner, A.; Znidar, D.; Otvös, S. B.; Snead, D. R.; Dallinger, D.; Kappe, C. O. A High-Yielding Synthesis of EIDD-2801 from Uridine. *Eur. J. Org. Chem.***2020**, 6736–6739. DOI:10.26434/chemrxiv.13058486.v1.

Teli, D.; Balar, P.; Patel, K.; Sharma, A.; Chavda, V.; Vora, L. Molnupiravir: A Versatile Prodrug against SARS-CoV-2 Variants. *Metabolites.* **2023**, *13*, 309. DOI: 10.3390/metabo13020309.

Toots, M.; Yoon, J.J.; Cox, R.M.; Hart, M.; Sticher, Z.M.; Makhsous, N.; Plesker, R.; Barrena, A.H.; Reddy, P.G.; Mitchell, D.G.; Characterization of orally efficacious influenza drug with high

resistance barrier in ferrets and human airway epithelia. *Sci. Transl. Med.* **2019**, *11*, eaax5866. DOI: 10.1126/scitranslmed.aax5866

Toots, M.; Yoon, J.J.; Hart, M.; Natchus, M.G.; Painter, G.R.; Plemper, R.K. Quantitative Efficacy Paradigms of the Influenza Clinical Drug Candidate EIDD-2801 in the Ferret Model. *Transl. Res.* **2020**, *218*, 16–28. DOI: 10.1016/j.trsl.2019.12.002.

Vashist, P.; Vashist, R.; & Tripathi, A. Scientific Assessment and Sorting of Topological Parameters Affecting Time in Recovering from COVID-19. *Int. J. Exp. Res. Rev.*, **2023**, *30*, 359-365. https://doi.org/10.52756/ijerr.2023.v30.033

Vasudevan, N.; Ahlqvist, G. P.; McGeough, C. P.; Paymode, D. J.; Cardoso, F. S. P.; Lucas, T.; Dietz, J. P.; Opatz, T.; Jamison, T. F.; Gupton, F. B.; Snead, D. R. A concise route to MK-4482 (EIDD2801) from cytidine. *Chem. Commun.* **2020**, *56*, 13363−13364. doi.org/10.1039/D0CC05944G.

Venkatanarayana, P.; Kolli, D.; Seelama, N. V.; Ramakrishna, D. S. Synthesis of molnupiravir (MK-4482, EIDD-2801): a promising oral drug for the treatment of COVID-19 starting from cytidine. *Nucleosides, Nucleotides & Nucleic Acids*, **2023**, *42*, 427–435. DOI: 10.1080/15257770.2022.2153140.

Wang, Z.; Yang, L. Broad-Spectrum Prodrugs with Anti-SARS-CoV-2 Activities: Strategies, Benefits, and Challenges. *J. Med. Virol*. **2022**, *94*, 1373–1390. DOI: 10.1002/jmv.27517.

Yip, A.J.W.; Low, Z.Y.; Chow, V.T.K.; Lal, S.K. Repurposing Molnupiravir for COVID-19: The Mechanisms of Antiviral Activity. *Viruses* **2022**, *14*, 1345. DOI: 10.3390/v14061345.

Yoon, J.J.; Toots, M.; Lee, S.; Lee, M.E.; Ludeke, B.; Luczo, J.M.; Ganti, K.; Cox, R.M.; Sticher, Z.M.; Edpuganti, V.; Orally Efficacious Broad-Spectrum Ribonucleoside Analog Inhibitor of Influenza and Respiratory Syncytial Viruses. *Antimicrob. Agents Chemother.* **2018**, *62*, e00766-18. DOI: 10.1128/AAC.00766-18.

HOW TO CITE

T. Sahoo, P. Shrivastava, A. Chandra, S. K. Biswas and B. V. Subba Reddy (2024). The Biological Activity and Synthesis of Orally Active COVID-19 (SARS-CoV-2) Antiviral Drug Molnupiravir. © International Academic Publishing House (IAPH), Dr. Suman Adhikari, Dr. Manik Bhattacharya and Dr. Ankan Sinha, *A Basic Handbook of Science, Technology and Innovation for Inclusive Development [Volume: 1]*, pp. 13-39. ISBN: 978-81-969828-4-3 DOI: https://doi.org/10.52756/ bhstiid.2024.e01.002

OPEN ACCESS PEER REVIEW
DOI:https://doi.org/10.52756/ bhstiid.2024.e01.003
Chapter- 3

Advanced Methods for the Separation and Identification of p and d block elements by Paper Chromatography

Arijit Das[a]*, Digvijoya Sarma[a], Rupak Das[b], Bijaya Paul[c], Pratima Debnath[d], Suman Adhikari[e], Arnab Bhattacharya[f], and Paresh Debnath[a]*

Keywords: Paper chromatography, transition elements, green mobile phase, coloured patches, retardation factor.

Abstract:

The objective of this study was to utilize paper chromatography (PC) as a cost-effective and accessible method to impart fundamental principles of chromatography to undergraduate students in introductory inorganic chemistry courses. The experiments focused on detecting and separating metal ions from various groups in the analytical table. Specifically, the study aimed to educate students on the separation and identification of metal ions, comparing color spots and retention factor values, and understanding the influence of alkalinity during metal ion oxidation. Paper chromatography and planar chromatography share the use of solid, flat stationary phases. In this study, Whatman quantitative grade 41 filter paper was employed as the stationary phase. Minimal sample quantities were utilized for qualitative analysis. Through the use of different eluting agents, PC was employed to separate and identify transition metal ions such as (Fe^{3+} & Cr^{3+}) in group III, (Pb^{2+} & Cu^{2+}) in group II, Co^{2+} & Ni^{2+} in group IV, (Co^{2+} & Cu^{2+}) in group IV and II, (Cu^{2+} & Fe^{3+}) in group II and III, and (Mo^{6+} & W^{6+}) in group VI, based on their distinct color spots and retention factor (R_f) values. This qualitative investigation enabled undergraduate students to appreciate the efficacy of PC in identifying and separating pairs of metal ions through observation of different color spots and their corresponding R_f values.

Arijit Das[a]*
[a]Department of Chemistry, Bir Bikram Memorial College, Agartala, Tripura, 799004, India
E-mail: arijitdas78chem@gmail.com; OrcidiD: https://orcid.org/0000-0001-7409-7237
Digvijoya Sarmaa[a]
[a]Department of Chemistry, Bir Bikram Memorial College, Agartala, Tripura, 799004, India
OrcidiD: https://orcid.org/0009-0007-9626-8819
Rupak Das[b]
[b]Department of Commerce, Bir Bikram Memorial College, Agartala, Tripura, 799004, India
OrcidiD: https://orcid.org/0009-0005-4897-145X
Bijaya Paul[c]
[c]Department of Chemistry, School Education, Govt. of Tripura, Agartala, 799001, India
OrcidiD: https://orcid.org/0009-0003-8931-2456
Pratima Debnath[d]
[d]Department of Chemistry, National Institute of Technology Agartala, Tripura-799046, India
OrcidiD: https://orcid.org/0000-0002-1653-2517
Suman Adhikari[e]
[e]Department of Chemistry, Govt. Degree College, Dharmanagar, Tripura(N)-799253, India
OrcidiD: https://orcid.org/0000-0002-6382-5400
Arnab Bhattacharya[f]
[f]Department of Chemistry, Tripura University, Tripura-799022, India
OrcidiD: https://orcid.org/0000-0001-7949-1081
Paresh Debnath[a]*
[a]Department of Chemistry, Bir Bikram Memorial College, Agartala, Tripura, 799004, India
E-mail: pareshchem1990@gmail.com; OrcidiD: https://orcid.org/0000-0003-0959-9374
***Corresponding Author**: arijitdas78chem@gmail.com&pareshchem1990@gmail.com

Dr. Suman Adhikari, Dr. Manik Bhattacharya and Dr. Ankan Sinha, A Basic Handbook of Science, Technology and Innovation for Inclusive Development [Volume: 1]. ISBN: 978-81-969828-4-3; pp- 40-61; Published online: 27th May, 2024

Introduction:

Paper chromatography (PC) experiments are frequently employed in introductory laboratory courses for both organic and inorganic chemistry, serving as valuable tools for teaching fundamental chromatographic principles and polarity concepts. In organic chemistry, PC finds applications in various experiments, including the detection of organic acids like citric acid, malic acid, tartaric acid, and lactic acid in wine and fruit juices (Samarasekara et al., 2018), partitioning of food and indicator dyes (Birdwhistell et al., 2002; Markow, 1988; Sharma et al., 2011), visualization of ninhydrin in amino acids and tomato extracts (Stoffyn et al., 1954; Fowden, 1951; Wu et al., 1958).In the realm of inorganic chemistry, PC serves as an effective method for the rapid identification and separation of metal ions. Qureshi et al. demonstrated a method for the quantitative partition of Fe(II) and Fe(III) using PC with a mixture of 4M HCl, n-butanol, acetic acid, and acetone (1:1:1:1) as the developing solvent(Qureshi et al., 1966).Berg et al. separated Co^{3+}, Cu^{2+} and Ni^{2+}ions as acetylacetonates using PC with a developing solvent comprising cyclohexane (84%), dioxane (10%), and methanol (6%)(Berg et al., 1955).Bhatnagar et al. (1977) described a novel mechanism for PC involving the partition of various metal ions viz.Ag^{+1}, Cu^{2+}, Ni^{2+}, Co^{2+}, Hg^{2+}, Pb^{2+}& Fe^{3+}using impregnated papers with aqueous glycine (2%, W/V) and ammonium thiocyanate (4%, W/V) solutions, employing polar and non-polar solvents such as alcohols, ketones, and chloroform(Bhatnagar et al., 1977).Furthermore, PC has been utilized for the separation of Pb^{2+}, Cu^{2+}, Fe^{3+}, Fe^{2+}, Ni^{2+}, Co^{2+}& UO_3^{2+}cations using stannic phosphate impregnated paper (Qureshi et al., 1966), as well as for the separation of Mo(VI) and Mo(V) ions by Stevens as oxinates examined via UV spectroscopy(Stevens, 1956).Recent studies explored the separation and examination of various metal cations Ni^{2+}, and Cu^{2+}, Ag^{+}, Fe^{3+}, Co^{2+}, Cu^{2+}, and Hg^{2+}using PC, employing different eluting and developing solutions (Altig, 2023*;* Paper Chromatography pdf, 2023). NCERT Unit 5 provided insights into separating inorganic compounds, including Pb^{2+} and Cd^{2+} cations, via chromatographic methods (NCERT Unit 5 pdf, 2023). Additionally, Das (2017) and Nad et al. (2003) detailed the chromatographic separation and identification of Co^{2+}, Ni^{2+}, and Cu^{2+} ions, utilizing an ethanolic solution of rubeanic acid as a spraying reagent (Das, 2017; Nad, 2003). The p and d block elements play a vital structural and functional role, influencing function of enzymes and structures of biomolecules (Bhattacharjee et al. 2022; Adhikari et al. 2020; Singh et al. 2018; Nath et al. 2024). Thus, the easy methods of separation and identification of p and d block elements plays a critical role in chemistry.

In our own research (Das et al., 2023), we identified and separated metal ions such as (Pb^{2+} & Cu^{2+}), (Co^{2+} & Ni^{2+}), (Cu^{2+} & Fe^{3+}), and (Co^{2+} & Cu^{2+}) using different eluting agents including 10% aqueous KI solution, 5% NH_4OH solution, 1N aqueous solution of potassium ferrocyanide, and 10% NH_4OH solution, respectively. These experiments were further refined and supplemented with two new PC experiments in this study (Das et al., 2023).

Hence, in this work, green solvent like water is used as the universal mobile phase (developer) along with potassium ferrocyanide $K_4[Fe(CN)_6]$ as eluting agent during separation

of metal ions like (Fe^{3+} and Cr^{3+}), metal ions (Pb^{2+} & Cu^{2+}) are separated using 1% aqueous KI solution as the eluting solvent, (Co^{2+} & Ni^{2+}) group IV metal ions are separated using 4% NH_4OH solution as the spraying solvent, (Co^{2+} & Cu^{2+}) group (IV) and group (II) cations are separated using 6% NH_4OH solution as the eluting agent, group II and group III metal ions (Cu^{2+} & Fe^{3+}) with 1N aqueous solution of potassium ferrocyanide $K_4[Fe(CN)_6]$ as spraying agent, and aqueous solution of $CuCl_2$. $2H_2O$ is used as eluting agent during separation of (Mo^{6+} and W^{6+}) metal ions.

Paper Chromatography Experiment-1: Separation of Group III Metal ions (Fe^{3+} and Cr^{3+}) by 1(N) $K_4[Fe(CN)_6]$ Solution

Experimental

Required chemicals and apparatus

(i) Chromatography Jar, (ii) Measuring cylinder, (iii) Capillary, (iv) Tiny test tube, (v) Beakers (10 mL, 100 mL, and 500 mL), (vi) Grade 41 Whatman quantitative filter paper, (vii) Chromium (III) oxide, (viii) Ferric chloride, (ix) 1(N) $K_4[Fe(CN)_6]$ solution.

Required solution

(i) Solution of metal salts/oxide: To make a saturated solution, metal salts/oxide were dissolved in 1 mg/mL of distilled water in a 10 mL beaker. Metal salts/oxide: $FeCl_3$ & Cr_2O_3

(ii)Eluting agents used: 100 mL 1(N) $K_4[Fe(CN)_6]$ solution was prepared in a 250 mL beaker with distilled water

Green developer

500 mL distilled water is used as green developer.

Experimental procedure

A strip of Whatman 41 grade filter paper was carefully positioned inside the chromatographic jar, with a dot placed approximately 0.5 centimetres from the bottom as the starting point for development. Using fresh capillaries for each application, saturated solutions of metal salts/oxides were individually deposited onto two locations at the top of the chromatographic paper. Subsequently, the paper was left exposed to air to allow the spotted areas to dry. Once dry, the chromatographic paper strip was placed back into the chromatography jar filled with a green solvent (distilled water), with the bottom end submerged in the solvent and the upper end secured to a steel bar. The solvent (green developer) was allowed to ascend through the paper strip until it reached the uppermost portion. The movement of the solvent front was then marked using a pen upon removal of the chromatographic paper from the jar. Afterwards, the chromatographic paper strip was dried to remove any remaining developer. Eluting agents, as specified previously, were then applied over the dry filter paper using a sprayer. In the first paper chromatography experiment, the reaction with 1(N)

$K_4[Fe(CN)_6]$ produced one Prussian blue spot and one light brown spot, indicating the presence of Fe^{3+} and Cr^{3+}ions, respectively. Each distinct zone of color was carefully outlined with a pencil for reference.

Results and Analysis

Reactions Involved During Formation of Color Spots by Interaction with Solute Zone

In the chromatographic filter paper strip, berlin blue or Prussian blue colored spot appeared (Kawatake et al., 2012) due to the formation of $Fe_4[Fe(CN)_6]_3$, iron(III) hexacyanidoferrate(II), when metal salt, $FeCl_3$ was combined with eluting solvent 1(N) $K_4[Fe(CN)_6]$.

$$4\ FeCl_3 + 3\ K_4[Fe(CN)_6] \rightarrow Fe_4[Fe(CN)_6]_3 \downarrow + 12KCl$$

(**Prussian blue spot**)

$$2Cr^{3+} + K_4[Fe(CN)_6] \rightarrow \{Cr[Fe(CN)_5OH]\}^{-1} \downarrow + 2\ CN^-$$

(**Brown spot**)

Conversely, in the filter paper strip, Cr^{3+} ion combined with a 1(N) aqueous solution of $K_4[Fe(CN)_6]$ to generate $\{Cr[Fe(CN)_5OH]\}^{-1}$, a light brown coloring spot (Bembi et al., 1975).

Figure 1. Separation of transition metal ions (Fe^{3+} and Cr^{3+}) by PC

Data Analysis

By comparing the retention factor values and observing the color spots of the two cations, (Fe^{3+} and Cr^{3+}), clear distinctions between them were made. The first spot, appearing as prussian blue, was attributed to the formation of $Fe_4[Fe(CN)_6]_3$. The distance travelled by the solute zone of Fe^{3+} (ds_1) was determined by the reaction between FeCl3 and an aqueous solution of 1 (N) $K_4[Fe(CN)_6]$. The second spot, representing Cr^{3+}, emerged as light brown due to the formation of $\{Cr[Fe(CN)_5OH]\}^{-1}$, formed from the reaction of Cr^{3+} in Cr_2O_3 with an aqueous solution of 1 (N) $K_4[Fe(CN)_6]$, indicating the distance travelled by another solute zone

(ds_2). Retention factors (R_f), or retardation factors, were then calculated (see Table-1). By comparing the color spots and Rf values, the two cations (Fe^{3+} and Cr^{3+}) were successfully identified and distinguished from one another.

$$\text{Retardation factor } (R_f) = \frac{\text{The solute zone center's travel distance in cm (ds)}}{\text{The solvent front's transit distance in cm (dm)}}$$

Paper Chromatography Experiment-2: Separation of Group II Metal ions (Pb^{2+} and Cu^{2+}) by 1% KI Solution

Experimental

Required chemicals and apparatus

(i) Jar for chromatography, (ii) Measuring cylinder, (iii) Capillary, (iv) Tiny test tube, (v) Beakers (10 mL, 100 mL, and 500 mL), (vi) Grade 41 Whatman quantitative filter paper, (vii) Lead nitrate, (viii) Copper sulfate, (ix) 1% KI solution

Required solution

(i) Solution of metal salts: To make a saturated solution, metal salts were dissolved in 1 mg/mL of distilled water in a 10 mL beaker. Metal salts: $Pb(NO_3)_2$ & $CuSO_4.5H_2O$

(ii) Eluting agents used:1% KI solution was prepared in a 100 mL beaker with distilled water

Green developer

500 mL distilled water is used as green developer.

Experimental procedure

A strip of Whatman 41 grade filter paper was positioned inside the chromatographic jar, with a dot placed approximately 0.5 centimetres from the bottom as the starting point for development. Saturated solutions of metal salts/oxides were carefully applied at two distinct locations near the top of the paper strip, each time using a fresh capillary. Once the spots were applied, the chromatographic paper was left outside to dry. Subsequently, the dried paper strip was suspended in the chromatography jar filled with green solvent (distilled water), ensuring the bottom end made contact with the solvent while the upper end was attached to a steel bar (Figure 2a). The green solvent was allowed to ascend through the paper strip until it reached the top, indicating the solvent front, which was marked with a pen upon removal from the jar (Figure 2b). Afterwards, the chromatographic paper was dried to remove excess solvent. Eluting agents, as specified, were sprayed onto the dry filter paper. In PC experiment 2, distinct brown and yellow spots emerged immediately upon reaction with 1% KI solution (Figure 2c), indicating the presence of Pb^{2+} and Cu^{2+} ions, respectively. These colorful zones were carefully marked with a pencil for identification.

Figure 2. Cu^{2+} and Pb^{2+} separation using paper chromatography by 1% KI solution

Results and Analysis

Reactions Involved During Formation of Color Spots by Interaction with Solute Zone

When 1% KI reacted with the metal salt $CuSO_4.5H_2O$solution, a distinctive brown spot appeared on the chromatographic paper due to a redox reaction. In this chemical interaction, $CuSO_4$ interacted with KI, leading to the conversion of Cu(II) ions into Cu(I) ions through the action of I^- ions. Simultaneously, the I- ions themselves were oxidized into I_2. Since I_2 is volatile, it quickly vaporized, leaving behind a zone where Cu^{2+} ions (the solute) reacted with potassium iodide. This phenomenon was promptly noticed, and a pen mark was made on the brown-colored spot for easy identification.

But lead nitrate [$Pb(NO_3)_2$] and potassium iodide (KI) combined to create an ion exchange that produced potassium nitrate (KNO_3) and a yellow-colored lead iodide spot (PbI_2).

$$2CuSO_4\ (aq) + 4KI\ (aq) \rightarrow 2Cu_2I_2 + I_2 + 2K_2SO_4$$

(Brown spot)

$$Pb(NO_3)_2\ (aq) + 2KI\ (aq) \rightarrow PbI_2(s)\ (\downarrow) + 2KNO_3(aq)$$

(Yellow spot)

Data Analysis

By comparing the color spots and their respective retardation factors, two distinct cations were identified and differentiated from each other. The metal cations were determined by examining the colorful patches that matched these two distinct cations. Following the release of I_2 due to the reaction of KI with $CuSO_4$, the first spot exhibited a brown hue. The travel distance of one solute zone, represented by Cu^{2+} (ds_1), and another solute zone, represented by Pb^{2+} (ds_2), were measured. Additionally, in each experiment, the solvent's travel distance (dm) was calculated by measuring the separation between the starting line and the solvent front

(water). Subsequently, the values of retardation factors (R_f) were computed, as detailed in Table-1.

Paper Chromatography Experiment-3: Separation of Group IV Metal ions (Ni^{2+} and Co^{2+}) by 4% NH_4OH Solution

Experimental

Required chemicals and apparatus

(i) Jar for chromatography, (ii) Measuring cylinder, (iii) Capillary, (iv) Tiny test tube, (v) Beakers (10 mL, 100 mL, and 500 mL), (vi) Grade 41 Whatman quantitative filter paper, (vii) Nickel nitrate, (viii) Cobalt nitrate, (ix) 4% NH_4OH solution.

Required solution

(i) Solution of metal salts: To make a saturated solution, metal salts were dissolved in 1 mg/mL of distilled water in a 10 mL beaker. Metal salts: $Ni(NO_3)_2.6H_2O$ & $Co(NO_3)_2.6H_2O$.

(ii) Eluting agents used: 4% NH_4OH solution was prepared in a 100 mL beaker with distilled water.

Green developer

500 mL distilled water is used as green developer.

Experimental procedure

A Whatman 41 grade filter paper strip was positioned inside the chromatographic jar, with a dot placed approximately 0.5 centimetres from the bottom as the starting point for development. Saturated solutions of metal salts/oxides were separately administered using fresh capillaries at two locations near the top of the chromatographic paper. Afterwards, the chromatographic paper containing the metal spots was left to dry outside. Once dried, the spotted paper strip was suspended again in the chromatography jar filled with green solvent (distilled water), with the bottom end submerged in the solvent and the upper end secured to a steel bar. The green solvent, acting as the developer, was allowed to ascend through the paper strip until it reached the topmost portion, indicating the solvent front. Upon removal from the chromatography jar, the solvent front was marked using a pen for reference. The chromatographic paper strip was then dehydrated to remove excess solvent. Following this, eluting agents, as specified, were sprayed over the dry filter paper. In PC experiment 3, the reaction with 4% NH_4OH resulted in the immediate emergence of green gel coloration and bluish-green coloration spots, indicating the presence of Ni^{2+} and Co^{2+} ions, respectively (Figure 3c). Initially, 1-2% NH_4OH solution was used, but the results for Ni^{2+} were not satisfactory. However, with 3% NH_4OH, color spots were obtained for both metal ions, although the intensity of the Ni^{2+}color spot was not very prominent (Figure 4). All colorful zones were carefully marked with a pencil for identification purposes.

Figure 3. Ni^{2+} and Co^{2+} separation using paper chromatography by 4% NH_4OH solution

Figure 4. Ni^{2+} and Co^{2+} separation using paper chromatography by 3% NH_4OH solution

Results and Analysis

Reactions Involved During Formation of Color Spots by Interaction with Solute Zone

Green gel and bluish green spots on the filter paper are the result of mixing nickel and cobalt nitrate solutions with 4% NH_4OH solution to create metal (II) hydroxide (The University of Colorado pdf, 2023).

$Ni^{2+} + NH_4OH \rightarrow Ni(OH)_2(s) \downarrow$

(Green gel spot)

$Co^{2+} + NH_4OH \rightarrow Co(OH)_2(s) \downarrow$

(Bluish green spot)

Data Analysis

By comparing their color spots and retention factor values, two cations, Co(II) and Ni(II), were distinguished from one another. When 4% NH_4OH solution reacted with $Ni(NO_3)_2.6H_2O$, nickel (II) hydroxide $Ni(OH)_2$ formed, resulting in the first spot appearing as green gel. On the other hand, when $Co(NO_3)_2.6H_2O$ reacted with a 4% NH_4OH solution, Co(OH)2 was produced, giving rise to the appearance of the second spot (Co2+) as bluish green. The travel distance of one solute zone, represented by Ni^{2+} (ds_3), and the travel distance of another solute zone, represented by Co^{2+} (ds_4), were measured. Subsequently, the values of retention factors (R_f) were calculated, as detailed in Table-1.

Paper Chromatography Experiment-4: Separation of Group IV and Group II Metal ions (Co^{2+} and Cu^{2+}) by 6% NH_4OH Solution.

Experimental

Required chemicals and apparatus

(i) Jar for chromatography, (ii) Measuring cylinder, (iii) Capillary, (iv) Tiny test tube, (v) Beakers (10 mL, 100 mL, and 500 mL), (vi) Grade 41 Whatman quantitative filter paper, (vii) Copper sulfate, (viii) Cobalt nitrate, (ix) 6% NH_4OH solution.

Required solution

(i) Solution of metal salts: To make a saturated solution, metal salts were dissolved in 1 mg/mL of distilled water in a 10 mL beaker. Metal salts: $Co(NO_3)_2.6H_2O$ & $CuSO_4.5H_2O$.

(ii)Eluting agents used: 6% NH_4OH Solution was prepared in a 100 mL beaker with distilled water.

Green developer

500 mL distilled water is used as green developer.

Experimental procedure

A strip of Whatman 41 grade filter paper was carefully placed inside the chromatographic jar, with a dot positioned approximately 0.5 centimetres from the bottom, serving as the starting point for development. Saturated solutions of metal salts/oxides were applied independently at two locations near the top of the chromatographic paper using fresh capillaries for each application. Subsequently, the chromatographic paper containing the two metal spots was left to dry externally. Once dried, the spotted paper strip was repositioned in the chromatography jar, submerged in green solvent (distilled water), with the bottom end in contact with the solvent and the upper end secured to a steel bar. The green solvent, acting as the developer, ascended through the paper strip until it reached the topmost portion, indicating the solvent front. After removal from the chromatography jar, the solvent front was marked using a pen for reference. The chromatographic paper strip was then dehydrated to remove excess developer. Following

this, eluting agents, as specified, were sprayed over the dry filter paper. In PC experiment 4, upon reaction with 6% NH_4OH, a green and blue spot instantaneously appeared (Figure 5c), indicating the detection of Co^{2+} and Cu^{2+} ions, respectively. All colorful zones were marked with pencil for identification purposes.

Figure 5. Co^{2+} and Cu^{2+} separation using paper chromatography by 6% NH_4OH solution

Results and Analysis

Reactions Involved During Formation of Color Spots by Interaction with Solute Zone

When a metal salt reacts with a 6% NH_4OH solution, it produces copper (II) hydroxide $Cu(OH)_2$, resulting in a distinct blue stain on the Whatman filter paper (Kawatake et al., 2012). This stands in contrast to the blue-green $Co(OH)_2$ formation from the reaction of Co(II) nitrate with a 4% NH_4OH solution (PC experiment 3). Instead, when Co(II) nitrate combines with a 6% NH_4OH solution, it forms green-colored spots due to the production of Co(III) hydroxide or $Co(OH)_3$.Typically, cobalt(II) salts exhibit stability; however, in basic solutions such as a 6% NH4OH solution, cobalt(II) readily transforms into cobalt(III). The basic nature of the reaction medium increases with higher NH_4OH solution concentrations (from 4% to 6%), leading to relatively rapid air oxidation of Co(II) to Co(III) (Kavitha et al., 2018; Clark, 2023; Adhikari et al. 2023). Consequently, the oxidation of bluish-green cobalt(II) hydroxide to cobalt(III) hydroxide results in the appearance of a green-colored spot. This phenomenon was further confirmed by spot testing $Co(NO_3)_2.6H_2O$ solution with separate solutions of 4% and 6% NH_4OH using Whatman chromatography paper (Figure 6). When cobalt (II) nitrate solution was spot tested with 4% NH_4OH, a blue-green color was observed (Figure 6b Left), while the addition of 6% NH_4OH resulted in immediate development of a green color (Figure 6b Right).

Co^{2+} + 6% NH_4OH → $Co(OH)_3$ (s) ↓

(Green spot)

Cu^{2+} + 6% NH_4OH → $Cu(OH)_2$(s) ↓

(Blue spot)

The green spot underwent FT-IR analysis using a Bruker Alpha II model spectrometer, which operated in the range of 4000–400 cm^{-1}. In cobalt(III) hydroxide, the hydroxyl group typically exhibits stretching and bending vibrations in the infrared region. A bending vibration is observed around 1638 cm^{-1}, while the broad band for the -OH stretching vibration is typically found within the range of 3490–3499 cm^{-1} (The Nature Vibrational Spectroscopy Webpage, 2023). These vibrational modes confirm the presence of hydroxyl groups in cobalt(III) hydroxide. The infrared spectrum also revealed the presence of the Co-O bond, which typically exhibits frequencies in the range of 400–600 cm^{-1}. However, in the green spot, the IR band corresponding to the Co-O bond was observed at 647 cm^{-1} (Figure 7). This higher frequency suggests a stronger Co-O bond, characteristic of higher oxidation states of cobalt atoms (+3 or +4) (Andris et al., 2019). In higher oxidation states, there is a positive shift in the IR frequency of the cobalt-oxygen bond due to the increased strength of the metal-oxygen bond. Therefore, the observed IR frequency of the cobalt-oxygen linkage at 647 cm^{-1} supports the presence of cobalt in the +3 oxidation state in cobalt(III) hydroxide, consistent with the green color of the spot.

Figure 6. $Co(NO_3)_2.6H_2O$ spot detection within the Whatman chromatography strip (a) prior to and (b) with the addition of 4% and 6% NH_4OH solution

Data Analysis

The color spots and retention factor values of two cations, Co^{2+} and Cu^{2+}, were compared to identify and distinguish them. The first spot turned green due to the reaction between $Co(NO_3)_2.6H_2O$ and a 6% NH_4OH solution, resulting in the formation of cobalt(III) hydroxide $Co(OH)_3$. Cobalt(II), being easily oxidized to cobalt(III) in a basic medium, travelled a distance indicated by (ds_7). On the other hand, the second spot (Cu^{2+}) appeared blue as a result of the

reaction between $CuSO_4.5H_2O$ and a 6% NH4OH solution, leading to the production of copper(II) hydroxide $Cu(OH)_2$. Cu^{2+}, representing the other solute zone, travelled a distance indicated by (ds_8). Subsequently, we calculated the retardation factors (R_f), as summarized in Table-1. This comparison of color spots and R_f values facilitated the clear identification and differentiation of the Co^{2+} and Cu^{2+}ions.

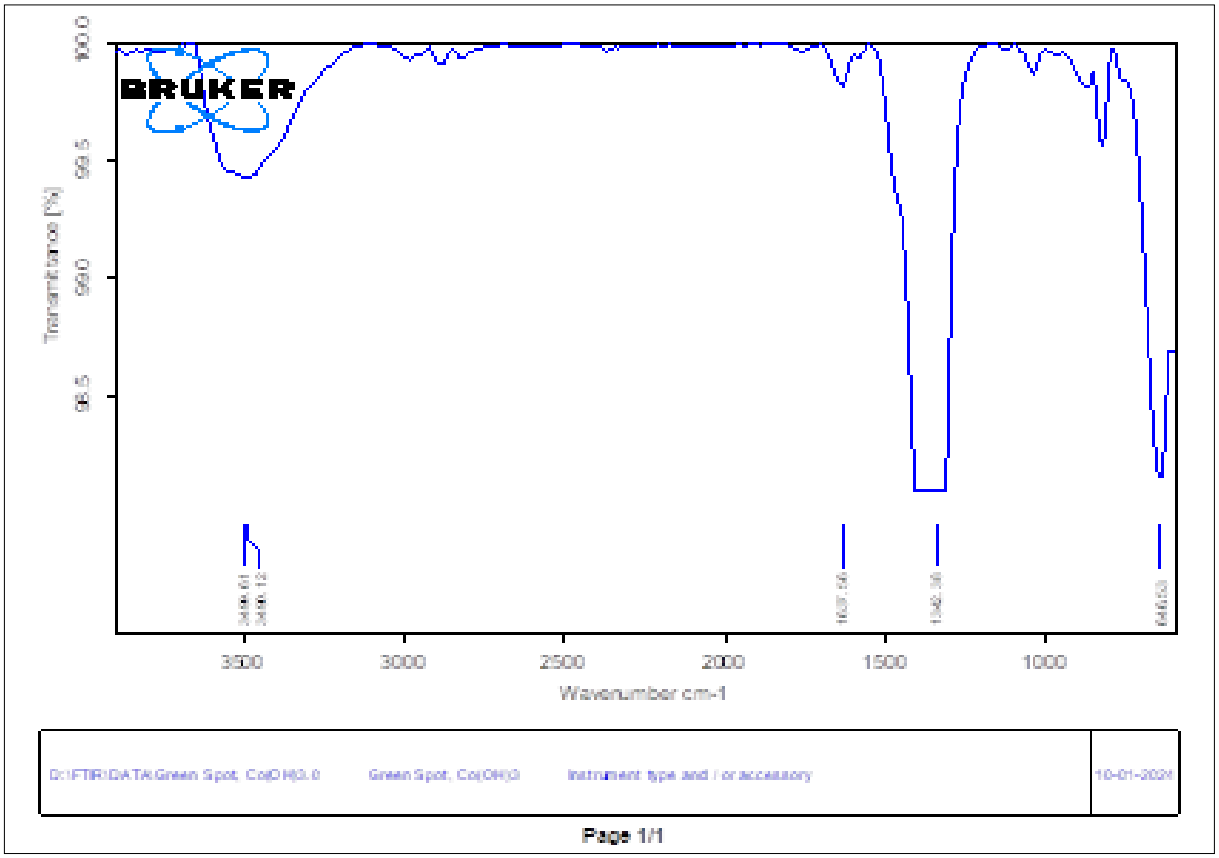


Figure 7. IR spectrum of green ppt of $Co(OH)_3$

Paper Chromatography Experiment-5: Separation of Group II and Group III Metal ions (Cu^{2+} and Fe^{3+}) by 1(N) $K_4[Fe(CN)_6]$ Solution

Experimental

Required chemicals and apparatus

(i) Chromatographic jar, (ii) Spraying bottle, (iii) 100 mL, 1N aqueous solution of potassium ferrocyanide, $K_4[Fe(CN)_6]$, (iv) Ferric chloride, $FeCl_3$, (v) Copper sulfate pentahydrate, $CuSO_4.5H_2O$, (vi) Spotting capillaries, (vii) Small test tubes, (viii) 100 mL Measuring cylinder, (ix) 10 mL, 250 mL beaker,(x) Whatman quantitative filter paper grade 41, (xi) Distilled water

Required solution

(i) Metal salts solution: Prepared saturated solution of ferric chloride and copper sulfate by dissolving them in distilled water (1mg/mL**)** in the 10ml beaker.

(ii) Eluting solution: Prepared 100 mL, 1N aqueous solution of potassium ferrocyanide $K_4[Fe(CN)_6]$ in the 250 mL beaker.

Green developer

500 mL distilled water is used as green developer.

Experimental procedure

A strip of Whatman grade 41 filter paper was suspended in the chromatographic jar, with a dot placed about 1 centimeter from the bottom, serving as the starting point for development. Using separate capillaries, saturated solutions of Fe^{3+} and Cu^{2+} were individually applied to the filter paper at two distinct locations, ensuring each solution was administered with a fresh capillary. After spotting, the filter paper with the two spots was left to dry outside. Once dried, the spotted filter paper strip was re-suspended in the chromatography jar filled with distilled water. The lower end made contact with the developer (water), while the upper end was pinned to a steel rod. The strip was positioned vertically, ensuring the point was always above the level of the developer, allowing the water to rise along the filter paper. As the water ascended, carrying the metal ions, the solvent front approached the upper end of the filter paper. After removing the filter paper from the chromatography jar, the solvent front was marked using a pen. The paper was then dried to remove the developer. Subsequently, potassium ferrocyanide 1N aqueous solution was used as an eluting or spraying reagent. It was applied to the dry filter paper using a sprayer. Upon interaction with the aqueous solution of $K_4[Fe(CN)_6]$, prussian blue and reddish-brown spots appeared immediately (Figure 8c), indicating the identification of Fe^{3+} and Cu^{2+} ions, respectively. Colored zones were indicated using a pen for clear identification.

Results and Analysis

Reactions Involved During Formation of Color Spots by Interaction with Solute Zone

When ferric chloride solution was mixed with 1N aqueous solution of $K_4[Fe(CN)_6]$, it resulted in the formation of a Prussian blue or Berlin blue coloration spot, corresponding to iron(III)hexacyanidoferrate(II), $Fe_4[Fe(CN)_6]_3$, on the Whatman grade 41 filter paper strip. Conversely, when copper sulfate reacted with 1N aqueous solution of $K_4[Fe(CN)_6]$, it led to the formation of a reddish-brown coloration spot, representing cupric ferrocyanide, $Cu_2[Fe(CN)_6]$, on the filter paper strip.

$$4\ FeCl_3 + 3\ K_4[Fe(CN)_6] \rightarrow Fe_4[Fe(CN)_6]_3 \downarrow + 12KCl$$

(Prussian blue spot)

$$2CuSO_4 + K_4[Fe(CN)_6] \rightarrow Cu_2[Fe(CN)_6] \downarrow + 2\ K_2SO_4$$

(Reddish brown spot)

Data Analysis

The colored spots corresponding to two different cations, (Cu^{2+} and Fe^{3+}), were observed and analyzed. By comparing their color spots and retention factor values, both cations were identified

and separated successfully. The first spot appeared as prussian blue, indicating the formation of iron(III)hexacyanidoferrate(II), $Fe_4[Fe(CN)_6]_3$. This spot represented the distance travelled by one solute zone, identified as Fe3+ (ds_9). Conversely, the second spot for Cu^{2+} appeared as reddish brown, indicating the formation of cupric ferrocyanide, $Cu_2[Fe(CN)_6]$. This spot represented the distance travelled by another solute zone, Cu^{2+} (ds_{10}). Subsequently, the retardation factors or retention factors (R_f) values were calculated and summarized in Table 1. This comparison facilitated the clear identification and separation of Cu^{2+} and Fe^{3+} ions.

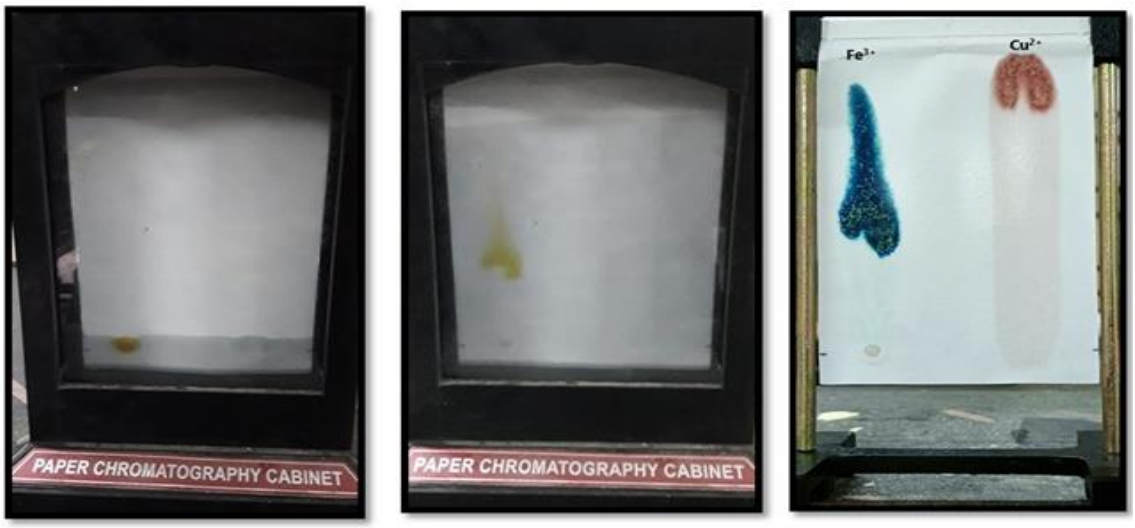


Figure 8. Separation of metal ions (Fe^{3+} and Cu^{2+}) by paper chromatography by using 1N aqueous $K_4[Fe(CN)_6].3H_2O$ solution

Paper Chromatography Experiment-6: Separation of Group VI Metal ions (Mo^{6+} and W^{6+}) by 1(N) $CuCl_2$. $2H_2O$ Solution

Experimental

Required chemicals and apparatus

(i) Jar for chromatography, (ii) Measuring cylinder, (iii) Capillary, (iv) Tiny test tube, (v) Beakers (10 mL, 100 mL, and 500 mL), (vi) Grade 41 Whatman quantitative filter paper, (vii) Sodium molybdate, (viii) Sodium tungstate, (ix) 1(N) $CuCl_2$. $2H_2O$ solution.

Required solution

(i) Solution of metal salts: To make a saturated solution, metal salts were dissolved in 1 mg/mL of distilled water in a 10 mL beaker. Metal salts: Na_2MoO_4. $2H_2O$ & Na_2WO_4. $2H_2O$

(ii) Eluting agents used:100 mL 1(N) copper (II) chloride solution was prepared in a 250 mL beaker with distilled water.

Green developer

500 mL distilled water is used as green developer.

Experimental procedure

A Whatman 41 grade filter paper strip was positioned inside the chromatographic jar, with a dot placed approximately 0.5 centimetres from the bottom, serving as the starting point for development. Saturated solutions of metal salts/oxides were individually administered using fresh capillaries at two locations near the top of the chromatographic paper. Subsequently, the chromatographic paper containing the two metal spots was left to dry outside. Once dried, the spotted paper strip was re-suspended in the chromatography jar filled with green solvent (distilled water). The bottom end made contact with the solvent, while the upper end was fastened to a steel bar. As the green solvent ascended through the paper strip, carrying the metal ions, it reached the topmost portion of the paper strip. Upon removal from the chromatography jar, the solvent front was marked using a pen. The paper strip was then dehydrated to remove excess solvent. Following this, eluting agents as specified were sprayed over the dry filter paper. In PC experiment 5, upon reaction with 1N copper (II) chloride $CuCl_2$ solution, a green coloration and a light sky-blue coloration spot emerged immediately (Figure 9c), indicating the identification of Mo^{6+} and W^{6+} ions, respectively. All colorful zones were marked with pencil for identification purposes.

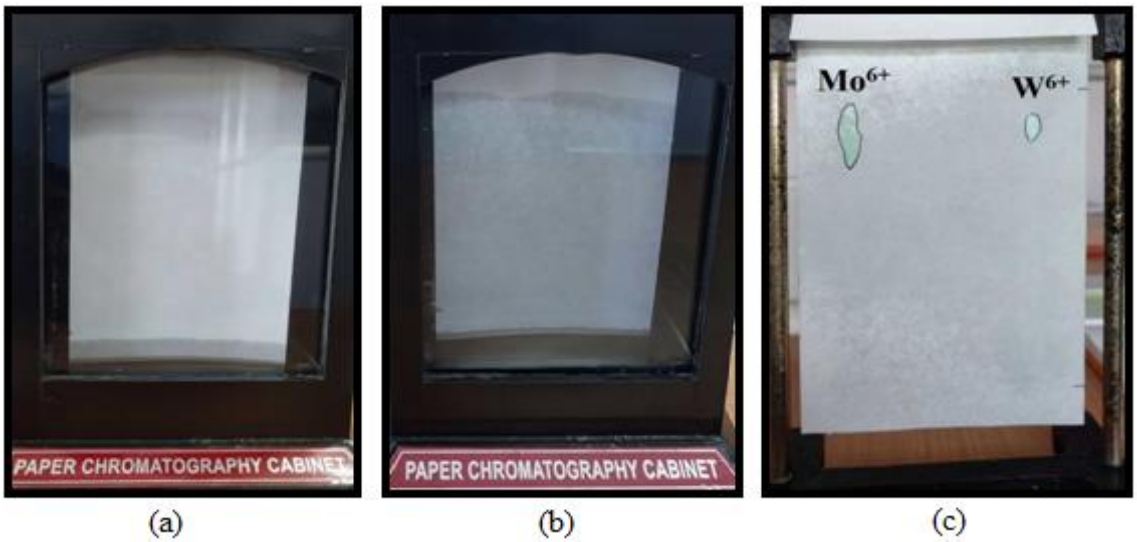


Figure 9. Separation of transition metal ions (Mo^{6+} and W^{6+}) by PC

Results and Analysis

Reactions Involved During Formation of Color Spots by Interaction with Solute Zone

Green and light sky-blue coloration spots on the filter paper are the result of mixing sodium molybdate, $Na_2MoO_4.\ 2H_2O$ and sodium tungstate, $Na_2WO_4.\ 2H_2O$ with copper (II) chloride $CuCl_2$ solution to create $CuMoO_4$ and $CuWO_4$ respectively (Science madness Discussion Board, 2007; Tan et al., 2020; Unadkat et al., 2020; Kannan et al., 2017).

$CuCl_2 + Na_2MoO_4 \rightarrow CuMoO_4\downarrow +2\ NaCl$

(Green spot)

$CuCl_2 + Na_2WO_4 \rightarrow CuWO_4\downarrow +2\ NaCl$

(Sky Blue spot)

Data Analysis

By contrasting their color spots and retention factor values, two cations, Mo(VI) and W(VI), were recognized and distinguished from each other. When the aqueous solution of copper (II) chloride reacted with sodium molybdate ($Na_2MoO_4.\ 2H_2O$), cupric molybdate ($CuMoO_4$) was formed, resulting in the emergence of the first spot as green (Mo^{6+}). On the other hand, when sodium tungstate ($Na_2WO_4.\ 2H_2O$) reacted with the aqueous solution of copper (II) chloride, $CuWO_4$ was produced, giving rise to the appearance of the second spot (W^{6+}) as light sky blue. The travel distance of one solute zone represented by Mo^{6+} (ds_{11}), and the travel distance of another solute zone represented by W^{6+} (ds_{12}) were measured. Subsequently, the values of retardation factors (R_f) were calculated and summarized in Table-1. This comparison facilitated the clear identification and differentiation of Mo(VI) and W(VI) ions.

Safety Hazards

To ensure the safe handling of corrosive and hazardous chemicals, it is imperative to advise students to wear appropriate eye protection, such as chemical splash goggles, along with disposable latex gloves to protect the skin. Additionally, a face shield should be worn to provide extra protection. Given the hazardous nature of NH_4OH, precautions should be taken to minimize risks. One such measure is to dilute the concentration of the eluting agent NH_4OH with water. Water is less toxic and less volatile, reducing the potential for harm. Furthermore, to enhance safety precautions, the dilution of NH_4OH should ideally be carried out under a fume hood to minimize exposure to harmful vapors. This approach ensures the safety of students and minimizes the risks associated with handling corrosive chemicals.

Evaluation of Learning Outcomes

Two groups of second-year undergraduate students, totalling 20 individuals, conducted a series of six experiments in the inorganic chemistry laboratory at Bir Bikram Memorial College. These experiments focused on the identification and separation of metal ions using paper chromatography, aiming to achieve specific learning objectives: i. Help students comprehend the fundamentals of paper chromatography, ii. Describe the factors influencing the

separation of metal ions using paper chromatography, iii. Utilize chromatogram interpretation to locate and analyze metal ions, iv. Establish connections between color patches and metal ion properties, v. Compare the qualitative separation of various metal ions using Rf values, vi. Identify and address common issues encountered during chromatographic procedures, vii. Evaluate the accuracy and reliability of experimental findings, viii. Present findings clearly and succinctly, ix. Emphasize caution when handling chemicals and scientific equipment. The sele-

Table 1: Metal ions separation and identification using paper chromatography

Experiment Number	Metal salt/oxide (Cation Present)	Eluting agent	Color spots	Distance travelled by solutes (ds in cm)	Distance travelled by mobile phase (dm in cm)	R_f value = ds/dm
1	$FeCl_3$ (Fe^{3+})	1(N) solution of $K_4[Fe(CN)_6].3H_2O$ (aq)	Prussian blue	10.7 (ds_1)	13.5	0.79
	Cr_2O_3 (Cr^{3+})		Light brown	11.8 (ds_2)	13.5	0.87
2	$CuSO_4.5H_2O$ (Cu^{2+})	1% KI solution (aq)	Brown	12.8 (ds_1)	14	0.91
	$Pb(NO_3)_2$ (Pb^{2+})		Yellow	11.6 (ds_2)	14	0.83
3	$Ni(NO_3)_2.6H_2O$ (Ni^{2+})	4% NH_4OH solution (aq)	Green gel	12.4 (ds_3)	15.0	0.82
	$Co(NO_3)_2.6H_2O$ (Co^{2+})		Bluish green	12.8 (ds_4)	15.0	0.85
4	$Co(NO_3)_2.6H_2O$ (Co^{2+})	6% NH_4OH solution (aq)	Green	12.1 (ds_7)	14.2	0.85
	$CuSO_4.5H_2O$ (Cu^{2+})		Blue	13.2 (ds_8)	14.2	0.93
5	$FeCl_3$ (Fe^{3+} ion)	1(N) solution of $K_4[Fe(CN)_6].3H_2O$ (aq)	Prussian blue	13.2 (ds_9)	15.8	0.835
	$CuSO_4.5H_2O$ (Cu^{2+} ion)		Reddish brown	14.3 (ds_{10})	15.8	0.905

6	$Na_2MoO_4.2H_2O$ (Mo^{6+})	1N solution of $CuCl_2.2H_2O$ (aq)	Green	12.5 (ds_{11})	13.1	0.95
	$Na_2WO_4.2H_2O$(W^{6+})		Light sky blue	11.7 (ds_{12})	13.1	0.89

-arning objectives cater to a comprehensive understanding of metal ion identification and separation through paper chromatography, encompassing critical thinking, practical skills, and theoretical understanding. When comparing the experimental R_f values with the student average R_f values shown in Table 2, the largest difference observed was 0.06. Post-lab questions related to chromatography theory were answered correctly by students with a 90% accuracy rate, and metal ions were identified correctly 85% of the time. According to survey responses, students expressed satisfaction with the experiments, rating them 9 out of 10 and finding them interesting to perform. They also indicated a willingness to recommend the lab to others, suggesting a positive learning experience overall.

Table 2. Comparison of the student average R_f values with our experimental R_f values

Experiment Number (Cations present)	Experimental R_f value	Student's R_f averages	Difference
1 (Fe^{3+}& Cr^{3+})	Fe^{3+} - 0.79 Cr^{3+} - 0.87	Fe^{3+} - 0.81 Cr^{3+} - 0.92	Fe^{3+} - (+ 0.02) Cr^{3+} - (+ 0.05)
2 (Cu^{2+}& Pb^{2+})	Cu^{2+} - 0.91 Pb^{2+} - 0.83	Cu^{2+} - 0.92 Pb^{2+} - 0.87	Cu^{2+} - (+ 0.01) Pb^{2+} - (+ 0.04)
3 (Ni^{2+}& Co^{2+})	Ni^{2+} - 0.82 Co^{2+}- 0.85	Ni^{2+} - 0.80 Co^{2+} - 0.83	Ni^{2+} - (− 0.02) Co^{2+} - (− 0.02)
4 (Co^{2+}& Cu^{2+})	Co^{2+} - 0.85 Cu^{2+} - 0.93	Co^{2+} - 0.84 Cu^{2+} - 0.87	Co^{2+} - (− 0.01) Cu^{2+} - (− 0.06)
5 (Cu^{2+}& Fe^{3+})	Cu^{2+} - 0.83 Fe^{3+} -0.90	Cu^{2+} - 0.85 Fe^{3+} -0.89	Cu^{2+} - (+ 0.02) Fe^{3+}- (− 0.01)
6 (Mo^{6+}& W^{6+})	Mo^{6+} - 0.95 W^{6+}- 0.89	Mo^{6+} - 0.91 W^{6+} - 0.86	Mo^{6+} - (−0.04) W^{6+}- (−0.03)

Conclusions

The separation and identification of metal ions [(Fe^{3+}, Cr^{3+}), (Pb^{2+} & Cu^{2+}), (Ni^{2+} & Co^{2+}), (Co^{2+} & Cu^{2+}), (Cu^{2+} & Fe^{3+}), and (Mo^{6+}, W^{6+})] were conducted using water as the mobile phase (green developer) in paper chromatography. Various eluting agents such as aqueous solution of 1N $K_4[Fe(CN)_6]$, aqueous solution of 1% KI, 4% NH_4OH, 6% NH_4OH, aqueous solution of 1N $K_4[Fe(CN)_6]$, and 1N $CuCl_2$ solution were employed. Through these improved qualitative analysis techniques, undergraduate students can effectively utilize paper chromatography (PC) to separate and identify different transition metal ions like [(Fe^{3+}, Cr^{3+}), (Pb^{2+} & Cu^{2+}), (Ni^{2+} & Co^{2+}), (Co^{2+} & Cu^{2+}), (Cu^{2+} & Fe^{3+}), and (Mo^{6+}, W^{6+})] in the analytical table. This approach facilitates hands-on learning and enhances understanding of transition metal ion separation and identification processes.

References:

Adhikari, S., Bhattacharjee, T., Nath, P., Das, A., Jasinski, J. P., Butcher, R. J., & Maiti, D. (2020). Bimetallic and trimetallic Cd (II) and Hg (II) mixed-ligand complexes with 1, 1-dicyanoethylene-2, 2-dithiolate and polyamines: Synthesis, crystal structure, Hirshfeld surface analysis, and antimicrobial study. *InorganicaChimica Acta*, *512*, 119877.https://doi.org/10.1016/j.ica.2020.119877

Adhikari, S., Sheikh, A. H., Kansız, S., Dege, N., Baildya, N., Mahmoudi, G., ... &Kłak, J. (2023). Supramolecular Co (II) complexes based on dithiolate and dicarboxylate ligands: Crystal structures, theoretical studies, magnetic properties, and catalytic activity studies in photocatalytic hydrogen evolution. *Journal of Molecular Structure*, *1285*, 135481.https://doi.org/10.1016/j.molstruc.2023.135481

Altig, J. CHEM 121 L. Section 1, Partner: Mr. Magoo, Paper chromatography of a Metal cation *Mixture*, PDF file, Available at (https://www.nmt.edu/academics/chemistry/people/jaltig/docs/ModelChromReport.pdf), 2009 (accessed Dec 08, **2023**).

Andris, E., Navrátil, R., Jašík, J., Srnec, M., Rodríguez, M., Costas, M., &Roithová, J. (2019). M− O Bonding Beyond the Oxo Wall: Spectroscopy and Reactivity of Cobalt (III)-Oxyl and Cobalt (III)-Oxo Complexes. *AngewandteChemie International Edition*, , 58(28), 9619-9624. https://doi.org/10.1002/ange.201904546.

Bembi, R., & Malik, W. U. (1975). Reaction of Cr (III) with Potassium Hexacyanoferrate (II). *Zeitschrift für PhysikalischeChemie*, 256(1), 865-869. https://doi.org/10.1515/zpch-1975-256108.

Berg, E. W., & Strassner, J. E. (1955). Paper Chromatography of Cobalt (III), Copper (II), and Nickel (II) Acetylacetonates. *Analytical Chemistry*,27(1), 127-129. https://doi.org/10.1021/ac60097a041.

Bhatnagar, R. P., & Bhatnagar, N. P. (1977). Mechanism of Paper Chromatography of Inorganic Ions on Impregnated Papers: Separation of Ag (I), Cu (II), Ni (II), Co (II), Hg

(II), Pb (II) & Fe (III). *Indian Journal of Chemistry*, 15(A), 1089-1091. https://nopr.niscpr.res.in/bitstream/123456789/53344/1/IJCA%2015A%2812%29%201089-1091.pdf.

Bhattacharjee, T., Adhikari, S., Sheikh, A. H., Mahmoudi, G., Mlowe, S., Akerman, M. P., ... &Saygideger, Y. (2022). Syntheses, crystal structures, theoretical studies, and anticancer properties of an unsymmetrical schiff base ligand N-2-(6-methylpyridyl)-2-hydroxy-1-naphthaldimine and its Ni (II) complex. *Journal of Molecular Structure*, *1269*, 133717.https://doi.org/10.1016/j.molstruc.2022.133717

Birdwhistell, K. R., & Spence, T. G. (2002). A New Glow on the Chromatography of M&M candies. *Journal of Chemical Education*, 79(7), 847. https://doi.org/10.1021/ed079p847.

Clark, J., Chemistry of cobalt. Available at (chem.libretexts.org)., https://chem.libretexts.org/Bookshelves/Inorganic_Chemistry/Supplemental_Modules_and_Websites_(Inorganic_Chemistry)/Descriptive_Chemistry/Elements_Organized_by_Block/3_d-Block_Elements/Group_09%3A_Transition_Metals/Chemistry_of_Cobalt(University of California, Davis, US), (accessed Dec 08, **2023**).

Das, A., Sharma, D., Debnath, P., & Paul, B. (2023). Metal Ions Separation Via Paper Chromatography: Enhanced Methods Using Eluting Solutions, *World Journal of Chemistry Education*, 11(4), 134-140. https://pubs.sciepub.com/wjce/11/4/2/index.html.

Das, S.C. (2017). "*Advanced Practical Chemistry*," 6th Edition, , 417-419, ISBN:81-901944-0-2.

Fowden, L. (1951). The quantitative recovery and colorimetric estimation of amino-acids separated by paper chromatography. *Biochemical Journal*, 48(3), 327. https://doi.org/10.1042/bj0480327.

Kannan, S., Mohanraj, K., & Siva Kumar, G. (2017). Effect of Annealing on the Preparation of $CuWO_4$ Particles. *Juniper Online Journal Material Science*, 2(1), 555577.https://doi.org/10.19080/JOJMS.2017.02.555577.

Kavitha, K. (2018). Effect of ammonia on the redox reaction of cobalt(II) with potassium ferricyanide in alkaline medium. *International Journal of Advance Research, Ideas and Innovation in Technology*, 4, 766-770. https://www.ijariit.com/manuscripts/v4i4/V4I4-1451.pdf.

Kawatake, K., & Shigemoto, N. (2012). Preparation of potassium iron (III) hexacyanoferrate (II) supported on activated carbon and Cs uptake performance of the adsorbent. *Journal of Nuclear Science and Technology* , 49(11), 1048-1056. https://doi.org/10.1080/00223131.2012.730894.

Markow, P. G. (1988). The ideal solvent for paper chromatography of food dyes. *Journal of Chemical Education*, 65(10), 899. https://doi.org/10.1021/ed065p899.

Nad, A. K. (2003). "*An Advanced Course in Practical Chemistry*,", 84-86, ISBN: 978 81 7381 302 3.

Nath, S., Datta, A., Das, A., & Adhikari, S. (2024). Metal-Based Drugs in Cancer Therapy. *Int. J. Exp. Res. Rev*, *37*, 159-173.https://doi.org/10.52756/ijerr.2024.v37spl.014.

Paper Chromatography-Separation and identification of Five Metal Cations (Experiment), PDF file. Available at (chem.libretexts.org), (online Library), Available at https://batch.libretexts.org/print/url=https://chem.libretexts.org/Ancillary_Materials/Laboratory_Experiments/Wet_Lab_Experiments/General_Chemistry_Labs/Online_Chemistry_Lab_Manual/Chem_11_Experiments/03%3A_Paper_Chromatography-_Separation_and_Identification_of_Five_Metal_Cations_(Experiment).pdf , (University of California, Davis, US), 2021 (accessed Dec 08, **2023**).

Qureshi, M., Akhtar, I., & Varshney, K. G. (1966). Fast Quantitative Separation of Iron (II) and Iron (III) by Paper Chromatography. *Analytical Chemistry*, 38(10), 1415-1417. https://doi.org/10.1021/ac60242a036.

Qureshi, S. Z. (1966). Chromatography of some metal ions on paper impregnated with stannic phosphate. Journal of Chromatography A. 22, 198-200. https://doi.org/10.1016/S0021-9673(01)97090-6.

Samarasekara, D., Hill, C., & Mlsna, D. (2018). Analysis and identification of major organic acids in wine and fruit juices by paper chromatography. *Journal of Chemical . Education*, 95(9), 1621-1625.https://doi.org/10.1021/acs.jchemed.8b00129.

Science laboratory manuals. PDF File, NCERT Unit 5, Chromatography, 34-39, Available athttps://ncert.nic.in/pdf/publication/sciencelaboratorymanuals/classXII/chemistry/lelm105.pdf (accessed Dec 08, **2023**).

Sciencemadness Discussion Board, Synthesis of an artificial analogue of a molybdenum mineral, **2007**. https://www.sciencemadness.org/talk/viewthread.php?tid=8643.

Sharma, V., McKone, H. T., & Markow, P. G. A. (2011). global perspective on the history, use, and identification of synthetic food dyes. *Journal of Chemical Education*, 88(1), 24-28. https://doi.org/10.1021/ed100545v.

Singh, M. K., Sutradhar, S., Paul, B., Adhikari, S., Laskar, F., Acharya, S., ... & Frontera, A. (2018). Mixed-ligand complexes of zinc (II) with 1, 1-dicyanoethylene-2, 2-dithiolate and N-donor ligands: A combined experimental and theoretical study. *Journal of Molecular Structure*, *1164*, 334-343.https://doi.org/10.1016/j.molstruc.2018.03.073

Stevens, H. M. (1956). The separation of molybdenum valencies by paper chromatography part II1. Analytica Chimica Acta, 14, 126-130. https://doi.org/10.1016/0003-2670(56)80138-4.

Stoffyn, P. J., &Jeanloz, R. W. (1954). Identification of amino sugars by paper chromatography. *Archives of Biochemistry and Biophysics*, 52(2), 373-379. https://doi.org/10.1016/0003-9861(54)90137-X.

Tan, W., & Luan, J. (2020). Investigation into the synthesis conditions of CuMoO 4 by an in situ method and its photocatalytic properties under visible light irradiation. *RSC Advances*, 10(16), 9745-9759. https://doi.org/10.1039/D0RA00496K.

The nature of vibrational spectroscopy, Michigan State University, (webpage), Available at https://www2.chemistry.msu.edu/faculty/reusch/virttxtjml/spectrpy/infrared/irspec1.htm (accessed Dec 08, **2023**).

The University of Colorado Boulder, Equilibrium – Complex ions – Metal + ammonia complexes, (Library webpage), Available at (https://www.colorado.edu/lab/lecture-demo-manual/e740-equilibrium-complex-ions-metal-ammonia-complexes), p.E740 (accessed Dec 08, **2023**).

Unadkat, S., & Solanki, G. K. (2020). Growth and Structural Characterization of CuWO4 Crystals by Flux Growth Method. *Research and Applications: Emerging Technologies*, 2(2), 7-12. http://hbrppublication.com/OJS/index.php/RAET/article/view/1349.

Wu, M. A., & Burrell, R. C. (1958). Flavonoid pigments of the tomato (Lycopersicum esculentum Mill.). *Archives of Biochemistry and Biophysics*, 74(1), 114-118. https://doi.org/10.1016/0003-9861(58)90205-4.

HOW TO CITE

Arijit Das, Digvijoya Sarmaa, Rupak Das, Bijaya Paul, Pratima Debnath, Suman Adhikari, Arnab Bhattacharya, and Paresh Debnath (2024). Advanced Methods for the Separation and Identification of p and d block elements by Paper Chromatography. © International Academic Publishing House (IAPH), Dr. Suman Adhikari, Dr. Manik Bhattacharya and Dr. Ankan Sinha, *A Basic Handbook of Science, Technology and Innovation for Inclusive Development [Volume: 1]*, pp. 40-61. ISBN: 978-81-969828-4-3 DOI:https://doi.org/10.52756/ bhstiid.2024.e01.003

OPEN ACCESS PEER REVIEW
DOI:https://doi.org/10.52756/ bhstiid.2024.e01.004
Chapter- 4

Green Solvents in Organic Synthesis: A Futuristic Approach

Ankita Chakraborty, Ph.D

Keywords: Green Solvents, Sustainable Chemistry, Organic Reactions.

Abstract:

The field of Green or Sustainable Chemistry has gained recognition as a significant scientific topic, gathering immense interest from the scientific community. The research conducted in this field relies significantly on the "Twelve Principles of Green Chemistry," which serve as the fundamental framework for all chemical processes. Researchers are highly interested in developing chemical processes that might mitigate the environmental harm caused by toxic solvents, taking into consideration environmental concerns. Extended exposure to hazardous solvents has a detrimental impact on living beings, causing significant harm to the majority of human organs. Volatile organic molecules derived from petrochemicals, commonly referred to as conventional organic solvents, provide a significant peril to terrestrial, atmospheric, and aquatic organisms. The concept of utilizing water, ionic liquids, organic carbonates, supercritical carbon dioxide, deep eutectic solvents, and non-toxic liquid polymers as catalysts or reaction mediums has gathered significant interest due to their potential to remove environmental hazards. These diverse combinations of solvents fall under the category of green solvents, which are distinguished by their low toxicity, easy handling and reusability. However, the total substitution of traditional solvents with environmentally friendly solvents has a negative effect on industrial production and chemical synthesis. Despite this, some effective alternatives have demonstrated their chemical efficiency and widespread utilization. This chapter will provide a concise overview of ecologically friendly solvent alternatives to traditional solvents, focusing on their application in chemical processes with a green matrix.

Introduction:

The advancement of synthetic organic chemistry is closely linked to the progress towards a more sustainable and environmentally conscious society. This growth has prompted an ethical response aimed at fostering eco-friendly research opportunities. Green Chemistry (Anastas and Eghbali, 2010) is a significant approach with environmental concerns in Chemical sciences. Currently, Green chemistry is widely recognized as a promising direction for the chemical industry, as it aims to promote bio-sustainability and operate at the molecular level. The principles of Green Chemistry take into account a holistic approach to green technology, ensuring safety, efficiency, and biodegradability. Conventional chemical processes, whether used in academia or in industry, contribute to environmental and health hazards, including air,

Ankita Chakraborty, Ph.D
Department of Chemistry, The ICFAI University Tripura,Kamalghat, Mohanpur, Agartala, Pin 799210, Tripura, India
E-mail: ankita.chakraborty10@gmail.com; Orcid iD: https://orcid.org/0000-0001-6544-986X
*__Corresponding Author__: ankita.chakraborty10@gmail.com

Dr. Suman Adhikari, Dr. Manik Bhattacharya and Dr. Ankan Sinha, A Basic Handbook of Science, Technology and Innovation for Inclusive Development [Volume: 1]. ISBN: 978-81-969828-4-3; pp- 62-70; Published online: 27th May, 2024

water, and soil pollution (Bhattacharya, 2015; Banerjee et al., 2021; Biswas & Saha, 2021; Mondal et al., 2022; Prasad et al., 2023). Given that the majority of organic reactions take place in a solution, selecting the appropriate solvent is a crucial requirement for any organic synthesis. In recent years, there has been a growing recognition of the necessity to decrease the utilization of traditional solvents in favour of less harmful alternatives, mostly due to concerns regarding toxicity and environmental implications. Therefore, from a synthetic perspective, it is imperative and very promising to explore environmentally friendly synthetic alternatives as substitutes for traditional ones.

Conventional Solvents Versus Green Solvents

Carbon-based chemicals, hydrocarbons, and halogenated hydrocarbons are the conventional organic solvents. The majority of them exhibit elevated vapor pressure and are incapable of mixing with water. Volatile organic molecules, which exhibit chemical diversity, are mostly derived by the petrochemical sources. Volatile organic solvents possess flammable, explosive, poisonous, narcotic, mutagenic, and carcinogenic properties, hence posing significant hazards during their use and storage. If they come into contact with the mucous linings, eyes, skin, etc., they can cause detrimental effects leading to health hazards. The intensity of the effects increases, leading to potential health risks when they are dispersed throughout the bloodstream or other vital organs of the body. From an environmental point of view, the majority of organic solvents are classified as volatile organic compounds. Their release into the environment contributes to environmental pollution by participating in the creation of photochemical smog and the halogenated solvents contribute to the depletion of the ozone layer. Organic solvents, such as dimethyl sulfoxide (DMSO), dimethyl formamide (DMF), halogenated hydrocarbons, and aromatics like benzene, toluene, and xylenes, are commonly employed in large quantities in many industrial applications despite their severe toxicity. Given this context, there is a pronounced inclination to substitute the majority of traditional organic solvents with alternative options that have a reduced environmental footprint while still yielding comparable outcomes. The concept of non-conventional or green solvents in synthesis emerges as an acceptable result. Solvents and solvent classes that have been classified as environmentally friendly solvents include water, ionic liquids, organic carbonates, supercritical carbon dioxide, deep eutectic solvents, non-toxic liquid polymers, and many more. These organic compounds are eco-friendly, non-evaporating, biocompatible, reusable, relatively recent materials, and serve as good solvents, reaction media, or occasionally catalysts for reactions. The scientific concept of substituting a solvent that is considered 'non-green' with a solvent that is considered 'green' in a given process inherently enhances its environmental efficacy (Chakraborty et al., 2016). However, this has sparked arguments on the comparative environmental friendliness of various solvents (Clark and Tavener, 2007). However, during this era of development, there have been other synthetic procedures that have been classified as 'Green' based on certain green criteria. These criteria have clearly defined the distinction between green and non-green processes. This

chapter will primarily focus on the utilization of water, ionic liquids, and deep eutectic solvents in the context of greener synthesis.

Water

Although water is often seen as a problem in modern organic synthesis for the laborious purification procedures and the need for final drying of the product, it can nevertheless be considered a more favourable solvent alternative. The use of water as a solvent has been observed to expedite certain reactions and exhibit notable selectivity, even for chemicals that possess limited solubility or insolubility. This phenomenon, commonly referred to as hydrophobic interaction, is widely recognized in biological science. Water is a superior choice over other green solvents due to its abundance, lack of toxicity, non-corrosiveness, and non-flammability. Furthermore, water possesses the ability to be confined due to its comparatively elevated vapor pressure in comparison to other organic solvents, rendering it an environmentally friendly and sustainable substitute (Zha et al., 2005; Kobayashi et al., 2002). Currently, there is a growing interest in organic reactions occurring in water, since it is a cost-effective, secure, and ecologically harmless solvent. The organic co-solvents and surfactants actively enhance the solubility in water when combined with water. The interaction between organic solutes and micelles is influenced by their polarity. Non-polar solutes tend to be confined within the micelle's interior, while moderately polar molecules tend to be located closer to the polar surface. On the other hand, distinctly polar solutes are found at the surface of the micelle and collectively contribute to the reaction in an aqueous medium. In 1980, Breslow(Rideout and Breslow, 1980) conducted a significant study that demonstrated the ability of water to accelerate the reaction rate of the Diels Alder reaction. Since then, water has gained recognition as a highly esteemed reaction medium, after the groundbreaking contributions of the Sharpless (Narayan et al., 2005) and Breslow (Breslow., 2004) groups. In recent times, water has emerged as a significant reaction medium in various chemical reactions. The activation of C-H bonds on water has emerged as an important field of study in recent times (Li and Dixneuf, 2013). Reactions such as Heck reaction (Fernandes et al., 2008) and Suzuki coupling (Liu et al., 2011) can now be conducted in aqueous environments with comparable or enhanced rates, yields, and selectivities when compared to their counterparts in organic solvents. The field of aqueous chemistry is mostly utilized in biological processes, and its advancement can contribute to our comprehension of the intricate mechanisms underlying the chemistry of life, which in turn are relevant to biotechnological applications.

Similarly, sustainable methods (Chakraborty et al., 2018; Chakraborty et al., 2019) were employed to synthesize pharmaceutically and morphologically significant pharmacophores utilizing water as a reaction medium, resulting in a higher yield of products. Due to the inherent difficulty of conducting organic reactions in water, the addition of surfactants as an additive has resulted in high product yields through micellar aggregation.

Ionic liquids

Ionic liquids are liquid electrolytes that consist exclusively of ions. The composition of ionic liquids can be altered by employing a specific strategy. Therefore, the term "designer solvents" has become widely employed. Typically, ionic liquids are composed of a salt in which one or both ions exhibit significant size, while the cation possesses a relatively low level of symmetry. Ionic liquids can be classified into two primary categories: simple salts, which consist of a single anion and cation, and binary ionic liquids, which involve an equilibrium. In the past decade, the scientific community has shown significant interest in ionic liquids (ILs) due to their unique features and their various applications in fields such as organic synthesis (Welton, 1999), catalysis(Zhao et al., 2002; Cole et al., 2002; Welton, 2004), biocatalysis (Sheldon et al., 2002) etc. Ionic liquids (ILs) are a highly suitable substitute for volatile organic solvents in environmentally friendly technologies, also known as "green technologies". This is due to their low vapor pressures, thermal and chemical stability, catalyst-like properties, non-flammability and non-corrosive nature. By adjusting the characteristics of their cations and anions, the physical qualities such as melting temperatures, viscosity, density, and hydrophobicity can be altered.

Ionic liquids can be categorized into three groups based on their acidic, basic and neutral nature namely acidic (Fig 4.1), basic (Fig 4.2), and neutral (Fig 4.3) ionic liquids. These classifications are determined by the presence of cations and anions in the liquid.

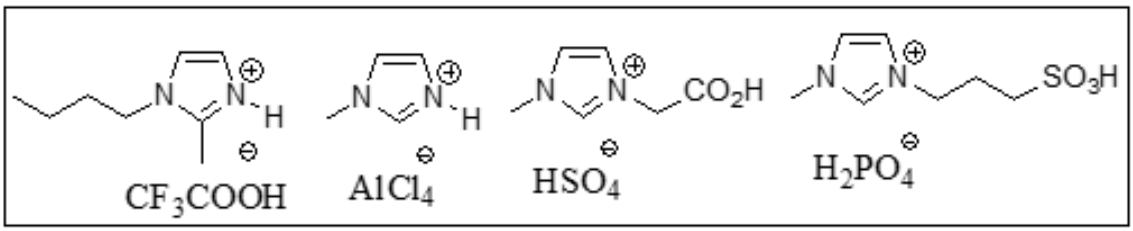


Figure.4.1. Acidic Ionic liquids

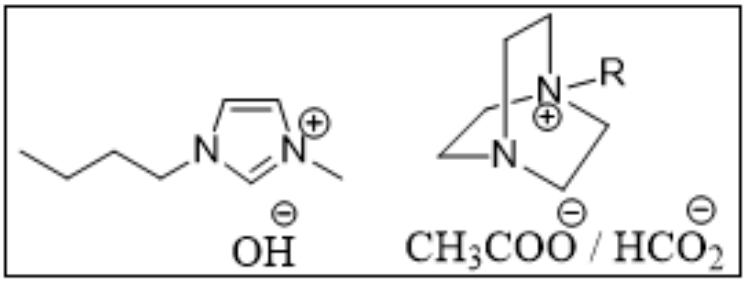


Figure.4.2. Basic Ionic liquids

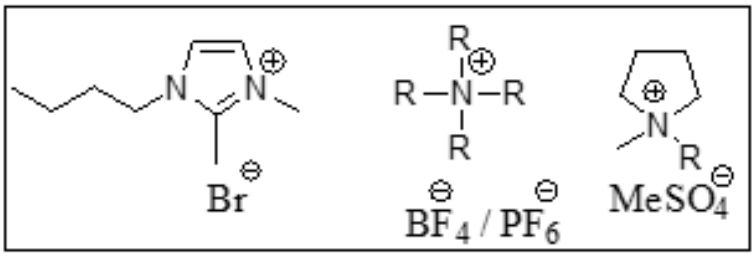


Figure.4.3. Neutral Ionic liquids

Ionic liquids have been documented to possess task-specific properties, as evidenced by several research articles that explore their utilization as solvents or catalysts to enhance reaction performance. Among the several reactions occurring in organic synthesis, the significance of protection and deprotection techniques in peptide synthesis has been underscored by the utilization of ionic liquids. Imidazolium-based ionic liquids (Chakraborty et al., 2016; Majumdar et al., 2014) have demonstrated significant efficacy in the protection of amine functionality, as well as in tolerating deprotection strategies (Majumdar et al., 2014). Additionally, they have played a role in carbon-carbon bond formation and cleavage (Chakraborty et al., 2016) resulting in substantial yield of products.

Deep eutectic solvents

Deep eutectic solvents (DESs) are a distinct category of ionic fluids that bear resemblance to ionic liquids at normal temperature. However, they are characterized by the presence of an organic molecule component as their primary constituent. The term "deep eutectic solvent" was initially introduced by Abbot (Abbot et al., 2003; Abbot et al., 2004) to describe ionic fluids that often consist of two substances capable of self-association, resulting in the formation of a eutectic mixture with a significantly lower melting point compared to the separate components. Various types of hydrogen bond acceptors (HBAs) and hydrogen bond donors (HBDs) (Fig 5.1) with distinct physicochemical properties are commonly encountered, necessitating the use of diverse appropriate methodologies for the synthesis of deep eutectic solvents (DESs). DESs are a new type of solvent that are both sustainable and environmentally friendly. They were initially introduced as versatile alternatives to traditional RTILs. DESs are typically created by reacting a quaternary ammonium halide salt, such as choline chloride, with metal salts or a hydrogen-bond donor (HBD) such as urea, carboxylic acids, amides, or polyalcohols. This reaction allows the DESs to form a complex with the halide ion, resulting in a significant decrease in the freezing point. DESs can be seen as closely related to room temperature ionic liquids, yet there is a distinct ecological distinction between the two. Specifically, it should be noted that DESs do not qualify as RTILs due to their composition, which does not only consist of ions but rather includes a molecule component, which may be more prevalent in some cases. Furthermore, DESs are more convenient to produce as they involve straightforward blending of the two constituents, produce no by products during the procedure, and do not require any purification. These characteristics align with the concepts of Green Chemistry. In practical

terms, DESs present themselves as appealing alternatives to RTILs due to their notable characteristics, such as minimal or low vapor pressure, humidity tolerance, thermal stability, tunability, and superiority in addressing various problems associated with RTILs. These substances possess cost-effectiveness, non-toxicity, synthetic availability, and biodegradability.

The utilization of deep eutectic solvents has been significantly increased in the synthesis of heterocyclic compounds. The Knoevenagel reaction (Liuet al., 2014), cyclization reaction (Sebest et al., 2020) andring opening reactions (Azizi and Gholibeglo, 2012) were facilitated by DES. The formation of carbon-sulfur bonds (Dilauro et al., 2017) is a subject of significant interest due to its presence in numerous biologically significant compounds and its relevance in the field of material sciences. The utilization of deep eutectic solvents presents an opportunity for the sustained advancement of nano material creation, in addition to organic synthesis. Deep eutectic solvents (DESs) play a crucial role in several manufacturing processes, facilitating the development and design of nano structures and nano composites (Mernissi Cherigui et al., 2017) with distinct morphology and properties. These methods can also be tailored to precise reaction conditions (Nam et al., 2023).

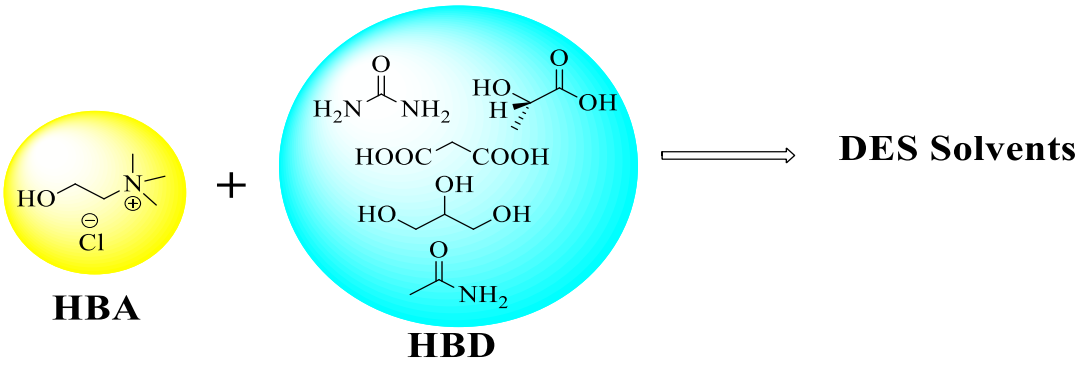


Figure.5.1. Hydrogen bond acceptors (HBA) and hydrogen bond donors (HBDs) constituting the deep eutectic solvents

Conclusion

This chapter provides a concise overview of various green solvents, including water, the universal solvent, ionic liquids, and deep eutectic solvents. It is important to note that there are numerous additional green solvents that can be included. In recent decades, these compounds have gained significant importance in the field of synthesis. The utilization of environmentally friendly solvents for the sensitive synthesis of heterocycles and asymmetric synthesis aligns closely with the concepts of green chemistry. The objective of Green Chemistry is to substitute frequently employed solvents with environmentally friendly alternatives in order to minimize environmental consequences. This chapter has the potential to shed light on the utilization of potential green alternatives in organic synthesis for the production of bioactive scaffolds. The solvents mentioned here demonstrate the superiority of environmentally friendly alternatives over traditional solvents. This could potentially facilitate the advancement of sustainable development and the subsequent implementation of Green Chemistry in near future.

References:

Abbott, A. P., Capper, G., Davies, D. L., Rasheed, R. K., and Tambyrajah, V. (2003). Novel solvent properties of choline chloride/ urea. *Chemical Communications (Cambridge, England)*, (1), 70-71.doi:10.1039/b210714g

Abbott, A. P., Boothby, D., Capper, G., Davies, D. L., and Rasheed, R. K. (2004). Deep eutectic solvents formed between choline chloride and carboxylic acids: versatile alternatives to ionic liquids. *Journal of the American Chemical Society*, *126*(29), 9142-9147. doi:10.1021/ja048266j

Anastas, P., and Eghbali, N. (2010). Green chemistry: principles and practice. *Chemical Society Reviews*, *39*(1), 301-312. doi:10.1039/b918763b

Azizi, N., and Gholibeglo, E. (2012). A highly efficient synthesis of dithiocarbamates in green reaction media. *RSC Advances*, *2*(19), 7413-7416. doi:10.1039/c2ra20615c

Banerjee, S., Mitra, S., Velhal, M., Desmukh, V., & Ghosh, B. (2021). Impact of agrochemicals on the environment and human health: The concerns and remedies. *Int. J. Exp. Res. Rev.*, *26*, 125-140. https://doi.org/10.52756/ijerr.2021.v26.010

Biswas, S., & Saha, S. (2021). A report groundwater arsenic contamination assay in the delta area of West Bengal. *Int. J. Exp. Res. Rev.*, 25, 84-88. https://doi.org/10.52756/ijerr.2021.v25.008

Bhattacharya, P. (2015). Transfer of heavy metals from lake water to biota: a potential threat to migratory birds of Mathura lake, West Bengal, India. *Int. J. Exp. Res. Rev.*, 1, 1-7. https://doi.org/10.52756/ijerr.2015.v01.001

Breslow, R. (2004). Determining the geometries of transition States by use of antihydrophobic additives in water. *Accounts of Chemical Research*, *37*(7), 471-478. doi:10.1021/ar040001m

Chakraborty, A., Purkait, R., De, U. C., Maiti, D. K., and Majumdar, S. (2016). Anion dependent imidazolium protic ionic liquid catalyzed solvent-free general strategy for chemoselective Fmoc and cbz protection of amines and their chiral analogues. *Chemistry Select*, *1*(11), 2668–2672. doi:10.1002/slct.201600267

Chakraborty, A., Debnath, S., Ghosh, T., Maiti, D. K., and Majumdar, S. (2018). An efficient strategy for N-alkylation of benzimidazoles/imidazoles in SDS-aqueous basic medium and N-alkylation induced ring opening of benzimidazoles. *Tetrahedron*, *74*(40), 5932-5941. doi:10.1016/j.tet.2018.08.029

Chakraborty, A., Ghosh, T., Maiti, D. K., and Majumdar, S. (2019). BMIm[OH] catalyzed rapid, mild and improved protocol for the synthesis of 3-hydroxy-3-(nitroalkyl)indolin-2-one derivatives in water. *Chemistry Select*, *4*(6), 1841-1845. doi:10.1002/slct.201804026

Chakraborty, A., Majumdar, S., and Maiti, D. K.(2016). Selective exploitation of acetoacetate carbonyl groups using imidazolium based ionic liquids: synthesis of 3-oxo-amides and

substituted benzimidazoles. *Tetrahedron Letters*, *57*(30), 3298-3302. doi:10.1016/j.tetlet.2016.06.048

Clark, J. H., and Tavener, S. J. (2007). Alternative solvents: Shades of green. *Organic Process Research and Development*, *11*(1), 149-155. doi:10.1021/op060160g

Cole, A. C., Jensen, J. L., Ntai, I., Tran, K. L. T., Weaver, K. J., Forbes, D. C., and Davis, J. H., Jr. (2002). Novel Brønsted acidic ionic liquids and their use as dual Solvent-Catalysts. *Journal of the American Chemical Society*, *124*(21), 5962-5963. doi:10.1021/ja026290w

Dilauro, G., Cicco, L., Perna, F. M., Vitale, P., and Capriati, V. (2017). Solvent-catalyzed umpolung carbon sulfur bond-forming reactions by nucleophilic addition of thiolate and sulfinate ions to in situ-derived nitrosoalkenes in deep eutectic solvents. *Comptes Rendus. Chimie*, *20*(6), 617- 623. doi:10.1016/j.crci.2017.01.008

Fernandes, T. de A., Carvalho, R. de C. C., Gonçalves, T. M. D., da Silva, A. J. M., and Costa, P. R. R. (2008). A tandem palladium-catalyzed Heck-lactonization through the reaction of ortho-iodophenols with β-substituted acrylates: synthesis of 4, 6-substituted coumarins. *Tetrahedron Letters*, *49*(20), 3322–3325. doi:10.1016/j.tetlet.2008.03.037

Kobayashi, S., Hamada, T., and Manabe, K. (2002). The catalytic asymmetric Mannich-type reactions in aqueous media. *Journal of the American Chemical Society*, *124*(20), 5640-5641. doi:10.1021/ja026094p

Li, B., and Dixneuf, P. H. (2013). sp^2 C-H bond activation in water and catalytic cross-coupling reactions. *Chemical Society Reviews*, *42*(13), 5744-5767. doi:10.1039/c3cs60020c

Liu, C., Ni, Q., Hu, P., and Qiu, J. (2011). Oxygen-promoted $PdCl_2$-catalyzed ligand-free Suzuki reaction in aqueous media. *Organic and Biomolecular Chemistry*, *9*(4), 1054-1060. doi:10.1039/c0ob00524j

Liu, S., Ni, Y., Wei, W., Qiu, F., Xu, S., and Ying, A. (2014). Choline chloride and urea based eutectic solvents: Effective catalytic systems for the Knoevenagel condensation reactions of substituted acetonitriles. *Journal of Chemical Research*, *38*(3), 186-188. doi:10.3184/174751914x13926483381319

Majumdar, S., De, J., Chakraborty, A., and Maiti, D. K. (2014). General solvent-free highly selective *N*-tert-butyloxycarbonylation strategy using protic ionic liquid as an efficient catalyst. *RSC Advances*, *4*(47), 24544- 24550. doi:10.1039/c4ra02670e

Majumdar, S., Chakraborty, M., Maiti, D. K., Chowdhury, S., and Hossain, J. (2014). Activation of 1,3-dioxolane by a protic ionic liquid in aqueous media: a green strategy for the selective hydrolytic cleavage of acetals and ketals. *RSC Advances*, *4*(32), 16497-16502. doi:10.1039/c4ra00870g

Mernissi Cherigui, E. A., Sentosun, K., Bouckenooge, P., Vanrompay, H., Bals, S., Terryn, H., and Ustarroz, J. (2017). Comprehensive study of the electro deposition of nickel nanostructures from deep eutectic solvents: Self-limiting growth by electrolysis of

residual water. *The Journal of Physical Chemistry. C, Nanomaterials and Interfaces*, *121*(17), 9337-9347. doi:10.1021/acs.jpcc.7b01104

Nam, N. N., Do, H. D. K., Trinh, K. T. L., and Lee, N. Y. (2023). Design strategy and application of deep eutectic solvents for green synthesis of nanomaterials. *Nanomaterials*, *13*(7), 1164. doi:10.3390/nano13071164

Narayan, S., Muldoon, J., Finn, M. G., Fokin, V. V., Kolb, H. C., and Sharpless, K. B. (2005). 'On water': unique reactivity of organic compounds in aqueous suspension. *Angewandte Chemie (International Ed. in English)*, *44*(21), 3275-3279. doi: 10.1002/anie.200462883

Prasad, N., Bhattacharya, T., & Lal, B. (2023). Chemometric Techniques in the Assessment of Ambient Air Quality and Development of Air Quality Index of Coal Mining Complex: A Statistical Approach. *Int. J. Exp. Res. Rev.*, *36*, 433-446. https://doi.org/10.52756/ijerr.2023.v36.018a

Rideout, D. C., and Breslow, R. (1980). Hydrophobic acceleration of Diels-Alder reactions. *Journal of the American Chemical Society*, *102*(26), 7816-7817. doi:10.1021/ja00546a048

Sebest, F., Lachhani, K., Pimpasri, C., Casarrubios, L., White, A. J. P., Rzepa, H. S., and Díez-González, S. (2020). Cycloaddition reactions of azides and electron-deficient alkenes in deep eutectic solvents: Pyrazolines, aziridines and other surprises. *Advanced Synthesis and Catalysis*, *362*(9), 1877-1886. doi:10.1002/adsc.201901614

Sheldon, R. A., Lau, R. M., Sorgedrager, M. J., van Rantwijk, F., and Seddon, K. R. (2002). Biocatalysis in ionic liquids. *Green Chemistry: An International Journal and Green Chemistry Resource: GC*, *4*(2), 147-151. doi:10.1039/b110008b

Welton, T. (1999). Room-temperature ionic liquids. Solvents for synthesis and catalysis. *Chemical Reviews*, *99*(8), 2071-2084. doi: 10.1021/cr980032t

Welton, T. (2004). Ionic liquids in catalysis. *Coordination Chemistry Reviews*, *248*(21-24), 2459-2477. doi:10.1016/j.ccr.2004.04.015

Zhao, D., Wu, M., Kou, Y., and Min, E. (2002). Ionic liquids: applications in catalysis. *Catalysis Today*, *74*(1-2), 157-189. doi:10.1016/s0920-5861(01)00541-7

Zha, Z., Hui, A., Zhou, Y., Miao, Q., Wang, Z., and Zhang, H. (2005). A recyclable electrochemical allylation in water. *Organic Letters*, *7*(10), 1903-1905. doi :10.1021/ol050483h

HOW TO CITE

Ankita Chakraborty, Ph.D (2024). Green Solvents in Organic Synthesis: A Futuristic Approach. © International Academic Publishing House (IAPH), Dr. Suman Adhikari, Dr. Manik Bhattacharya and Dr. Ankan Sinha, *A Basic Handbook of Science, Technology and Innovation for Inclusive Development [Volume: 1]*,pp. 62-70. ISBN: 978-81-969828-4-3 DOI:https://doi.org/10.52756/ bhstiid.2024.e01.004

OPEN ACCESS PEER REVIEW
DOI: https://doi.org/10.52756/ bhstiid.2024.e01.005
Chapter- 5

Integration of artificial intelligence toward better agricultural sustainability

Mayuri Bhagawati*, Chayan Dhar, Dipan Sarma, Manna Das, Badal Kumar Datta

Keywords: Agriculture, Artificial Intelligence (AI), Sustainability, Agroecology, Agribots.

Abstract:

The development and even survival of human civilization is highly dependent on agriculture. Modern human society, with a vast population, is continuously pressurizing agricultural techniques to modify themselves in a way that satisfies the hunger of this rapidly growing population. To ensure food security, several methods and chemical inputs have been applied in the field of farming which disturb their average ecological balance, reduce the nutrient content in the food, affect the average fertility of the soil, cause overexploitation of the natural resources, and even responsible for various fatal health issues in humans. Thus, an alternative resolution is needed, which is Artificial Intelligence. Integration of AI has proved to be a boon for the present-day farmers. AI eases farming practices by monitoring crop health, predicting pests, diseases, drought, weather forecasting, harvesting, categorizing harvested ones, aiding farmers in making necessary decisions regarding selling, etc. They also facilitate sustainability as early prediction of weeds, pests, and diseases would directly reduce the content of chemical inputs in the field; this, in turn, supports soil health and also checks overexploitation of groundwater while irrigating the croplands. Except for the doubt and misconceptions of the farmers about the potency of these AI-based tools in fulfilling their needs and the high cost, AI as a whole is a complete solution to the modern farming society for benefiting themselves and fulfilling the market demand without disturbing our ecosystem.

Introduction:

The role of agriculture in the developing human society is peerless. But the requirement of society is rising tremendously day by day along with drastically enhancing population, which ultimately compels the traditional agricultural systems to transform themselves into modernized methodologies that employ noxious chemical fertilizers, pesticides, weedicides, high-tech machines, and so on. While fulfilling the needs of the exploding population, the modern

Mayuri Bhagawati*
[1]Department of Botany, Tripura University (A Central University) Suryamaninagar – 799022, Tripura
E-mail: mayuribot13@gmail.com; Orcid iD: https://orcid.org/0000-0003-3940-6828
Chayan Dhar
[1]Department of Botany, Tripura University (A Central University) Suryamaninagar – 799022, Tripura
Dipan Sarma
[1]Department of Botany, Tripura University (A Central University) Suryamaninagar – 799022, Tripura
[2]Department of Botany, Govt. Degree College, Dharmanagar-799253, Tripura
E-mail: dipanphd@gmail.com; Orcid iD: https://orcid.org/0000-0002-5643-6327
Manna Das
[2]Department of Botany, Govt. Degree College, Dharmanagar-799253, Tripura
E-mail: arkaprabhapal0610@gmail.com
Badal Kumar Datta
[1]Department of Botany, Tripura University (A Central University) Suryamaninagar – 799022, Tripura
***Corresponding Author**: mayuribot13@gmail.com & dipanphd@gmail.com

Dr. Suman Adhikari, Dr. Manik Bhattacharya and Dr. Ankan Sinha, A Basic Handbook of Science, Technology and Innovation for Inclusive Development [Volume: 1]. ISBN: 978-81-969828-4-3; pp- 71-85; Published online: 27th May, 2024

farming society has become highly dependent on modern technologies and chemical inputs, and sustainability is merely unnoticed (Mohan et al., 2023). This dependency of agriculture on modern methods ultimately radiates its adverse effects on the abiotic components of the ecosystem as well as on the biota belonging to the agroecosystem and even biomagnified to wider audiences, i.e., the consumers (Sarkar et al., 2016; Ray, 2019; Banerjee et al., 2021). The introduction of precision agriculture has also proved to be a boon in this field. Intellectual solutions provided by artificial intelligence have been implemented in recent years in the field of agriculture to develop methods that boost productivity by considering problems, predicting pests, calamities, and crop maturation, specifying chemical inputs, managing weeds, optimizing resource utilization, and many more (Talaviya et al., 2020; Rozaini et al., 2023; Chaudhary et al., 2023; Dawn et al., 2023). Early prediction and specification of chemical inputs lead to their minimal use in this field, enhancing sustainability (Raj et al., 2023). The perfect balanced use of high-tech sensors and analytical tools contributed by AI and their alliance with the principles of agroecology can potentially solve a lot of modern problems to achieve sustainable agriculture (Sasso et al., 2021; Cousin et al., 2021; Rout and Samantaray, 2022). The contemporary initiative of involving the intellect of artificial intelligence in the field of farming aids in real-time monitoring, control, and automation. Various wireless sensors acquire information on various environmental parameters like soil moisture, temperature, humidity, and other factors. Technologies such as drones, GPS, farm automation, robots, etc., directly aid in agricultural mapping, soil analysis, geospatial data access, resource monitoring, management, crop health monitoring, chances of success or failure of crops, calamities, and many more. These datasets help the AI make necessary decisions based on these crucial parameters. Critical decisions include sowing, fertilizer, pesticide and weedicide applications, irrigation, harvesting, market analysis, distribution, etc.

Green Revolution in the Agricultural Sectors:

The term green revolution is used to describe the agricultural revolution of the 1960s. During the mid-20th century, the world, especially the undeveloped countries, needed agricultural stability. This goal is achieved by introducing genetically modified crop varieties such as HYV, mechanization, better irrigation facilities, and chemical inputs such as pesticides, fertilizers, and so on (Somvanshi and Singh, 2020). Green Revolution became a savior for those who were under poverty levels or were under threat of falling into poverty levels in the coming years. The achievements of the Green Revolution are remarkable and include increased productivity, benefits farmers by boosting income and food security, the introduction of technologies that make farming easier, economic strengthening of developing and underdeveloped countries, and many more (Pingali, 2012).

Negative effects of agricultural modernization:

The inevitable detrimental consequences of modernized agricultural practices must be mentioned to understand how they are affecting the ecosystem, health, and some other fields.

Biomagnification of harmful chemical pesticides, fertilizers, and weedicides to higher ecosystem trophic levels is a common side effect of modern agriculture. Biomagnification and subsequent bioaccumulation of these pollutants are very serious issues to deal with. Nearly 42% decline in species richness was observed within the last 30-40 years in Europe. In humans, exposure to these contaminants can directly or indirectly affect health by inducing different types of cancers like leukemia, lymphoma, and brain cancer (Ali et al., 2021). Also, the continuous demand for crop production needs a large land area for production, which directly leads to a decline, i.e., destruction of natural habitats by up to 47% which in turn stimulates land degradation, soil erosion, extinction of diversity of crop or wild varieties, negate adaptivity, evolutionary potential and enhances vulnerability (Somvanshi and Singh, 2020; Lopez et al., 2022). Many authors also highlight the serious issue of crop genetic erosion to help us understand that the cultivation of only particular highly yielding varieties of crops is destroying the great varieties of germplasms that are getting lost due to their underutilization in the agricultural sector. In addition, modernization also negatively affects traditional agricultural knowledge utilization (Khoury et al., 2022).

Need for an alternative solution:

The limitations of modern agricultural methodologies enhanced the urge of the researchers to develop a way of agriculture that boosts productivity with minimum effect on the environment. For this, thoughtful consideration of all the fields that are directly or indirectly influenced by them should be done. The assessment of environmental, medical, traditional, and all other fields that are affected by modern techniques and chemical pesticides was done in the last few decades to construct a practicable solution to abate their fatal effects with minimal efforts and by not compromising the benefit, economic stability of the global farming society. The utility of modern techniques and chemical inputs can't be totally stopped, but they can surely be reduced to a considerable amount to avoid its deleterious aftermath.

Transformative approaches: Solutions:

A practicable solution is extensively needed for achieving sustainable agriculture and promoting healthy and disease-free lifestyles. The negative consequences of modernized agricultural practices are, in turn, countered by practically employing the intellect of artificial intelligence. This alternative path can effectively meet the continuously growing global demands for food without pressurizing the agroecosystem.

Smart agricultural approach:

The re-establishment of the devastated ecosystem of the croplands is highly desirable to avoid more severe environmental hazards. Precision farming has become the soul of smart, sustainable agriculture. It involves using technologies such as sensors, GPS, drones, data analytics, IoT, ICT, and AI to achieve sustainable and profitable agricultural practices. Both the Internet of Things (IoT) and Artificial Intelligence (AI) are the most trusted platforms for the

advancement of smart agricultural practices. IoT is a versatile technology integrating highly intellectual devices within a single global network: the Internet. Implementation of IoT has proven to be highly reliable. Implementation of IoT-mediated automatic irrigation system is a specified technique that proves that their implementation in the agricultural sector is highly justified. IoT in this sector also plays a great role in agricultural product management. Thus, it is vital in both production and post-production activities (Alreshidi, 2019). The smart and multidisciplinary technology of AI implies a branch of computer science that deals with the production of devices that mimic human intelligence in performing tasks and involve deep learning, machine learning, etc. (Raj et al., 2022). Different Artificial intelligence algorithms were integrated into the field of agriculture for the fulfillment of certain desired goals. Oliveira et al., 2021 highlighted that AI-based algorithms MLP, CNN, R-CNN, R-YOLO, and SVM aid in disease detection, weed detection, selection of specific weedicide, location of plant products and its qualitative assessment like ripening, and assessment of yield. ANN algorithms were reported to be widely applied as predictive AI models (Liu et al., 2020; Liu et al., 2021; Buyrukoglu et al., 2021) and can be implemented in weed controlling (Monteiro et al., 2021), managing water (Alvim et al., 2022), pest management (Markovic et al., 2021). Robotics is another highly applied technology in the agricultural field. It is highly interconnected with AI to boost its intellectual properties for proper decision-making, deep learning, change adaptation, etc. Integration of robots for the purpose of agricultural modification and sustainability is a very popular approach in modern times (Azmi et al., 2021; Unal et al., 2021; Ghafar et al., 2021; Roshanianfard et al., 2021; Hespeler et al., 2021). Adhikari et al., 2022 claimed that CNN reflects very high performance in flood predictions, whereas, for drought forecasting, the performance of WANFIS is remarkable. Also, they pointed out that the climatic conditions of a particular area have almost no effect on these models. Zhang et al., 2021 employed Multiple Linear Regression (MLR), Long Short-Term Memory (LSTM), and Random Forest (RF) models to evaluate the Rate of Intensification (RI) and flash drought monitoring. The probability of Detection (POD), False Alarm Ratio (FAR), and Critical Success Index (CSI) of flash drought derived from RF were 0.93, 0.15, and 0.80, respectively for the RF model which reveals its enhanced potency to achieve the respective goals compared to the other two AI models. By employing ANN models, Liu et al., 2020 successfully prepared the integrated agricultural drought index to predict the risk of upcoming drought. Liu et al., 2021 mentioned the successful implementation of artificial neural networks, regression algorithms, and gene-expression programming for predicting the growth rate of rice on the basis of the ambient temperature of warm regions. The authors also pointed out that the ANN models are better, even not wrong, to mention best in comparison to the other 2 models. Similarly, Buyrukoglu et al., 2021 predict the population of Generic *E. coli* based on the Weather Station Measurements by using ANN and some other models. Almomani et al. (2020) successfully employed the ANN algorithms for the prediction of aerobic digestion, i.e., the production of biogas from the wastes generated by agricultural sectors. Besides ANN various other AI models were also employed

for the predictive purposes. Malhotra and Firdaus, 2022 highlighted using AI-based predictive models for yield prediction. Laktionov et al., 2023 reported the use of Explainable Artificial intelligence models (XAI) for the purpose of monitoring and predicting the diseases of corn. Jain and Ramesh., 2021 successfully utilized CNN-LSTM models for the preparation of pest prediction and classification model for yellow stem border disease in Rice. Artificial Neural Networks, Random Forest, and Multiple Linear Regression algorithms were taken into account by Silva et al., 2024 for predicting the yield as well as the quality of carrots.

Table 1. Various applications and achievements of different AI technologies.

Sl no.	AI model/ technology	Applications	Achievements	References
1	Artificial Neural Network	Growth Prediction of Carrot	Mean of accuracy i.e., R^2 = 0.68	Silva et al., 2024
2	Convolutional Neural Network	Identification of plant diseases	93.75% accuracy	Chen et al., 2021
3	ANN	The growth rate of rice	R^2 =0.99	Liu et al., 2021
4	Adaptive Neuro-Fuzzy Inference System	Early prediction of disease in corn (Fusarium Head Blight, Southern Corn Leaf blight, Northern Corn Leaf blight.	The R^2 value is 0.96, 0.75, 0.8 for FHB, SCLB, and NCLB, respectively.	Laktionov et al., 2023
5	CNN-AlexNet with PSO Optimization.	Detecting plant disease in 5 crops (Wheat, cotton, grape, corn, cucumber)	Specificity 98.56%, accuracy 98.83%, sensitivity 98.78%, precision 98.67% and F score 98.47%	Elaraby et al., 2022.
6	YOLOv5s, YOLOv5m and YOLOv5l	Detection of weeds in wheat fields.	Precision is 0.59, 0.67, 0.84 and F-score is 0.51, 0.57, and 0.54 for YOLOv5s, YOLOv5m, and YOLOv5l, respectively.	Haq et al., 2023
7	Random Forest	Rate of Intensification and Flash Drought Monitoring	POD, FAR, and CSI of flash drought derived from RF were 0.93, 0.15, and 0.80 respectively	Zhang et al., 2021
9	ANN-MLP	Weed control and crop-	Accuracy 0.98, precision	Monteiro et

		weed competition modeling.	0.94, and F score 0.98	al., 2021
10	Long Short-Term Memory	Prediction of irrigation water and energy necessity to achieve optimum water use efficiency as well as yield.	R^2 between 0.90 - 0.92	Mohammed et al., 2023
11	ANN	Prediction of Generic *E. coli* population.	Mean Absolute Error values range between 0.87-46.6	Buyrukoglu et al., 2021
12	Mask R-CNN and YOLOv5	Identification and quality detection of apples, bananas, oranges, and tomatoes.	mAP values for quality detection models of apple, banana, orange, and tomato are 99.6, 93.1, 96.7, and 95%, respectively.	Goyal et al., 2023
13	ML	Prediction of pests like *Helicoverpa armigera*	76.5% accuracy but with the extension of five days, accuracy increased to 86.3%, and the percentage of false detection was 11% only.	Markovic et al., 2021
14	Zero sheet transfer learning (Fine-tuned VGG-16 network)	Fruit ripe and unripe prediction	Accuracy range between 70-82.	Dutta et al., 2023
15	CNN with fuzzy C means segmentation.	Detection and classification of diseases in banana plants.	Accuracy 93.45%.	Krishnan et al., 2022
16	ML, YOLO v 4 (You Only Look Once v4)	Yield prediction and detection of *Citrus* fruit.	24% reduction in error.	Vijayakumar et al., 2021
17	ML (Machine Learning)	Sorting and categorizing of fruits based on ripe,or unripe, i.e., grading.	95% accuracy	Chopra et al., 2021
18	CNN, VGG 16, VGG 19, ResNet,	Detection of leaf disease in tomato.	Inception V3 has the highest accuracy 85 and 93.7 by	Ahmad et al., 2020

	Inception V3		feature extraction and parameter tuning of field data. It also has the highest precision and F1 score 0.845, and 0.87 respectively.	
19	CNN-AlexNet	Classification and modeling for leaf disease in maize.	99.16 % accuracy	Singh et al., 2022
20	ANN	Integrated agricultural drought index preparation	Not mentioned	Liu et al., 2020
21	CNN+ LSTM	Predicting rainfall and monitoring fruit health	89.38% accuracy, 0.316 loss score of rainfall prediction.	Kaplun et al., 2024
22	PCA with whale optimization algorithm and DNN	Tomato crop disease classification.	94% testing accuracy and 99% training accuracy.	Gadekallu et al., 2021
23	CNN and AlexNet	Fruit maturity classification and detection of quality.	98.25 and 81.75 % accuracy for CNN and AlexNet, respectively.	Aherwadi et al., 2022
24	AI and 6G-IoT	Smart agricultural irrigation system development	Accuracy 86.34%, Sensitivity 89.28% and Precision 91 %.	Sitharthan et al., 2023
25	CNN	Identification of tomato leaf disease	98.4% accuracy	Agarwal et al., 2020.
26	CNN integrated with attention strategy.	Infection detection in tomato leaves	98% accuracy	Karthik et al., 2020
27	Recursive architecture based on neural networks (RNN)	Prediction of disease and monitor farm.	Precision, specificity, accuracy, and F1-score are 89%, 89%, 96%, and 75%, respectively.	Wongchai et al., 2022

Sustainability achievements through AI-based agricultural approaches:

Today's modern world is highly curious to understand and solve each and every problem in more or less in every field. From the middle of the 20th century, the serious issue of agricultural development, i.e., enhancing yield, profit margins, food safety, and security, was considered, and the solutions suggested by scientists throughout the world were applied. As a result, the present scenario of the global agricultural sector is much better than earlier. Still, the methods

employed to stabilize farming, in turn, weaken the stability and disturb the normal functioning of the ecosystem, decrease the levels of natural resources, and also reflect its negative consequences on human life. According to FAO World Food and Agriculture – Statistical Yearbook 2023, 27% i.e., 830 million of the world's population is dependent on agriculture for their livelihood in the year 2021 and the whole world is dependent on this sector for food i.e. survival. So, the yield-enhancing factors cannot be compromised at all as they will directly influence food security, but it is necessary to understand and find out which yield-enhancing factors are having deteriorating effects on the ecosystem and how their negative effects can be minimized.

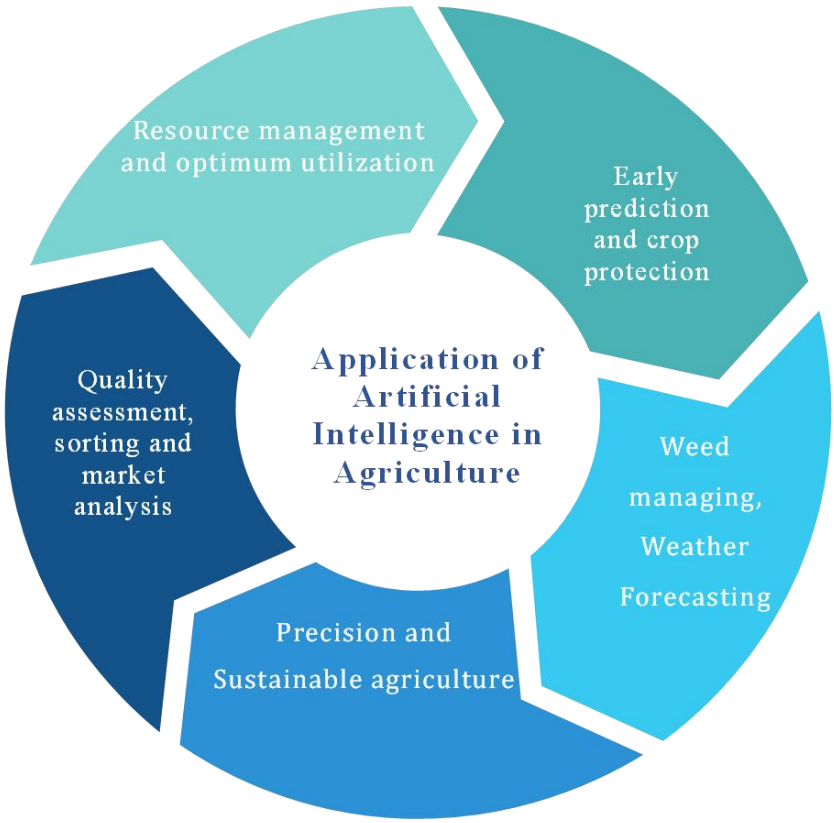


Figure 1. Application of AI tools in agriculture

Early Prediction:

The most common application of artificial intelligence is prediction. The predictive analysis is essential to precisely predict sowing time, harvesting time, pest attack, chances of diseases, market analysis, and price-related factors for specific crops. Artificial Neutral Networks is a specific type of AI technology commonly employed to predict different parameters. According to the United Nations FAO World Food and Agriculture – Statistical Yearbook 2023, the global use of pesticides up to 62% within just 2000-2021, and 56%, i.e., 195 million tonnes of inorganic N2 were utilized within 2021. Specific steps must be taken to control and minimize the application of more chemical inputs in agricultural systems. Early detection, i.e., predicting

diseases and stresses like drought before their arrival, can help farmers apply the resources wisely and minimize the use of pesticides. As disease is predicted earlier, farmers can be able to adopt steps that can minimize the chances of pest attack or disease spread. The synergism and integration of AI for prediction-based sustainability goal enhancement are reported (Wongchai et al., 2022). It is claimed that early prediction of pests in the cropland by employing ML models like AdaBoost, K-Nearest Neighbors, Decision Tree, Neural Net, and Poly SVM can allow the farmers to take necessary steps to check the attack, minimize the use of harmful insecticides by developing better alternative protective measures (Markovic et al., 2021).

Resource Management and Optimum Utilization:

Management and analysis of natural resources like water and soil are crucial for increasing growth, avoidance of stress, and boosting crop productivity along with sustainability by decreasing the chance of over-irrigation, soil erosion, etc. Many authors have pointed out AI-mediated resource management, such as Jez et al., 2021; Elbeltagi et al., 2022; Awais et al., 2023. According to the United Nations World Water Development Report (2023), about 25% of the groundwater has been withdrawn for the purpose of irrigating cropland. Areas with high irrigation and urbanization witnessed high levels of water scarcity. This problem can arise further if an alternative approach is not taken. This competition between cities and the agricultural sector withdraws nearly 72% of the global freshwater. This decline in the water level is so high that if it's controlled or water use is not reduced, the world may witness a water crisis that will be highly destructive for the survival of humanity.

AI-based Machine learning and deep learning technologies for successful soil texture assessment and soil water content analysis. AI-based technology monitoring is much easier, beneficial, and time-saving compared to commonly applied soil parameter measuring techniques and thus supports real-time decision-making (Awais et al., 2023). Algorithms based on Convolutional Neural Networks to predict the yield and also for advanced irrigation management is employed. Scientists used the term smart irrigation, which implies the precise, sustainable use of water resources to fulfill the requirement of crop plants to achieve high yields. They also pointed out that these AI-mediated methods, along with other components, are highly beneficial in decreasing the unnecessary use of water and energy (Sinwar et al., 2020). Also, these highly intellectual devices efficiently aid in reducing the load on the human brain for agricultural planning and other human efforts. Mohammed et al. (2023) highlighted that LSTM and XGBoost can accurately predict the need for water and energy in agricultural systems. These two models were successfully exploited to achieve the goal of sustainable irrigation in arid areas where the availability of water is a great deal. Since preserving water is a highly essential synergistic approach of utilizing the intellect of AI-based algorithms to ensure minimum water use with an extremely low rate of water wastage for achieving optimum growth, it is a great approach towards sustainable agriculture. It is also pointed out that the use of AI is

a practicable solution for managing water resources, studying the optimum water level required by the plants, and boosting yield (Alvim et al., 2022).

AI-mediated Agroecology: A Sustainable Approach towards Automated Agroecology:

Over-exploitation of nature and natural resources and continuous devastation of the environment by using chemical inputs ultimately led to the introduction of new disciplines naming agroecology that not only studies the effect of these toxicities on the health of crops, cropland, and the biota directly or indirectly related to the agroecosystem but also suggests a practicable solution to maintain sustainability and regenerate traditional methods to enhance production for the fulfillment to needs of a growing market, minimized external resource utilization, maintains a balance within the agricultural ecosystems and thus enhancing agricultural sustainability. Agroecology is a transformative, integrated, or transdisciplinary approach that combines traditional agricultural knowledge with the principles of ecology to fulfill its ultimate goal of agricultural sustainability. It also involves the study of interactions and the interrelationships between different biotic communities residing in their respective agrobiology; it also considers the effects of environmental conditions on these communities and their respective effects on production (Seremesic et al., 2021). Many authors have previously reported the synergistic approach of combining the intellect of AI with the principles of agroecology (Rout and Samantaray., 2022; Cousin et al., 2021). One successful example of AI-integrated agroecological management in Brazil. Artificial intelligence algorithms were applied to create the Species distribution models. These models were created by combining the intellect of AI with the georeferenced programming techniques and the combined data from the Global Biodiversity Information Facility (GBIF), WORLDCLIM, and ENVIREM. The final processed model facilitates the small-scale farming societies from Brazil to understand and cultivate crops with higher adaptivity to a particular region. This positively influences the growth and yield, solves the problems that have adverse effects on the economic status of farmers, and also aids in developing ecosystem-friendly agricultural approaches (Sasso et al., 2021).

Agribot: AI-mediated Robotics for agricultural sustainability:

Mohan et al., 2023 studied the integration of several robotic systems for the purpose of agricultural development. The authors highlighted a real-time robotic weed knife control system for crops like lettuce and tomato, a laser weeding prototype robot. Both systems provide a solution that counters the costly traditional hand-oriented weed removal systems and checks the utilization of chemical inputs, thus benefiting pollution control and facilitating sustainability. They utilize computer vision and machine learning technologies to detect and eliminate the target weeds without causing any harm to the crops.

Limitations:

High cost is a serious concern that limits farmers' implementation of smart technologies. Threads related to privacy, i.e., confidentiality of the farmer’s data, are also a serious concern to

deal with (Jose et al., 2021). The requirement of high computational power for the functioning of AI, in turn, leads to increasing the extent of global warming (Singh and Kaur., 2022). Another problem is the doubt of farmers about the abilities of AI to solve real-life problems. According to them, a man can have a better understanding of the problems as compared to machines. They find it difficult to understand the processing related to AI, and the expense of these high-tech devices shifts their attention only toward the problems and overshadows the positive impacts of AI (Mohan et al., 2023). Lack of knowledge of the rural farmers about the existence of such intellectual, smart agricultural methods is also a big hindrance in the way of developing AI-based agricultural methods (Javaid et al., 2023).

Conclusion:

In summary, it is clear that urgent action is needed to address the detrimental impacts of modern agricultural practices on ecosystems and human well-being. The dependency on chemical inputs and high-tech machinery, driven by the escalating demands of a growing population, has led to the neglect of sustainability. However, integrating artificial intelligence (AI) offers a transformative solution. AI facilitates early prediction of pests, diseases, and environmental conditions, optimizing resource utilization while minimizing the reliance on harmful chemicals. Smart agricultural approaches powered by AI enable precision farming and efficient resource management. Furthermore, AI-driven agroecological principles offer sustainable solutions by leveraging traditional knowledge with modern technology. Despite challenges like cost and farmer hesitation, the transformative potential of AI in advancing agricultural sustainability cannot be overlooked. Efforts to overcome limitations and promote awareness among farmers are essential for realizing the full benefits of AI in agriculture.

References:

Agarwal, M., Gupta, S. K., & Biswas, K. K. (2020). Development of Efficient CNN model for Tomato crop disease identification. *Sustainable Computing: Informatics and Systems*, *28*, 100407.

Aherwadi, N., Mittal, U., Singla, J., Jhanjhi, N. Z., Yassine, A., & Hossain, M. S. (2022). Prediction of fruit maturity, quality, and its life using deep learning algorithms. *Electronics*, *11*(24), 4100.

Ahmad, I., Hamid, M., Yousaf, S., Shah, S. T., & Ahmad, M. O. (2020). Optimizing pretrained convolutional neural networks for tomato leaf disease detection. *Complexity*, 1-6.

Ali, S., Ullah, M. I., Sajjad, A., Shakeel, Q., & Hussain, A. (2021). Environmental and health effects of pesticide residues. *Sustainable Agriculture Reviews 48: Pesticide Occurrence, Analysis and Remediation Vol. 2 Analysis*, 311-336.

Alreshidi, E. (2019). Smart sustainable agriculture (SSA) solution underpinned by internet of things (IoT) and artificial intelligence (AI). *arXiv preprint arXiv:1906.03106*.

Alvim, S. J., Guimarães, C. M., Sousa, E. F. D., Garcia, R. F., & Marciano, C. R. (2022). Application of artificial intelligence for irrigation management: a systematic review. *Engenharia Agrícola*, 42.

Awais, M., Naqvi, S. M. Z. A., Zhang, H., Li, L., Zhang, W., Awwad, F. A., Ismail, A.A.I., Khan, M.I., Raghavan, V., & Hu, J. (2023). AI and machine learning for soil analysis: an assessment of sustainable agricultural practices. *Bioresources and Bioprocessing*, *10*(1), 90.

Banerjee, S., Mitra, S., Velhal, M., Desmukh, V., & Ghosh, B. (2021). Impact of agrochemicals on the environment and human health: The concerns and remedies. *Int. J. Exp. Res. Rev.*, *26*, 125-140. https://doi.org/10.52756/ijerr.2021.v26.010

Buyrukoğlu, G., Buyrukoglu, S., & Topalcengiz, Z. (2021). Comparing regression models with count data to artificial neural network and ensemble models for prediction of generic *Escherichia coli* population in agricultural ponds based on weather station measurements. *Microbial Risk Analysis*, *19*, 100171.

Chaudhary, Yashi, & Pathak, H. (2023). MCIP: Mining Crop Image Data On pyspark data frame Using Feature Selection and Cluster Based Techniques. *Int. J. Exp. Res. Rev.*, *34*(Special Vol.), 106-119. https://doi.org/10.52756/ijerr.2023.v34spl.011

Chen, J., Chen, J., Zhang, D., Nanehkaran, Y. A., & Sun, Y. (2021). A cognitive vision method for the detection of plant disease images. *Machine Vision and Applications*, *32*, 1-18.

Chopra, H., Singh, H., Bamrah, M. S., Mahbubani, F., Verma, A., Hooda, N., Rana, P.S., Singla, R.K., & Singh, A. K. (2021). Efficient fruit grading system using spectrophotometry and machine learning approaches. *IEEE Sensors Journal*, *21*(14), 16162-16169.

Cousin, P., Husson, O., Thiare, O., & Ndiaye, G. (2021, May). Technology-enabled sustainable agriculture: The agroecology case. In *2021 IST-Africa Conference*, IEEE, 1-8.

Dawn, N., Ghosh, T., Ghosh, S., Saha, A., Mukherjee, P., Sarkar, S., Guha, S., & Sanyal, T. (2023). Implementation of Artificial Intelligence, Machine Learning, and Internet of Things (IoT) in revolutionizing Agriculture: A review on recent trends and challenges. *Int. J. Exp. Res. Rev.*, *30*, 190-218. https://doi.org/10.52756/ijerr.2023.v30.018

de Lima Silva, Y. K., Furlani, C. E. A., & Canata, T. F. (2024). AI-Based Prediction of Carrot Yield and Quality on Tropical Agriculture. *AgriEngineering*, *6*(1), 361-374.

Dutta, J., Patwardhan, M., Deshpande, P., Karande, S., & Rai, B. (2023). Zero-shot transfer learned generic AI models for prediction of optimally ripe climacteric fruits. *Scientific Reports*, *13*(1), 7347.

Elaraby, A., Hamdy, W., & Alruwaili, M. (2022). Optimization of Deep Learning Model for Plant Disease Detection Using Particle Swarm Optimizer. *Computers, Materials & Continua*, *71*(2).

Elbeltagi, A., Kushwaha, N. L., Srivastava, A., & Zoof, A. T. (2022). Artificial intelligent-based water and soil management. In *Deep learning for sustainable agriculture* (pp. 129-142). Academic Press.

FAO. 2023. *World Food and Agriculture – Statistical Yearbook 2023*. Rome.

Gadekallu, T. R., Rajput, D. S., Reddy, M. P. K., Lakshmanna, K., Bhattacharya, S., Singh, S., Jolfaei, A., & Alazab, M. (2021). A novel PCA–whale optimization-based deep neural network model for classification of tomato plant diseases using GPU. *Journal of Real-Time Image Processing*, *18*, 1383-1396.

Goyal, K., Kumar, P., & Verma, K. (2023). AI-based fruit identification and quality detection system. *Multimedia Tools and Applications*, *82*(16), 24573-24604.

Haq, S. I. U., Tahir, M. N., & Lan, Y. (2023). Weed detection in wheat crops using image analysis and artificial intelligence (AI). *Applied Sciences*, *13*(15), 8840.

Jain, S., & Ramesh, D. (2021, July). AI based hybrid CNN-LSTM model for crop disease prediction: An ML advent for rice crop. In *2021 12th International Conference on Computing Communication and Networking Technologies (ICCCNT)* (pp. 1-7). IEEE.

Javaid, M., Haleem, A., Khan, I. H., & Suman, R. (2023). Understanding the potential applications of Artificial Intelligence in Agriculture Sector. *Advanced Agrochem*, *2*(1), 15-30.

Jose, A., Nandagopalan, S., & Akana, C. M. V. S. (2021). Artificial Intelligence techniques for agriculture revolution: a survey. *Annals of the Romanian Society for Cell Biology*, 2580-2597.

Kaplun, D., Deka, S., Bora, A., Choudhury, N., Basistha, J., Purkayastha, B., ... & Misra, D. D. (2024). An intelligent agriculture management system for rainfall prediction and fruit health monitoring. *Scientific Reports*, *14*(1), 512.

Karthik, R., Hariharan, M., Anand, S., Mathikshara, P., Johnson, A., & Menaka, R. (2020). Attention embedded residual CNN for disease detection in tomato leaves. *Applied Soft Computing*, *86*, 105933.

Khoury, C. K., Brush, S., Costich, D. E., Curry, H. A., De Haan, S., Engels, J. M., Guarino, L., Hoban, S., Mercer, K.L., Miller, A.J., Nabhan, G.P., Perales, H.R., Richards, C., Riggins, C., & Thormann, I. (2022). Crop genetic erosion: understanding and responding to loss of crop diversity. *New Phytologist*, *233*(1), 84-118.

Krishnan, V. G., Deepa, J. R. V. P., Rao, P. V., Divya, V., & Kaviarasan, S. (2022). An automated segmentation and classification model for banana leaf disease detection. *Journal of Applied Biology and Biotechnology*, *10*(1), 213-220.

Laktionov, I., Diachenko, G., Rutkowska, D., & Kisiel-Dorohinicki, M. (2023). An explainable AI approach to agrotechnical monitoring and crop diseases prediction in Dnipro region of Ukraine. *Journal of Artificial Intelligence and Soft Computing Research*, *13*(4), 247-272.

Liu, L. W., Ma, X., Wang, Y. M., Lu, C. T., & Lin, W. S. (2021). Using artificial intelligence algorithms to predict rice (*Oryza sativa* L.) growth rate for precision agriculture. *Computers and Electronics in Agriculture*, *187*, 106286.

Liu, X., Zhu, X., Zhang, Q., Yang, T., Pan, Y., Sun, P., 2020. A remote sensing and artificial neural network-based integrated agricultural drought index: index development and applications. *Catena,* 186, 104394.

Malhotra, K., & Firdaus, M. (2022). Application of artificial intelligence in IoT security for crop yield prediction. *ResearchBerg Review of Science and Technology*, *2*(1), 136-157.

Marković, D., Vujičić, D., Tanasković, S., Đorđević, B., Ranđić, S., & Stamenković, Z. (2021). Prediction of pest insect appearance using sensors and machine learning. *Sensors*, *21*(14), 4846.

Mohammed, M., Hamdoun, H., & Sagheer, A. (2023). Toward Sustainable Farming: Implementing Artificial Intelligence to Predict Optimum Water and Energy Requirements for Sensor-Based Micro Irrigation Systems Powered by Solar PV. *Agronomy*, *13*(4), 1081.

Mohan, S. S., Venkat, R., Rahaman, S., Vinayak, M., & Babu, B. H. (2023). Role of AI in agriculture: applications, limitations and challenges: A review. *Agricultural Reviews*, *44*(2), 231-237.

Monteiro, A. L., de Freitas Souza, M., Lins, H. A., da Silva Teofilo, T. M., Júnior, A. P. B., Silva, D. V., & Mendonça, V. (2021). A new alternative to determine weed control in agricultural systems based on artificial neural networks (ANNs). *Field Crops Research*, *263*, 108075.

Oliveira, L. F., Moreira, A. P., & Silva, M. F. (2021). Advances in agriculture robotics: A state-of-the-art review and challenges ahead. *Robotics*, *10*(2), 52.

Pingali, P. L. (2012). Green revolution: impacts, limits, and the path ahead. *Proceedings of the national academy of sciences*, *109*(31), 12302-12308.

Raj, E. F. I., Appadurai, M., & Athiappan, K. (2022). Precision farming in modern agriculture. In *Smart Agriculture Automation Using Advanced Technologies: Data Analytics and Machine Learning, Cloud Architecture, Automation and IoT* (pp. 61-87). Singapore: Springer Singapore.

Ray, A. (2019). Micro level problems and management of agricultural activities Jagadishnagar village, Magrahat Block -1, South 24 Parganas, West Bengal, India. *Int. J. Exp. Res. Rev.*, *19*, 31-39. https://doi.org/10.52756/ijerr.2019.v19.004

Rout, S., & Samantaray, S. (2022, November). Interplay of Artificial Intelligence and Ecofeminism: A Reassessment of Automated Agroecology and Biased Gender in the Tea Plantations. In *2022 International Conference on Advancements in Smart, Secure and Intelligent Computing (ASSIC)* (pp. 1-6). IEEE.

Rozaini, I. A., Ahmad Zakey, N. E. N., Mohd Zaman, M. H., Ibrahim, M. F., Mustaza, S. M., & Mohamed Moubark, A. (2023). Bilateral Teleoperation with a Shared Design of Master and Slave Devices for Robotic Excavators in Agricultural Applications. *Int. J. Exp. Res. Rev.*, *35*, 119-127. https://doi.org/10.52756/ijerr.2023.v35spl.011

Sarkar, S., Chakrobarty, K., & Moitra, M. (2016). A study on abundance and group diversity of soil microarthropods at four different soil habitats in North Dinajpur, West Bengal, India. *Int. J. Exp. Res. Rev.*, 7, 32-37.

Sasso, M. A., & Costa, P. D. P. (2021). Artificial Intelligence Applied To Agroecology: A Model For Brazilian Territory. In *2021 ASABE Annual International Virtual Meeting* (p. 1). American Society of Agricultural and Biological Engineers.

Seremesic, S., Jovovic, Z., Jug, D., Djikic, M., Dolijanovic, Z., Bavec, F., Jordanovska, S., Bavec, M., Durdevic, B & Jug, I. (2021). Agroecology in the West Balkans: pathway of development and future perspectives. *Agroecology and Sustainable Food Systems*, *45*(8), 1213-1245.

Singh, P., & Kaur, A. (2022). A systematic review of artificial intelligence in agriculture. *Deep Learning for Sustainable Agriculture*, 57-80.

Singh, R. K., Tiwari, A., & Gupta, R. K. (2022). Deep transfer modeling for classification of Maize Plant Leaf Disease. *Multimedia Tools and Applications*, *81*(5), 6051-6067.

Sitharthan, R., Rajesh, M., Vimal, S., Kumar, S., Yuvaraj, S., Kumar, A., I, R.J., & Vengatesan, K. (2023). A novel autonomous irrigation system for smart agriculture using AI and 6G enabled IoT network. *Microprocessors and Microsystems*, *101*, 104905.

Somvanshi, P. S., Pandiaraj, T., & Singh, R. P. (2020). An unexplored story of successful green revolution of India and steps towards ever green revolution. *Journal of Pharmacognosy and Phytochemistry*, *9*(1), 1270-1273.

Soria-Lopez, A., Garcia-Perez, P., Carpena, M., Garcia-Oliveira, P., Otero, P., Fraga-Corral, M., Cao, H., Prieto, M.A., & Simal-Gandara, J. (2023). Challenges for future food systems: From the Green Revolution to food supply chains with a special focus on sustainability. *Food Frontiers*, *4*(1), 9-20.

Talaviya, T., Shah, D., Patel, N., Yagnik, H., & Shah, M. (2020). Implementation of artificial intelligence in agriculture for optimisation of irrigation and application of pesticides and herbicides. *Artificial Intelligence in Agriculture*, *4*, 58-73.

Vijayakumar, V., Costa, L., & Ampatzidis, Y. (2021). Prediction of citrus yield with AI using ground-based fruit detection and UAV imagery. In *2021 ASABE Annual International Virtual Meeting* (p. 1). American Society of Agricultural and Biological Engineers.

Wongchai, A., rao Jenjeti, D., Priyadarsini, A. I., Deb, N., Bhardwaj, A., & Tomar, P. (2022). Farm monitoring and disease prediction by classification based on deep learning architectures in sustainable agriculture. *Ecological Modelling*, *474*, 110167.

Zhang, L., Liu, Y., Ren, L., Teuling, A. J., Zhu, Y., Wei, L., Zhang, L., Jiang, S., Yang, X., Fang, X., & Yin, H. (2022). Analysis of flash droughts in China using machine learning. *Hydrology and Earth System Sciences*, *26*(12), 3241-3261.

HOW TO CITE

Mayuri Bhagawati*, Chayan Dhar, Dipan Sarma, Manna Das, Badal Kumar Datta (2024). Integration of artificial intelligence toward better agricultural sustainability. © International Academic Publishing House (IAPH), Dr. Suman Adhikari, Dr. Manik Bhattacharya and Dr. Ankan Sinha, *A Basic Handbook of Science, Technology and Innovation for Inclusive Development [Volume: 1]*, pp. 71-85. ISBN: 978-81-969828-4-3.

DOI: https://doi.org/10.52756/ bhstiid.2024.e01.005

OPEN ACCESS PEER REVIEW
DOI: https://doi.org/10.52756/ bhstiid.2024.e01.006
Chapter- 6

A Brief Review on Plant Growth Promoting Rhizobacteria

Folguni Laskar[a]*

Keywords: Plant growth-promoting rhizobacteria, N_2-fixation, sustainable agriculture, fertilizers, rhizospheric bacteria.

Abstract:

Plant growth-promoting rhizobacteria (PGPR) are helpful bacteria residing in the rhizosphere (root zone) of plants. The PGPR also refers to free-living soil bacteria that are favourable to plant development and can colonize plant roots. This book chapter explores the prospects of PGPR in promoting plant growth and development. It highlights how PGPR employ several mechanisms, for example, N_2-fixation, nutrient solubilization, phytohormone production, and induced systemic resistance, to enhance plant health and yield. The increasing demand for eco-friendly agricultural practices positions PGPR as an auspicious substitute for chemical fertilizers and pesticides. Finally, current challenges and future directions in exploring the full potential of PGPR for sustainable agriculture are discussed, emphasizing the need for further research and technological innovations to optimize their efficacy and application strategies.

Introduction:

The ever-growing demand for food security necessitates a sustainable approach to agriculture (Shah et al. 2021). Chemical fertilizers and pesticides, while historically effective in boosting yields, have raised concerns about environmental pollution and potential harm to human health (Dhakal et al. 2026; Banerjee et al. 2021). In this context, PGPR has appeared as a capable alternative (Shah et al. 2021). PGPR is nitrogen-fixing bacteria or diazotrophs that support plant growth and/or prevent and reduce disease. These are members of a class of bacteria present at root surfaces, close to roots, and in the rhizosphere (Tang et al. 2021). Main crops like rice, wheat, maize, and sugarcane are associated with PGPR, which promotes plant growth by various means.

As stated by Davison (Davison 1988), Brierley (Brierley 1985), and Ehrlich (Ehrlich 1990), these bacteria's primary roles include: (1) providing nutrients to crops; (2) inducing plant hormones to promote plant development; (3) regulating or suppressing the action of plant pathogens; (4) enhancing soil structure; and (5) bioaccumulation or microbial leakage of chemicals. Recently, bioremediation of contaminated soils has also employed microorganisms in the soil to mineralize organic contaminants. Based on their level of

Folguni Laskar[a]*
[a]Guest lecturer, Department of Botany, Govt. Degree College, Dharmanagar, Tripura(N) –799253, India
E-mail: folguni80@gmail.com; Orcid iD: https://orcid.org/0009-0005-9219-2912
***Corresponding Author**: folguni80@gmail.com

Dr. Suman Adhikari, Dr. Manik Bhattacharya and Dr. Ankan Sinha, A Basic Handbook of Science, Technology and Innovation for Inclusive Development [Volume: 1]. ISBN: 978-81-969828-4-3; pp- 86-103; Published online: 27th May, 2024

adherence to the plant, two categories of microorganisms are distinguished: endophytic and rhizospheric colonizers.

PGPR can enhance plant growth directly through boosting nutrient cycling processes including biological nitrogen fixation, phosphorus solubilization, and phytohormone synthesis, or indirectly through manufacturing biocontrol chemicals that impede phytopathogens (Tang et al. 2021). Plant-microbe relations in the rhizosphere are crucial for sustainable crop production because they influence nutrient mobilization, transformation, and solubilization from a limited pool. This allows plants to absorb essential nutrients and reach their full genetic potential. In a cohesive nutrient management in plants, the employment of biological techniques is currently gaining popularity as a complement to chemical fertilizers for increasing crop production. Several researchers reported the utilization of PGPR has found a possible part in emerging sustainable crop production. Numerous non-symbiotic (*Azospirillum, Azotobacter, Bacillus, and Klebsiella sp*.) and symbiotic (*Rhizobium sp*.) bacteria are currently being employed globally to increase plant productivity (Hayat et al. 2010).

Burr and Caesar referred PGPR as nodule-promoting rhizobacteria (NPR) or plant-health promoting rhizobacteria (PHPR) (Burr and Caesar 1984). These bacteria are linked to the rhizosphere, a crucial soil biological habitat for relations between microbes and plants. Symbiotic bacteria and free-living rhizobacteria are the two categories into which PGPR can be separated based on their interactions with the plants.

Several bacteria, such as species of *Azospirillum*, *Pseudomonas*, *Azotobacter*, *Azoarcus*, *Bacillus*, *Beijerinckia*, *Burkholderia*, *Klebsiella*, *Herbaspirillium*, and *Serratia*, have exhibited plant development features (Kour et al. 2019). Numerous researchers have confirmed the ability of PGPR in plant growth development (Hayat et al. 2010). According to studies, PGPR bacterial isolates can fix N_2 and generate species that endorse plant development.

It has been established that the interior of sugarcane is home to several types of diazotrophic bacteria (Taulé et al. 2012; Sharma et al., 2024). The roots and stems of sugarcane comprise high concentrations of Acetobacter diazotrophicus, a recently identified diazotrophic bacteria that can reach 106 per gram fresh weight (Sinha et al. 2024). After infecting sugarcane tissues, research using electron microscopy of A. diazotrophicus gave precise information regarding where the bacteria were located in the sugarcane tissues of micropropagated plantlets. The *α-Proteobacterium Herbaspirillum seropedicae* was found in large quantities in the sugarcane leaves, stems, and roots. *Herbaspirillum rubrisubalbicans*, which was previously known as *Pseudomonas rubrisubalbicans*, is also a close relative of *H. seropedicae*, and it causes mottled stripe disease in sugarcane (Hayat et al. 2010). *H. rubrisubalbicans* is also capable of fixing nitrogen. Sugarcane tissue frequently contained a second novel type of diazotrophic bacteria, previously known as isolate E-bacteria but now

provisionally called *Burkholderia brasilensis* Also found in maize plants were *Herbaspirillum seropedicae* and *Burkholderia sp.*

This book chapter aims to provide an outline of how PGPR promotes plant growth and elucidate their potential applications in modern agriculture. By delving into the latest research findings and highlighting current challenges and opportunities, this review seeks to underscore the significance of PGPR as an encouraging avenue for sustainable crop production.

Diversity of rhizospheric bacteria and crop improvement

The diversity of rhizospheric bacteria plays a critical role in crop improvement and agricultural sustainability (Mukhtar et al. 2019). The rhizosphere, the soil region directly encouraged by plant roots, harbors a complex microbial community that interacts with plants in several ways, influencing their development, health, and productivity. The rhizosphere is a hotspot for microbial activity due to the constant supply of nutrients from root exudates. Certain rhizosphere bacteria, called PGPR, directly contribute to development of plant and health by several methods. The use of diazotrophs as biofertilizers for rice production has been the subject of widespread study for several years (Jha et al. 2020). The "hot-spot," or aggregates with accrued organic compound and the rice rhizosphere, is the only area with significant microbial activity. Rice agro-ecosystem soils of India comprise a rich diversity of PGPR enhanced development and yield of cultivated rice (Kumar et. al. 2020). Various scientists and researchers all over the world have isolated and utilised these bacteria for crop improvement in different crops (Kumar et al. 2020). They isolated bacteria from rhizospheric soil or non-rhizospheric soil. Plant growth supporting bacteria were selected for use in crop improvement. The diazotrophs are isolated much from rhizospheric soil compared to non-rhizospheric soil because plant exudes and rotting plant materials provide a source of organic substance to help the growth of these diazotrophs. The presence of microorganisms in the root tissue or rhizoplane area of a plant is termed root colonisation, while the existence of microbes in the adjacent soil of the root is termed rhizosphere colonisation (Compant et al. 2010). *Citrobacter, Enterobacter, Erwinia,* and *Klebsiella* are among the facultative anaerobic bacteria whose associations and capacities for nitrogen fixation. Important agricultural plants like rice, maize, wheat, and some grasses have been found to harbor a variety of bacterial species, including *Gluconacetobacter diazotrophicus*, *Herbaspirillum*, *Azoarcus*, *Azospirillum*, *Serratia*, *Burkholderia*, *Enterobacter*, *Rhizobium*, and *Klebsiella* (Kour et al. 2019). *Alcaligenes faecalis, Enterobacter cloacae, Klebsiella planticola, Azospirillum brasilense, Klebsiella oxytoca, and Azospirillum lipoferum* are the commonly associated N_2-fixing bacteria in the rice rhizosphere (Afzal et al. 2019). Certain strains of *Azospirillum brasilense* and *Alcaligenes faecalis* have been identified. The only strains that have been shown to be safe and effective for use as biofertilizer are *Enterobacter cloacae, Alcaligenes faecalis, Azospirillum, and Klebseilla pneumoniae.* Associative N_2-fixing

bacteria can have up to 10^3–10^7 cells/g of soil, which is a higher density in paddy than in dry land (Burns and Hardy 2012). In the rhizosphere, associative N_2-fixing bacteria are primarily found. Microaerophilic bacteria, including *Azospirillum spp., Burkholderia spp., and Herbaspirillum spp*. were found colonizing the shoots, roots, and leaves of maize, rice, and wheat (Alves et al. 2015). Research on nitrogen-fixing bacteria linked to cereals has grown significantly. Numerous non-diazotrophic bacterial species and an extensive variety of plant species have been found to exhibit bacterial colonization of the internal tissues of healthy plants.

From the rhizosphere of wetland rice, diazotrophic bacteria have been recovered, including *Klebsiella oxytoca, Enterobacter cloacaeae, Alcaligenes*, and *Azospirillum*. Nitrogen-fixing bacteria that can invade the inner workings of plant tissues have been discovered. *Herbaspirillum seropedicae* was isolated from rice, sorghum, and maize plants, and *Gluconacetobacter diazotrophicus* (synon. *Acetobacter diazotrophicus*) was isolated from sugarcane plants. *Herbaspirillum* is an endophyte that colonizes a variety of cereals, including rice, sugarcane, maize, and sorghum. *Herbaspirillum* was able to fix N_2 under aseptic conditions at an estimated 33–58 mg tube^{-1}. *Herbaspirillum seropedicae* colonizes the inside of wheat roots between cells, acting as an endophytic diazotroph of wheat. *Herbaspirillum rubrisubalbicans*, as an obligatory endophyte of stems, roots, and leaves, *Herbaspirillum seropedicae* is similarly present in the stems and roots of sugarcane (Monteiro et al. 2012).

Reis et al., reported that B. tropicalis is limited to the stems and roots of sugarcane, but *Burkholderia brasilensis* is an endophyte of the plant's stems, roots, and leaves (Reis et al. 2000). Additionally, these organisms can create compounds that are hostile to nematodes. The N_2-fixing bacteria that were recovered from the paddy field ranged from 1.41 x 10^6 cfu to 1.24 x 10^8 cfu/g weight of the soil.

The N_2-fixing capacity of strains of *Stenotrophomonas maltophilia, Pseudomonas fluorescens,* and *Bacillus fusiformis* were reported (Park et al. 2005). These strains have been found from the rhizosphere soils of wheat, maize, and rice crops rich in inorganic fertilizers. A nitrogen-fixing bacterium called *Sphingomonas azotifigens sp. nov*. was identified from the roots of Oryza sativa, the cultivable endophytic bacterial community-which included *A. junii, Acinetobacter calcoaceticus, Burkholderia sp., B. gladioli, Enterobacter sakazaki, Klebsiella pneumoniae, Pseudomonas oryzihabitans, P. straminea, Ralstonia pickettii*, and *Sphingomonas sp*.—was extracted from soybean stems, roots, and leaves (Xie & Yokota 2006).

Derxia has been found in the rhizosphere of various rice cultivators. Diazotrophs are found in many species of the Enterobacteriaceae family, especially those found in the rice rhizosphere. These genera include several unnamed species along with *Klebsiella, Enterobacter, Citrobacter, and Pseudomonas*, which are examples of diazotrophs having PGP activity. These plant-associated bacteria include *Pseudomonas putida* or *Pseudomonas*

fluorescens, Citrobacter freundii, Enterobacter cloacae, and Klebsiella pneumoniae. Several N_2-fixing bacteria were reported in graminaceous plants. These included rhizospheric bacteria (*Azotobacter paspali* and *Beijerinckia fluminensis*), associative bacteria (*A. amazonense, Azospirillumlipoferum, A. brasilense,*), and endophytic bacteria (*H. rubrisubalbicans, Herbaspirillum seropedicae, Burkholderia brasilensis, Gluconacetobacter diazotrophicus,* and *B. tropica*) (Andrews et al. 2003).

Zhang et al. detected soil bacteria that belonged to genera like *Alcaligenes, Azotobacter, Beijerinckia, Azospirillum, Bacillus, Derxia, Campylobacter*, numerous members of Enterobacteriaceae (*Pantoae, Klebsiella*), and *Pseudomonas stutzeri* by using traditional microbiological techniques that involved culturing bacteria (Zhang et al. 2008). Some isolates, like those of *Gluconacetobacter* and *Herbaspirillum, Azoarcus, Burkholderia*, or *K. pneumoniae* strain 342, happened to be endophytes. In cultivated rice (*Oryza sativa L.* cultivar KDML-105), the population of feasible endophytic diazotrophic bacteria was examined in various soil settings (Prakamhang et al. 2009). The nitrogen fixing capacity of particular consortia and single isolates was evaluated. It was demonstrated that a single isolate from every diazotrophic consortia could both promote and inhibit N_2-fixation. It was discovered that a few isolates shared close ties with *Pseudomonas spp., Pantoea agglomerans, Brevundimonas aurantiaca, Enterobacter dissolvens*, and Enterobacteriaceae.

Stenotrophomonas maltophilia, which was formerly known as *Pseudomonas maltophilia* and *Xanthomonas maltophilia*, is commonly found in close proximity to plants. It has been identified and isolated from the rhizosphere of various plants, including grass, oat, wheat, cucumber, oilseed, grape, maize, potato, and lettuce. Understanding and employing rhizosphere bacterial diversity is a propitious method for sustainable agriculture.

Effect of rhizosphere on the diazotrophs of rice plants

The rhizosphere, the soil area impacted by plant roots, plays a significant role in shaping the population and activity of diazotrophic bacteria connected with rice (Dobbelaere et al. 2003). Diazotrophs are microorganisms capable of atmospheric N_2-fixing into a form that plants can use, thus contributing to the N_2 nutrition of rice, that is essential for their growth and development. Numerous chemical, physical, and biological aspects of the soil affect the development and colonization of bacteria on plant roots. Rice liberates several organic molecules, for example, amino acids, sugars, organic acids, and phenolic compounds, into the rhizosphere through root exudation. These biomolecules assist as an energy and carbon source for diazotrophic bacteria, promoting their growth and activity. The prevalence and dispersal of diazotrophic bacteria in maize plants can be exaggerated by biological aspects, for example, cultivar category and stage of plant development. Research on the microbial colonization of maize roots confirmed that plant development significantly impacts on fluorescent pseudomonas populations that reside in maize roots.

Muthukumarasamy et al., working with 16 kinds of sugarcane, found that N_2-fertilizor was the restraining aspect for the separation of *Gluconacetobacter diazotrophicus*, but that N_2-fertilized samples had no effect on the isolation of *Herbaspirillum spp* (Muthukumarasamy et al. 1999). It was discovered that high N_2-fertilization levels had a detrimental impact on *G. diazotrophicus* capacity to form colonies (CFU). However, since the nitrogen fertilizer changes the physiological condition of the plant, which in turn disturbs the plant's relationship with the endophyte, this detrimental effect on the bacteria does not appear to be a straight result of the nitrogen fertiliser.

The availability of nitrogen is a significant issue that influences the action of diazotrophic bacteria. The accessibility of C, N, or P can restrict the growth of bacteria in aquatic environments. Microbial development was facilitated by carbon and energy supplies found in organic matter derived from organic rich strata. The ideal conditions for microbial development and nutrient availability are often found in soil solutions with a neutral pH. The interrelationship between bacteria and plants can also be impacted by the type of soil, as it might have different chemical and biological qualities. It was found that ammonium in the soil can prevent diazotrophic bacteria from growing. This detrimental effect is also seen in the diazotrophic population living in plants with high N_2-fertilization levels.

Biotic and environmental factors can impact the number of diazotrophic bacteria that are certainly linked with the maize rhizosphere. The study assessed the impact of two distinct maize genotypes, both with and without N_2-fertilizer, on the distribution and population dynamics of diazotrophic bacteria linked to maize across various stages of plant ontogenesis. Utilizing maize cultivars (Santa Helena 8447 and Santa Rosa 3063) that had been earlier chosen from 32 cultivars against the highest and lowest retort to N_2-fertilizer (Roesch et al. 2006). The analysis was conducted in an area with and without N_2-fertilizer. They concluded that because roots were the favoured place of colonization regardless of cultivar category or development phase, the ontogenic phase of the maize plants had an impact on the dynamics of the diazotrophic bacterial population but not the cultivar type. Additionally, they noticed that the diazotrophic bacterial population was adversely disturbed by adding N_2-fertilizer during the initial phases of maize growth.

Plant-bacteria interaction

Plant-bacteria interactions are fundamental to the health and development of plants, in addition to the functioning of ecosystems (Singh et al. 2017). These interactions may be helpful, neutral, or detrimental, reliant on various influences, for example, the identity of the plant and bacteria species involved, environmental conditions, and the specific mechanisms of interaction. Some bacteria form symbiotic relationships with plants, where both partners benefit. Examples include N_2-fixing bacteria, for example, *Rhizobium spp*. in legumes and *Frankia spp*. in actinorhizal plants, which provide plants with fixed N_2 in exchange for organic compounds. PGPR are free-living soil bacteria which are good for plant development. They can colonize roots and endorse plant development. PGPR are related to the rhizosphere,

a crucial soil ecological habitat for plant-microbe interactions. PGPR can be separated in two categories depending on their interactions with plants: free-living rhizobacteria and symbiotic bacteria.

A wide variety of bacteria, such as species of *Azospirillum, Enterobacter, Pseudomonas, Klebsiella, Bacillus, Azotobacter, Arthobacter, Burkholderia, Alcaligens, and Serratia*, have been isolated from the rhizosphere of diverse agricultural plants (Di Benedetto et al. 2017). The majority of these bacteria have several features that endorse plant development, such as the fixation of atmospheric N_2, the solubilization of minerals, the synthesis of phytohormones (gibberellic acid and IAA), siderophores, and some antagonistic compounds that are useful in the administration of plant diseases. The potential of the advantageous PGPR as biofertilizers has led to a sharp rise in attention in them in recent years. The environment and the genotype of the organisms are both crucial for a productive plant-bacterium relationship. Engelhard et al. documented the impact of plant genotype in wild rice types and traditional rice that assist a better population of *Azoarcus sp*. compared to current variations (Engelhard et al. 2000). It was also found that *Asaia bogorensis*, a species of *Acetobacterium,* has been shown to increase the development of pineapple plants, most likely by creating phytohormones or by engaging in N_2-fixation activities. The availability of nitrogen to the roots plays a significant role in the interface between plants and microorganisms. Even while just a few non-legumes have been identified to contain biologically fixed nitrogen, this process has significantly affected the ecology of both wild and developed ecosystems. According to Pereg Gerk et al., the discovery of spontaneous *A. brasilense* mutants with increased acetylene reduction ability with wheat suggested that populations in nature are highly flexible and that few genotypes that fix a lot of nitrogen might be preferred under specific circumstances (Pereg Gerk et al. 2000). Sugar cane is an excellent crop that help N_2-fixation since some cultivars may obtain more than 150 kg N/ha/year from BNF. Thus, the capability of related bacteria for N_2-fixation benefits certain crops inherently. Okon and Labandera-Gonzales found that *Azospirillum* inoculation may significantly boost yields, from 5 to 30%, especially when chemical N_2-fertilizer use was minimal (Okon and Labandera-Gonzales 1994). This was based on their analysis of 20 years of field inoculation globally. Nevertheless, they thought that the growth endorsing impact was most likely related to phytohormone synthesis.

Following the inoculation of rice with certain strains of *A. amazonense,* considerable nitrogen fixation was found, as revealed by the ^{15}N isotope dilution process. Several researchers also provided evidence of promoting plant development resulting from endophyte nitrogen fixation. This supports the idea that studying a relationship between the rhizosphere and agriculture could be very beneficial. It was observed that fusion transcripts of *nifH* were found in rice inoculated with *Azoarcus* sp. BH72 when altered with a negligible organic source. However, the *nifH* reporter was relatively weak and delayed. Hurek et al. discovered that significant transcripts of *nifH* were observed in Kallar grass strain BH72, both in plants

grown in greenhouses and in noninoculated plants growing in the wild, and that this strain bestowed to N_2 uptake (Hurek et al. 2002).

Comprehending the interactions between plants and bacteria is crucial for various applications in agriculture, including the development of sustainable crop management practices, biofertilizers, biocontrol agents, and the exploitation of beneficial microbial communities to enhance crop productivity while minimizing environmental impacts.

Inoculation of diazotrophs for crop improvement

Inoculating rice with bacteria is one of the sustainable and viable methods. Inoculation of diazotrophic bacteria for crop improvement involves the deliberate introduction of N_2-fixing bacteria in the rhizosphere or plant tissues to enhance nitrogen availability and promote plant growth (Doty 2011). This practice is particularly beneficial in agricultural systems with high nitrogen demand, such as those involving N_2-fixing crops like legumes or in areas where synthetic nitrogen fertilizers are expensive or environmentally unsustainable. As a result of their capability to fix atmospheric N_2, certain soil bacteria, including *Clostridium*, *Azospirillum*, *Herbaspirillum*, and *Burkholderia*, may provide rice with additional N_2. Some of these bacteria can also create phytohormones that promote plant development and/or antagonists that prevent soil-borne plant diseases and fix nitrogen dioxide. It has been demonstrated that diazotrophs, which effectively colonize the root endosphere, fix nitrogen. Diazotrophic bacteria can fix N_2 in a form that plants can utilize (ammonium). Inoculating crops with these bacteria can supplement or even replace the need for synthetic nitrogen fertilizers, reducing production costs and minimizing environmental pollution from nitrogen runoff.

Microscopic inspection revealed that gus-tagged *Achromobacter xyloxidans* had colonized the vascular zones and intercellular spaces of roots. The researchers observed a noteworthy rise in the length of shoots and roots, weight, and content of chlorophyll-a of rice plants upon inoculation with gus-tagged WM234C-3. The cross-infection ability and characteristics that promote plant growth indicated that, following a thorough and critical pathogenicity test, endophytic bacteria can be used as agricultural agents for several crops.

The impact of PGPR on field grownup maize yield, seed germination, and seedling growth was investigated by Gholami et al. *Pseudomonas putida* strain R-168, *P. flurescens* strain R-93, *P. flurescens* strain DSM-50090, *P. putida* strain DSM291, *A lipoferum* DSM1691, and *A brasilense* DSM 1690 were the bacterial strains utilized in the experiment (Gholami et al. 2009). According to the findings, maize seed inoculation greatly improved seed germination and seeding vigor.

In their study, Mirza et al. (2006) explored the consequences of inoculating two rice types, Super Basmati and Basmati 385, with the K1 strain of the genus *Pseudomonas* (Mirza et al. 2006). They then compared the results to those of three non-Pseudomonas N_2-fixing PGPR, namely *Azospirillum lipoferum* strain N4, *Azospirillum brasilense* strain Wb3, and *Zoogloea* strain Ky1. They stated that in every infected treatment, there was a greater shoot biomass

and/or grain production for both types of rice compared to the noninoculated control plants. For both rice types, the impact of Pseudomonas strain K1 on grain yield was similar to that of *Zoogloea* sp. Ky1 and *A. brasilense* Wb3. These findings demonstrate the value of investigating N_2-fixing pseudomonads as possible PGPR inoculants for rice. Feng et al. also examined how the rice endophyte *Pantoea agglomerans* YS19 affected photosynthetic allocation and host plant development (Feng et al. 2006). They found that endophyte YS19 stimulates photosynthetic allocation and influences host plant growth. Inoculating endophytic diazotroph *Pantoea agglomerans* YS19 increased the biomass of the host rice seedlings grown for 12 days, by 18.7% on N_2-supplemented medium or by 63.4% on N_2-free media. YS19 cell culture sprayed on rice during the premilk phase greatly improved the product of photosynthetic absorption. Applying YS19 cell culture during the late milk stage prevented the formation of the plant sink.

Tran Vân et al. found that the inoculation of rice with *Burkholderia vietnamiensis* caused in a considerable upsurge in grain yields, reaching up to 8 t ha^{-1} (Tran Vân et al. 2000). It was discovered that this strain may save 25–30 kgN ha^{-1}. In greenhouse research by Mirza et al., inoculating rice with *Herbaspirillum* resulted in a considerable increase in production, reaching 7.5 g $plant^{-1}$ (Mirza et al. 2000). They researchers measured BNF in super basmati and basmati rice by means of various *Herbaspirillum* strains. For basmati and super basmati, the %N values were 19.5–38.7 and 38.1–58.2, respectively.

Sharma et al. (2010) investigated a study in the summers of 2008 and 2009 to examine the effects of four NPK fertiliser levels combined with varying concentrations of biofertilizers (*Azotobacter* and PSB) on the development and production of the hybrid cauliflower variety known as "Swati" (Sharma and Sharma 2010). Both alone and in combination, the application of biofertilizers improved height of plant, number of leaves/plants, gross weight/plant, curd depth, curd diameter, curd yield, and profit cost ratio. When 100% NPK + seedlings dipping of both inoculants were added to the plots, the highest commercial output (247 q/ha) was detected. Additionally, the yield (238.66 q/ha) attained by applying 75% NPK + *Azotobacter* + PSB was found to be equivalent to that of 100% prescribed NPK, ensuing in a savings of 25% NPK fertilisers with the highest profit cost ratio.

It was observed that the performance of phosphate solubilising bacteria in increasing the development and production of sunflowers (*Helianthus annus* L.) in the presence of phosphorous fertiliser (Zehra 2010). The intention of this analysis was to assess the result of the PSB, *Bacillus* M-13, with and without variable quantities of phosphorous fertiliser on the development and production of sunflowers in field circumstances. The PSB mobilised phosphorous proficiently in the sunflower and enhanced quality of seed and oil production. Furthermore, when PSB was employed in combination with phosphorous fertilisers, a superior result was observed.

Inoculation of diazotrophic bacteria offers a promising strategy for improving crop productivity, reducing environmental impacts, and promoting sustainable agricultural

development. Moreover, the success of inoculation depends on aspects, for example, the selection of effective bacterial strains, proper application methods, and environmental conditions conducive to bacterial colonization and nitrogen fixation.

Molecular characterization of diazotrophs

Molecular characterization of diazotrophs involves the use of numerous molecular biology methods to recognize, classify, and analysis the genetic diversity, phylogeny, and functional genes related with N_2-fixing bacteria (Liu et al. 2017). These techniques provide insights into the taxonomic composition, ecological roles, and N_2-fixation potential of diazotrophic communities in different environments. The discovery of diazotrophs in rice paddy field soil has, up to this point, primarily been accomplished through cultivation-based study, which is followed by morphological and/or genetic recognition of specific isolates. Molecular biological approaches have provided considerable support for identifying and classifying of bacterial isolates in recent times. After the invention of *nif* gene cloning and DNA sequencing amplification by polymerase chain reaction (PCR), an alternate method of identifying nitrogen fixers gained popularity. As a result, *nif* DNA was found in hypothetical nitrogen-fixing isolates and was established by PCR amplification and nucleotide sequencing of the amplified sequence.

Zehr and McReynolds (1989) created a set of universal *nifH* primers, among other oligonucleotides, to amplify *nifH* remains from ecological materials (Zehr and McReynolds 1989). This is significant for ecological investigations of N_2-fixers in rhizosphere soil. Another benefit is that it allows one to evaluate the variety of bacteria while accounting for the non-culturable population, all without isolating strains. Utilizing conserved 16S rRNA gene sequences, strain-specific probes were also created to track populations of specific nitrogen-fixing species in environmental samples.

Noteworthy progresses have been attained in the targeted identification of bacteria using rRNA-targeted oligonucleotide probes. These probes can target regions of the 23S or 16S rDNA with highly variable sequences. Numerous phylogenetic oligonucleotide probes were created for *Burkholderia sp*., *Acetobacter diazotrophicus, Azoarcus, Herbaspirillum spp*., and *Azospirillum spp*. One of the earliest genes still in existence and active in the annals of gene evolution is the nitrogenase iron protein gene (*nifH*). The contours of the *nifH* tree are said to be substantially in line with the 16S rRNA phylogeny.

N_2-fixing heterotrophic bacteria are linked to fixation of N_2 in the rice root region. However, because it is generally accepted that only a tiny proportion of naturally occurring prokaryotes may indeed be culturable, investigations on the rhizospheric nitrogen fixing microflora have, up till now, suffered from the usage of specific media for counts and isolation.

It is now feasible to depict both non-culturable and culturable bacteria thanks to the progress of novel molecular methods and tactics like rRNA sequencing, FISH (fluorescence in situ hybridization), random amplified polymorphic DNA (RAPD), DGGE (denaturating

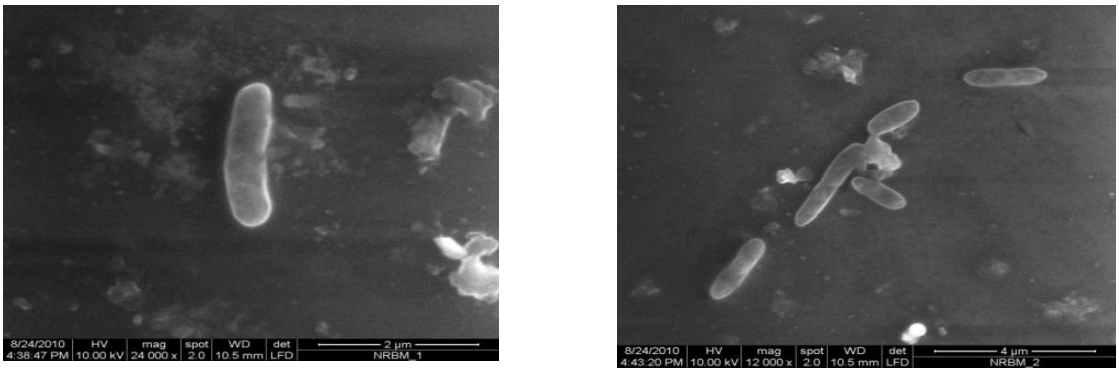
gradient gel electrophoresis), TGGE (temperature gradient gel electrophoresis), and SSCP (single strand conformation polymorphism) (Dubey et al. 2006). But little is known about the intricate web of interactions that makes up life in the rhizosphere of crops, and its revelation is anticipated to unveil many previously unknown truths.

Six *Burkholderia* isolates were isolated by Roy et al. (2013) from rice rhizosphere soils in South Assam, India's tropical lowlands. SDSA-I10/1, one of the identified *Burkholderia* isolates, was chosen for 16S rDNA sequencing due to its increased nitrogen fixing capacity (Roy et al. 2013). *Burkholderia caribensis* strain SDSA-I10/1 (GU372342) was isolated from the isolate SDSA-I10/1, which exhibited the strongest similarity to *Burkholderia caribensis* MWAP84 (Y17011). This strain can be employed as an indigenous microbial inoculant for exhaustive rice harvesting in tropical lowlands since it considerably increases the development and production characteristics of rice when injected than uninoculated control plants.

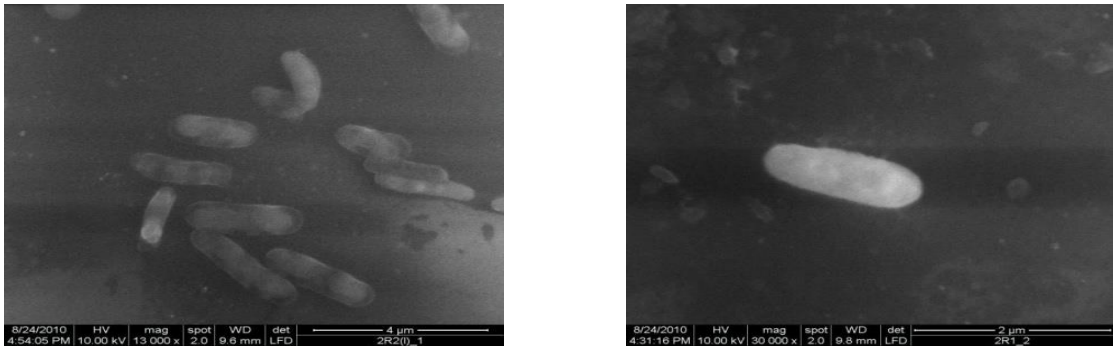
Shu et al. employed DGGE) and qPCR techniques to evaluate the molecular diversity and extent of *nifH* gene sequences in bulk paddy soil and rhizosphere, respectively, in orthodox administration and varying durations of organic compounds (2, 3, 5, 9 years) (Shu et al. 2012). Based on the *nifH* gene sequence, the phylogenetic distribution of clones revealed that the taxonomic groups comprised Betaproteobacteria (24.1%), Alphaproteobacteria (27.6%), and Gammaproteobacteria (48.3%). The majority of the diazotrophs were members of the orders Rhizobiales and Pseudomonadales. Using qPCR, they quantified the amount of *nifH* gene sequences in the soil; 2.27×10^5 to 1.14×10^6 copies/g were found. They discovered that *nifH* gene numbers in organic soil, both rhizosphere and bulk, were substantially greater compared to CM soil, except two years of organically managed soil. Furthermore, compared to bulk soil, the organic rhizosphere soil (3, 5, and 9 years) had noticeably greater nifH gene copy numbers. Shahi et al. (2011) used conventional microbiological and biochemical approaches to isolate and screen 114 diazotrophic bacteria from the rice rhizosphere of 5 districts in Eastern Uttar Pradesh, India, for PGP actions (Shahi et al. 2011). Amplified ribosomal DNA restriction analysis (ARDRA) and DGGE were used to analyze the molecular diversity of the isolates, and the results showed clear variations between each isolate. Twenty-one (21) isolates out of the 114 displayed numerous features that promoted plant development and were very active in PGP. Based on 16S rDNA sequencing, these isolates were identified, and they belonged to the following genera: g-proteobacterium strain VA3S1, *Rhizobium, Agrobacterium, Pantoea, Bacillus, Microbacterium, Sphingomonas, Pseudomonas, Enterobacter, Advenella, Ancylobacter,* and *Microbacterium.*

Roesch et al. examined the effects of two genotypes of maize, both with and without N_2-fertilizer, as well as the size of the population of diazotrophic bacteria that are certainly linked with the maize rhizosphere (Roesch et al. 2006). Using two cultivars of maize (Santa Helena 8447 and Santa Rosa 3063), the population dynamics and distribution of diazotrophic bacteria related with maize over several plant ontogenic phases were also investigated. They

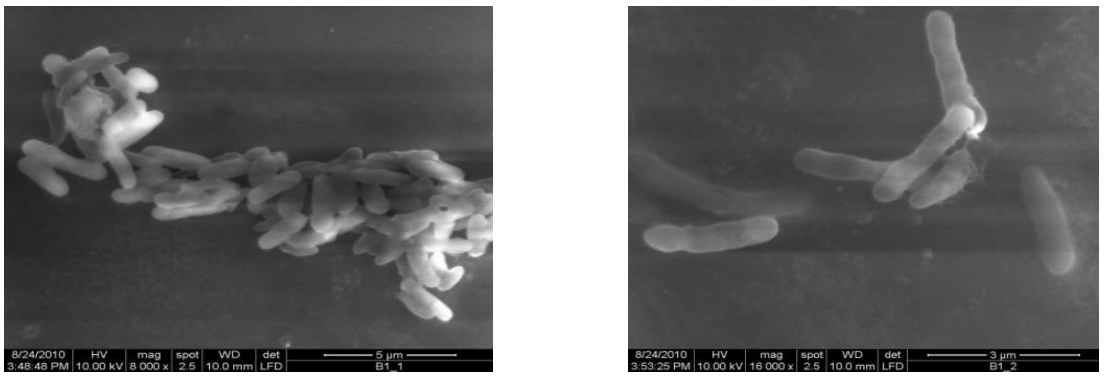
employed molecular and microbiological methods to describe the population structure of diazotrophic bacteria. The most likely number of bacteria was determined by means of semi-solid N_2-free media. Additionally, DNA was extracted from soil and plant tissue and amplified using nested PCR for *nifH* gene fragments, and restriction endonucleases TaqI and HaeIII were used for RFLP analysis.



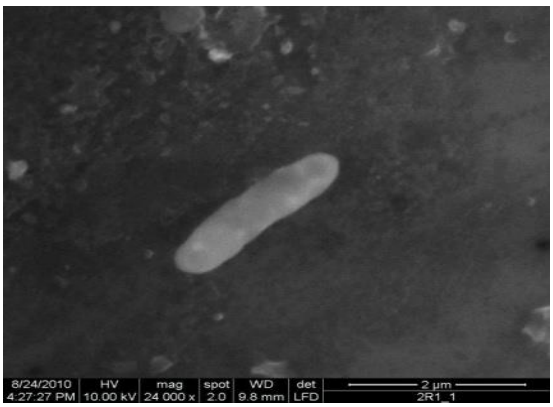
Sphingomonas azotifigens.



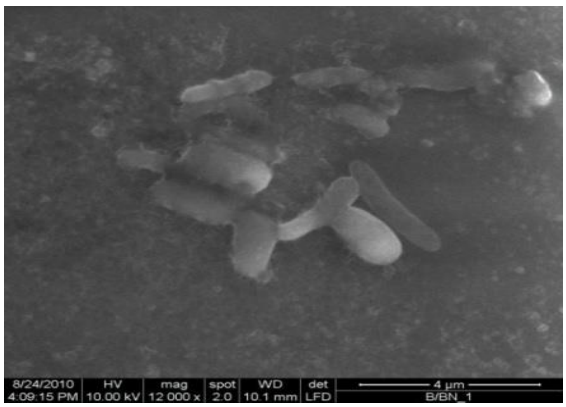
Stenotrophomonas maltophila. ***Pseudomonas putida.***



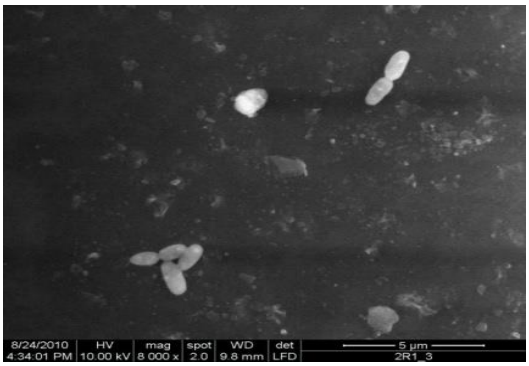
Herbispirillum sp. ***Herbispirillum rubrisubalbicans.***



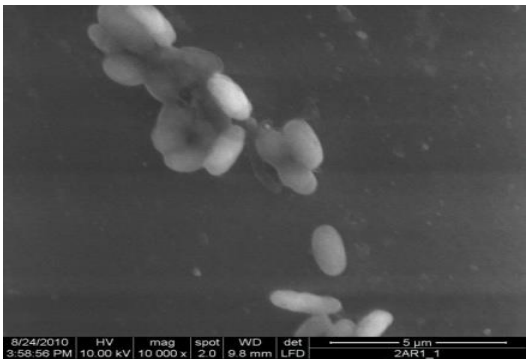
Acinetobacter radioresistans.



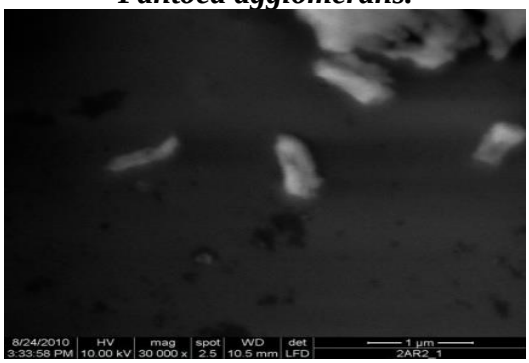
Enterobacter cloaceae subsp. dissolvens.



Pantoea agglomerans.



Achromobacter xyloxidans.



Alcaligenes faecalis

Klebsiella pneumoneae

Figure 1. Electron micrographs diazotrophs

By employing molecular techniques, researchers can gain a deeper comprehending of the diversity, ecology, and functional potential of diazotrophic bacteria in various ecosystems, paving the way for the progress of novel approaches for crop improvement, sustainable agriculture, and environmental management.

Challenges and Future Perspective:

Despite the immense potential of PGPR, there are still challenges, such as regulatory hurdles, market acceptance, and widespread adoption. Addressing these challenges will be decisive for understanding the full prospective of PGPR in sustainable agriculture. Different PGPR strains have varying effects on different plant species. Identifying and selecting the most effective strains for specific crops and soil conditions remains a challenge. Furthermore, developing cost-effective methods for large-scale production and formulating PGPR into user-friendly biofertilizers is crucial for practical application. Indeed, environmental factors can impact the efficiency of PGPR in the field. A deeper consideration of the complex interactions between PGPR, plants, and the surrounding microbiome is necessary to optimize their beneficial effects.

Studying the composition and interactions of the entire rhizosphere microbial community will provide insights for exploring the synergistic effects of PGPR with other beneficial microbes. Screening for PGPR with unique and potent plant growth-promoting traits from diverse environments remains a promising avenue. Genetic modification could potentially improve specific functionalities of PGPR strains, such as nitrogen fixation or stress tolerance. Advances in biotechnology offer opportunities to enhance the effectiveness of PGPR. This includes genetic engineering to improve traits such as stress tolerance, nutrient utilization, and colonization ability. Moreover, developing efficient methods for applying PGPR to crops and integrating them into existing agricultural practices is essential for wider adoption. By addressing these challenges and exploring future directions, researchers can continue to advance our understanding of PGPR and unlock their full potential for sustainable agriculture.

Conclusion:

In conclusion, the study of PGPR offers promising intuitions into sustainable agricultural development. The book chapter shows that PGPR play fundamental roles in increasing plant growth, enhancing nutrient uptake, and conferring resistance against pathogens. Their multifaceted mechanisms, for example, N_2-fixation, phosphate solubilization, and generation of phytohormones, underscore their significance in agricultural ecosystems. Furthermore, the symbiotic connection between plants and PGPR highlights the potential for these bacteria to be biofertilizers and biocontrol agents, reducing reliance on chemical inputs and mitigating environmental degradation. However, despite considerable advancements in understanding PGPR functions, challenges remain in optimizing their application, ensuring efficacy across different environmental conditions, and scaling up their use in commercial agriculture. Moving forward, interdisciplinary research efforts encompassing microbiology, plant biology, and agronomy will be critical for unlocking the potential of PGPR in sustainable agriculture, ultimately contributing to global food security and environmental sustainability. Further exploring PGPR diversity and formulation strategies will be crucial for maximizing their beneficial effects and fostering a more sustainable and productive agricultural landscape.

References:

Afzal, I., Shinwari, Z. K., Sikandar, S., & Shahzad, S. (2019). Plant beneficial endophytic bacteria: Mechanisms, diversity, host range and genetic determinants. *Microbiological research*, *221*, 36-49.

Alves, G. C., Videira, S. S., Urquiaga, S., & Reis, V. M. (2015). Differential plant growth promotion and nitrogen fixation in two genotypes of maize by several *Herbaspirillum* inoculants. *Plant and Soil*, *387*, 307-321.

Andrews, M., James, E. K., Cummings, S. P., Zavalin, A. A., Vinogradova, L. V., & McKenzie, B. A. (2003). Use of nitrogen fixing bacteria inoculants as a substitute for nitrogen fertiliser for dryland graminaceous crops: progress made, mechanisms of action and future potential. *Symbiosis*, *35*(1), 209-229.

Banerjee, S., Mitra, S., Velhal, M., Desmukh, V., & Ghosh, B. (2021). Impact of agrochemicals on the environment and human health: The concerns and remedies. *Int. J. Exp. Res. Rev.*, *26*, 125-140. https://doi.org/10.52756/ijerr.2021.v26.010

Brierley, J. A. (1985). Use of microorganisms for mining metals. In: Halvorson HO, Pramer D, Rogul M (eds) Engineered organisims in the environment: scientific issues. ASM Press, Washington, pp 141–146.

Burns, R. C., & Hardy, R. W. (2012). Nitrogen fixation in bacteria and higher plants.

Burr, T. J., Caesar, A., & Schrolh, M. N. (1984). Beneficial plant bacteria. *Critical Reviews in Plant Sciences*, *2*(1), 1-20.

Compant, S., Clément, C., & Sessitsch, A. (2010). Plant growth-promoting bacteria in the rhizo- and endosphere of plants: their role, colonization, mechanisms involved and prospects for utilization. *Soil Biology and Biochemistry*, *42*(5), 669-678.

Davison, J. (1988). Plant beneficial bacteria. *Bio/technology*, *6*(3), 282-286.

Dhakal, K., Singh, K., Adhikari, S., Ojha, R., & Sapkota, M. (2016). Response of application of different sources of nutrients as fertilizer on growth and yield of Cauliflower (*Brassica oleracea* L. var. botrytis) and its residual effect on soil. *Int. J. Exp. Res. Rev.*, *7*, 10-17.

Di Benedetto, N. A., Corbo, M. R., Campaniello, D., Cataldi, M. P., Bevilacqua, A., Sinigaglia, M., & Flagella, Z. (2017). The role of plant growth promoting bacteria in improving nitrogen use efficiency for sustainable crop production: a focus on wheat. *AIMS microbiology*, *3*(3), 413.

Dobbelaere, S., Vanderleyden, J., & Okon, Y. (2003). Plant growth-promoting effects of diazotrophs in the rhizosphere. *Critical reviews in plant sciences*, *22*(2), 107-149.

Doty, S. L. (2011). Nitrogen-fixing endophytic bacteria for improved plant growth. *Bacteria in agrobiology: plant growth responses*, 183-199.

Dubey, S. K., Tripathi, A. K., & Upadhyay, S. N. (2006). Exploration of soil bacterial communities for their potential as bioresource. *Bioresource Technology*, *97*(17), 2217-2224.

Ehrlich, H. L. (1990). Geomicrobiology (2ndedn) Dekker. *New York*, p 646.

Engelhard, M., Hurek, T., & Reinhold-Hurek, B. (2000). Preferential occurrence of diazotrophic endophytes, *Azoarcus* spp., in wild rice species and land races of Oryza sativa in comparison with modern races. *Environmental Microbiology*, *2*(2), 131-141.

Feng, Y., Shen, D., & Song, W. (2006). Rice endophyte *Pantoea agglomerans* YS19 promotes host plant growth and affects allocations of host photosynthates. *Journal of applied microbiology*, *100*(5), 938-945.

Gholami, A., Shahsavani, S., & Nezarat, S. (2009). The effect of plant growth promoting rhizobacteria (PGPR) on germination, seedling growth and yield of maize. *International Journal of Agricultural and Biosystems Engineering*, *3*(1), 9-14.

Hayat, R., Ali, S., Amara, U., Khalid, R., & Ahmed, I. (2010). Soil beneficial bacteria and their role in plant growth promotion: a review. *Annals of microbiology*, *60*, 579-598.

Hurek, T., Handley, L. L., Reinhold-Hurek, B., & Piché, Y. (2002). *Azoarcus* grass endophytes contribute fixed nitrogen to the plant in an unculturable state. *Molecular Plant-Microbe Interactions*, *15*(3), 233-242.

Jha, P. N., Gomaa, A. B., Yanni, Y. G., El-Saadany, A. E. Y., Stedtfeld, T. M., Stedtfeld, R. D., ... & Dazzo, F. B. (2020). Alterations in the endophyte-enriched root-associated microbiome of rice receiving growth-promoting treatments of urea fertilizer and Rhizobium biofertilizer. *Microbial ecology*, *79*, 367-382.

Kour, D., Rana, K. L., Yadav, N., Yadav, A. N., Kumar, A., Meena, V. S., ... & Saxena, A. K. (2019). Rhizospheric microbiomes: biodiversity, mechanisms of plant growth promotion, and biotechnological applications for sustainable agriculture. *Plant growth promoting rhizobacteria for agricultural sustainability: from theory to practices*, 19-65.

Kumar, R., Mishra, J. S., Rao, K. K., Mondal, S., Hazra, K. K., Choudhary, J. S., ... & Bhatt, B. P. (2020). Crop rotation and tillage management options for sustainable intensification of rice-fallow agro-ecosystem in eastern India. *Scientific reports*, *10*(1), 11146.

Liu, H., Zhang, L., Meng, A., Zhang, J., Xie, M., Qin, Y., ... & Qiu, L. (2017). Isolation and molecular identification of endophytic diazotrophs from seeds and stems of three cereal crops. *PLoS One*, *12*(10), e0187383.

Mirza, M. S., Rasul, G., Mehnaz, S., Ladha, J. K., So, R. B., Ali, S., & Malik, K. A. (2000). Beneficial effects of inoculated nitrogen-fixing bacteria on rice. *The quest for nitrogen fixation in rice*, 191-204.

Mirza, M. S., Mehnaz, S., Normand, P., Prigent-Combaret, C., Moënne-Loccoz, Y., Bally, R., & Malik, K. A. (2006). Molecular characterization and PCR detection of a nitrogen-fixing *Pseudomonas* strain promoting rice growth. *Biology and Fertility of Soils*, *43*, 163-170.

Monteiro, R. A., Balsanelli, E., Wassem, R., Marin, A. M., Brusamarello-Santos, L. C., Schmidt, M. A., ... & Souza, E. M. (2012). *Herbaspirillum*-plant interactions: microscopical, histological and molecular aspects. *Plant and Soil*, *356*, 175-196.

Mukhtar, S., Mehnaz, S., & Malik, K. A. (2019). Microbial diversity in the rhizosphere of plants growing under extreme environments and its impact on crop improvement. *Environmental Sustainability*, *2*(3), 329-338.

Muthukumarasamy, R., Revathi, G., & Lakshminarasimhan, C. (1999). Influence of N fertilisation on the isolation of *Acetobacter diazotrophicus* and *Herbaspirillum spp*. from Indian sugarcane varieties. *Biology and Fertility of Soils*, *29*, 157-164.

Okon, Y., & Labandera-Gonzalez, C. A. (1994). Agronomic applications of *Azospirillum*: an evaluation of 20 years worldwide field inoculation. *Soil Biology and Biochemistry*, *26*(12), 1591-1601.

Park, M., Kim, C., Yang, J., Lee, H., Shin, W., Kim, S., & Sa, T. (2005). Isolation and characterization of diazotrophic growth promoting bacteria from rhizosphere of agricultural crops of Korea. *Microbiological Research*, *160*(2), 127-133.

Pereg Gerk, L., Gilchrist, K., & Kennedy, I. R. (2000). Mutants with enhanced nitrogenase activity in hydroponic *Azospirillum brasilense*-wheat associations. *Applied and environmental Microbiology*, *66*(5), 2175-2184.

Prakamhang, J., Minamisawa, K., Teamtaisong, K., Boonkerd, N., & Teaumroong, N. (2009). The communities of endophytic diazotrophic bacteria in cultivated rice (Oryza sativa L.). *Applied soil ecology*, *42*(2), 141-149.

Reis, V. M., Baldani, J. I., Baldani, V. L. D., & Dobereiner, J. (2000). Biological dinitrogen fixation in gramineae and palm trees. *Critical Reviews in Plant Science*, *19*(3), 227-247.

Roesch, L. F. W., Olivares, F. L., Pereira Passaglia, L. M., Selbach, P. A., de Sá, E. L. S., & de Camargo, F. A. O. (2006). Characterization of diazotrophic bacteria associated with maize: effect of plant genotype, ontogeny and nitrogen-supply. *World Journal of Microbiology and Biotechnology*, *22*, 967-974.

Roy, B. D., Deb, B., & Sharma, G. D. (2013). Isolation, characterization and screening of Burkholderia caribensis of rice agro-ecosystems of South Assam, India. *African Journal of Agricultural Research*, *8*(4), 349-357.

Sharma, K. C., & Sharma, L. K. (2010). Effect of bio-fertilizers and NPK levels on growth and yield of mid-maturity group of cauliflower under mid hill subhumid conditions of Himachal Pradesh. *Journal of Hill Agriculture*, *1*(1), 19-22.

Shah, A., Nazari, M., Antar, M., Msimbira, L. A., Naamala, J., Lyu, D., ... & Smith, D. L. (2021). PGPR in agriculture: A sustainable approach to increasing climate change resilience. *Frontiers in Sustainable Food Systems*, *5*, 667546.

Shahi, S. K., Rai, A. K., Tyagi, M. B., Sinha, R. P., & Kumar, A. (2011). Rhizosphere of rice plants harbour bacteria with multiple plant growth promoting features. *African Journal of Biotechnology*, *10*(42), 8296-8305.

Shu, W., Pablo, G. P., Jun, Y., & Danfeng, H. (2012). Abundance and diversity of nitrogen-fixing bacteria in rhizosphere and bulk paddy soil under different duration of organic management. *World Journal of Microbiology and Biotechnology*, *28*, 493-503.

Sharma, D., Singh, P., & Punhani, A. (2024). Sugarcane Diseases Detection using the Improved Grey Wolf Optimization Algorithm with Convolution Neural Network. *International Journal of Experimental Research and Review*, *38*, 246-254. https://doi.org/10.52756/ijerr.2024.v38.022

Sinha, S. K., Kumar, A. D., Kumari, A., & Singh, A. K. (2024). The Integrated Effect of Organic Manure, Biofertilizer and Inorganic Fertilizer on Soil Properties, Yield and Quality in

Sugarcane Plant-ratoon System under Calcareous Soil of Indo-gangetic Plains of India. *Journal of Scientific Research and Reports*, *30*(5), 193-206.

Singh, R. K., Singh, P., Li, H. B., Yang, L. T., & Li, Y. R. (2017). Soil–plant–microbe interactions: use of nitrogen-fixing bacteria for plant growth and development in sugarcane. *Plant-Microbe Interactions in Agro-Ecological Perspectives: Volume 1: Fundamental Mechanisms, Methods and Functions*, 35-59.

Tang, A., Haruna, A. O., Majid, N. M. A., & Jalloh, M. B. (2020). Potential PGPR properties of cellulolytic, nitrogen-fixing, phosphate-solubilizing bacteria in rehabilitated tropical forest soil. *Microorganisms*, *8*(3), 442.

Taulé, C., Mareque, C., Barlocco, C., Hackembruch, F., Reis, V. M., Sicardi, M., & Battistoni, F. (2012). The contribution of nitrogen fixation to sugarcane (*Saccharum officinarum L.*), and the identification and characterization of part of the associated diazotrophic bacterial community. *Plant and Soil*, *356*, 35-49.

Trân Van, V., Berge, O., Ngô Kê, S., Balandreau, J., & Heulin, T. (2000). Repeated beneficial effects of rice inoculation with a strain of *Burkholderia vietnamiensis* on early and late yield components in low fertility sulphate acid soils of Vietnam. *Plant and Soil*, *218*, 273-284.

Verma, P., Yadav, A. N., Kumar, V., Singh, D. P., & Saxena, A. K. (2017). Beneficial plant-microbes interactions: biodiversity of microbes from diverse extreme environments and its impact for crop improvement. *Plant-microbe interactions in agro-ecological perspectives: volume 2: microbial interactions and agro-ecological impacts*, 543-580.

Xie, C. H., & Yokota, A. (2006). *Sphingomonas azotifigens sp*. nov., a nitrogen-fixing bacterium isolated from the roots of Oryza sativa. *International journal of systematic and evolutionary microbiology*, *56*(4), 889-893.

Zehr, J. P., & McReynolds, L. A. (1989). Use of degenerate oligonucleotides for amplification of the nifH gene from the marine cyanobacterium *Trichodesmium thiebautii*. *Applied and environmental Microbiology*, *55*(10), 2522-2526.

Zehra, E. K. İ. N. (2011). P-Solubilizing Bacteria and Phosphorus Fertilizer Applications to Sunflower Improves Seed Set, Seed Filling Efficiency and Concentration of Macro-and. *Turkish Journal of Field Crops*, *16*(2), 183-189.

Zhang, Y., Kang, X., Liu, H., Liu, Y., Li, Y., Yu, X., ... & Chen, Q. (2018). Endophytes isolated from ginger rhizome exhibit growth promoting potential for *Zea mays*. *Archives of Agronomy and Soil Science*, *64*(9), 1302-1314.

HOW TO CITE

Folguni Laskar (2024). A Brief Review on Plant Growth Promoting Rhizobacteria. © International Academic Publishing House (IAPH), Dr. Suman Adhikari, Dr. Manik Bhattacharya and Dr. Ankan Sinha, *A Basic Handbook of Science, Technology and Innovation for Inclusive Development [Volume: 1]*, pp. 86-103. ISBN: 978-81-969828-4-3 DOI: https://doi.org/10.52756/bhstiid.2024.e01.006

OPEN ACCESS PEER REVIEW
DOI: https://doi.org/10.52756/ bhstiid.2024.e01.007
Chapter- 7

Women's empowerment and financial inclusion in India: 2006-2019

Nikhil Kumar Mandal[a]*

Keywords: Women, empowerment, financial inclusion, microfinance programs, Self-Help Groups (SHGs), poverty alleviation.

Abstract:

Women play a vital role in the fabric of society globally, and their active involvement in development programs is essential for fostering a healthy and progressive environment, particularly in developing nations like India. However, historically, women's potential has been overlooked, leading to systemic neglect across various dimensions, including economic, socio-cultural, familial, legal, political, and psychological realms. As a result, women often lag behind men, facing deprivation and barriers to accessing resources and opportunities. Hence, the discussion on women's empowerment through financial inclusion in India is crucial within the academic sphere.

This paper seeks to investigate the impact of microfinance programs facilitated by Self-Help Groups (SHGs) in collaboration with banks on poverty alleviation in India since 2006. Specifically, it focuses on the economic empowerment of women over the past thirteen years and their pivotal role in mitigating poverty through microfinance initiatives in the country. Drawing on a range of secondary sources, including reputable data, the study underscores the positive correlation between increased participation in microfinance programs and women's empowerment.

Economic empowerment through microfinance not only enhances women's decision-making power but also amplifies their influence in critical areas such as education, healthcare, and family welfare. Beyond individual empowerment, women's active engagement in microfinance initiatives catalyses broader societal progress, thereby contributing significantly to the socioeconomic development of India.

In conclusion, economic empowerment through microfinance emerges as a powerful mechanism for enhancing women's agency and fostering societal advancement, ultimately paving the way for inclusive and sustainable development across India.

Introduction:

In recent years, women's empowerment has been a burning issue in India. Microfinance helps to acquire empowerment of women. As a result, they can participate in decision making, access resources, are able to properly plan their time for their work as well as their family, and they can also know the difference between right and wrong, and free themselves from any irrelevant customs, traditions, and practices. Women are an integral part of the society of any country of the world. Therefore, their participation in developing programs is highly needed for a healthy / better environment for the society. Specially developing countries like India require it. Unfortunately, the hidden capabilities of women have been neglected from the beginning of society. They are deprived of facilities of different dimensions by men. Women are backward

Nikhil Kumar Mandal[a]*
[a]Department of Economics, Chakdaha College, Nadia, West Bengal, India
E-mail: nkm.eco@chakdahacollege.ac.in; Orcid iD: https://orcid.org/0009-00015064-5400
***Corresponding Author**: nkm.eco@chakdahacollege.ac.in

Dr. Suman Adhikari, Dr. Manik Bhattacharya and Dr. Ankan Sinha, A Basic Handbook of Science, Technology and Innovation for Inclusive Development [Volume: 1]. ISBN: 978-81-969828-4-3; pp- 104-116; Published online: 27th May, 2024

compared to men in multiple dimensions such as Economic, Socio-culture, Familial / Interpersonal, Legal, Political and psychological awareness (Moirangleima, 2016; Maiti, 2017). Therefore, they are able to acquire empowerment through these dimensions. Women have been economically or socially deprived by men from the beginning, but they have a vital role in the development of any country in the world (Kaur & Batra, 2023). Although women have been economically or socially deprived by men since the beginning, they play an important role in the development of any country in the world. For that reason, two dimensions such as Economic and Socio-culture have been discussed in this paper.

In addition, we have dealt with the women's participation rate through financial inclusion by microfinance programs at which they are able to remove their own poverty due to participation in the production process by receiving the factor of production as capital from banks. They are employed by themselves in different informal sectors. For example, in West Bengal, The large members of SHGs are engaged in main economic activities such as paddy processing, vegetable cultivation, goat rearing, dairy, fishery, biri and spices making, etc, and a relatively smaller number of SHGs are involved in jute diversity product, weaving and silk thread making, etc. The common feature is that member of SHGs do not have access to a strong marketing network for selling their product due to a lack of capital. They force their products to be sold in the local market network. For example, members of SHGs are engaged in the cultivation of vegetables and other economic activities; they easily sell these items in local hats/markets. Women prove that they are just as much an earning member of society as men. They used to earn money for their family. Further, women spend more of their income on their children first, such as for education, health, etc. As a result, women will build a healthy society and economic development of a country. They play an important role in the financial sector in transaction-related matters. For example, Women are very responsible members of the society to the bank regarding loan repayment. Their repayment performance of women is better than that of men, as per bank records.

Objectives & Methodology:

Objectives

This paper aims to explore the impact of microcredit programs facilitated by Self-Help Groups (SHGs) in collaboration with banks on poverty alleviation in India since 2006. Specifically, it delves into the economic empowerment of women over the past thirteen years, focusing on their role in poverty reduction through microfinance initiatives in India.

By operating Self-Help Groups (SHGs), this study examines how microcredit programs have been utilized as a tool for economic empowerment and poverty reduction among marginalized communities, particularly women, in West Bengal. It seeks to analyse the effectiveness of these programs in fostering financial inclusion, enhancing livelihood opportunities, and ultimately lifting individuals and households out of poverty.

Through a comprehensive examination of the socio-economic impact of microfinance interventions, this paper aims to contribute to a deeper understanding of the role of SHGs and microcredit programs in addressing poverty challenges in India, with a specific focus on the context of West Bengal.

Methodology

This study relies on secondary sources of information, with relevant data collected from various reputable sources. The primary sources include the National Microfinance Conclave, 2014, and the Status of Microfinance in India spanning from 2006-07 to 2018-19. These sources encompass data from organizations such as NABARD, the World Bank, and RBI. Additionally, information has been gathered from published books and journals.

The final table presented in the paper is derived from straightforward mathematical calculations. It measures women's participation rates in microcredit programs based on two key economic factors: the number of women involved and the amount of SHG savings with banks or amount of loans disbursed to SHGs or amount of loans outstanding against SHGs. This data is systematically organized and displayed in the table for analysis and interpretation.

Women's Empowerment:

In India, the focus on empowering women, particularly at the grassroots level, gained momentum during the eighth five-year plan (1992-1997). This emphasis was channelled through initiatives such as the empowerment of women via Panchayati Raj Institutions. Furthermore, efforts were directed towards implementing the National Policy for Empowerment of Women, which had been recently adopted in 2001. These measures aimed to translate policy objectives into actionable strategies, with a specific focus on ensuring the survival, protection, and development of women and children through a rights-based approach.

During the tenth five-year plan (2002-2007), India continued its commitment to empowering women by addressing critical issues such as economic participation, decision-making both internally and externally, access to higher education, and the right to choose a life partner. These areas were identified as major challenges hindering women's empowerment in the country.

The recognition of these challenges underscored the need for comprehensive strategies and policy interventions aimed at overcoming barriers to women's empowerment. Efforts were made to create opportunities for women to actively participate in economic activities, have a voice in decision-making processes at various levels, access higher education, and exercise agency in choosing their life partner. These initiatives marked significant steps towards advancing gender equality and women's empowerment in India.

Defining women's empowerment is a complex task with various perspectives in the literature. Generally, it entails enabling women to lead lives of dignity, humanity, respect, self-esteem, and self-reliance, allowing them to make decisions autonomously. According to Gutierrez (1990), empowerment involves enhancing personal, interpersonal, or political power to enable

individuals to improve their life circumstances. Nobel laureate A.K Sen (1993) views empowerment as reflected in an individual's capability set, influenced by personal attributes and social structures.

Women's empowerment encompasses their involvement in societal programs. For instance, Hashemi et al. (1996) measured women's empowerment based on indicators like mobility, ability to make significant purchases, and political and legal awareness. Mayoux (1998) emphasizes empowerment as a process of internal change and the capacity to make decisions, while Kabeer (2001) stresses the importance of increasing women's decision-making power within households to enhance their agency.

The United Nations' Guidelines on Women's Empowerment outline five components, including self-worth, choice determination, access to opportunities and resources, control over one's life, and the ability to influence social change. Malhotra, Schuler, and Boender (2002) expand on this, highlighting the multidimensional nature of women's empowerment across economic, socio-cultural, familial, legal, political, and psychological realms.

Access to credit and participation in income-generating activities, as noted by Cheston and Kuhn (2002), are crucial for strengthening women's bargaining power within households. Microfinance has gained prominence in recent years for its role in enhancing women's decision-making power by facilitating economic engagement.

Krishna (2003) defines empowerment as enhancing individuals' capacity to make development and life choices, translating these into desired actions and outcomes. Kabeer (2005) describes empowerment as the process by which those previously deprived of choice gain such an ability. Women's empowerment is seen as a developmental process in society (Rahman et al., 2009).

Studies, such as that by Ranjula Bali Swaina and Fan Yang Wallentin (2009), indicate that participation in microfinance programs, such as Self-Help Groups in India, empowers women by enabling them to resist gender norms and make choices. Similarly, Sujay Bhattacharya (2015) highlights the collective movement of Self-Help Groups as a means of achieving women's empowerment.

Overall, women's empowerment involves enhancing agency, decision-making power, and access to resources, contributing to their ability to lead fulfilling lives and effect societal change.

Women's Participation rate and Financial Inclusion:

The examination of women's inclusion in the financial sector reveals a historical deprivation perpetuated by societal norms favouring men. Over time, efforts have been made to address this disparity, with some literature referring to increased participation in microfinance programs as a form of women's empowerment. This connection suggests a positive correlation between the participation rate in microfinance programs and the empowerment of women. Consequently, it becomes essential to analyse the extent of women's participation in microcredit programs at a national level.

The participation rate of women in microfinance programs serves as a gauge of their involvement in productive activities. By engaging in these programs, women establish themselves as earning members within households and contribute to the economic dynamics of society. Moreover, their involvement positions them not only as labourers but also as critical thinkers, contributing to the advancement of rural economies.

Within microfinance institutions, women actively engage in discussions with other members to address existing challenges. This collaborative effort aims to improve the conditions within these institutions and consequently enhance the rural economy. Thus, the participation rate in microfinance programs serves as a tangible measure of women's empowerment in this context.

The involvement of women in microfinance programs signifies a step towards their empowerment within the financial sector and broader society. By analysing and fostering increased participation rates, societies can work towards creating more inclusive and equitable financial systems, ultimately leading to socioeconomic progress for all members.

In this section of the study, our focus is on examining the detailed aspects of women's participation rates within microfinance programs across India, particularly concerning economic factors. We have delineated three key parameters for analysis: savings linked with banks as of March 31st, the amount of loans disbursed during the year, and the outstanding loan amounts as of March 31st. Table 1, provided below, presents the relevant data for our investigation.

Table 1 illustrates the quantitative representation of women's involvement in microfinance programs, showcasing the number of women participants alongside the corresponding economic figures. The data presented encompasses a comprehensive overview of women's engagement with microfinance initiatives, highlighting their contributions to savings, loan disbursements, and outstanding loan balances.

By scrutinizing these economic indicators, we aim to gain insights into the extent of women's participation in microfinance activities, as well as their impact on financial inclusion and empowerment. This detailed analysis will enable us to assess the efficacy of microfinance programs in fostering economic agency and advancement among women across diverse regions of India.

Table 1 presents the percentage of women Self-Help Groups (SHGs) in India over the past thirteen years, along with their corresponding distributions in savings linked with banks, loans disbursed, and outstanding loans.

On average, the percentage distribution of the number of SHGs and their savings linked with banks stands at 82.09% and 82.45% respectively. Similarly, for loans disbursed, the average percentages are 86.23% for the number of SHGs and 88% for savings linked with banks. For outstanding loans, the average percentages are 84.08% for the number of SHGs and 85.72% for savings linked with banks. These figures span from the fiscal year 2006-07 to 2018-19, showcasing trends in women's participation in microfinance activities over time.

Analysis reveals that the number of women's SHGs engaging in savings linked with banks has shown a consistent increasing trend in India from 2007-08 to 2018-19. The participation rate for

the number of SHGs involved in savings demonstrates an upward trajectory, starting at 78.62% in 2006-07, peaking at 86.41% in 2014-15, and then slightly decreasing to 85.19% in 2018-19.

In contrast, the percentage of SHGs involved in loans disbursed displays a steady increase over the years. Beginning at 86.63% in 2006-07, this figure steadily climbs to 91.78% by 2017-18, indicating a positive trend in loan disbursal activities among women's SHGs at the national level. Regarding loans outstanding, the percentage distribution shows a fluctuating pattern. Starting at 82.55% in 2006-07, it dips to 77.58% in 2008-09 before experiencing a broad increase from 2009-10 onwards, reaching 87.87% by 2018-19.

Table 1: The percentage distribution of number and amount of women SHGs to total, by Saving , Loan Disbrushed and Outstanding in India during 2006-07 to 2018-19 (%)

Particulars	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	Average
	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	
SHG Savings with Banks #	78.62	79.57	79.46	76.4	81.7	79.1	81.1	84.15	86.41	85.58	85.36	84.5	85.19	82.09
Loans Disbursed to SHGs during the year	86.63	84.79	85.39	81.6	85	80.4	85.1	84.3	89.05	88.92	90.42	91.8	87.66	86.23
Loans Outstanding against SHGs #	82.55	80.46	77.58	80.3	83.2	83.8	84.4	81.2	86.35	86.37	88.36	90.6	87.87	84.08
	Amt.	Amt.	Amt.	Amt.	Amt.	Amt.	Amt.	Amt.	Amt.	Amt.	Amt.	Amt.	Amt.	Amt
SHG Savings with Banks #	86.12	82.12	79.96	72.6	75.5	77.9	79.3	80.96	83.77	87.91	88.64	89.3	87.78	82.45
Loans Disbursed to SHGs during the year	86.41	84.46	85.91	86	86.8	85.5	86.7	87.6	83.53	92.29	93.09	94.4	91.32	88.00
Loans Outstanding against SHGs #	81.97	78.45	81.93	82.1	83.7	83.8	83.3	84.2	89.05	90.04	91.66	93.1	90.97	85.72

Note: No. = Number of SHGs, Amt. = Amount and # during the year ended 31 March

Source:NABARD: Rural Credit Innovations Department

These trends underscore the evolving landscape of women's participation in microfinance programs in India, with notable progress in savings, loan disbursal, and loan repayment activities over the examined period. Such insights are invaluable for policymakers and stakeholders seeking to further enhance the effectiveness and reach of microfinance initiatives aimed at empowering women economically across the nation.

Examining the amount distribution for the same period reveals distinct trends in the participation rates of women's Self-Help Groups (SHGs) in savings linked with banks, loans disbursed, and outstanding loans.

For savings linked with banks, the percentage participation rate of women's SHGs demonstrates a steady decreasing tendency up to 2009-10, followed by an increase. This trend is

evident from the figures, starting at 75.5% in 2010-11, peaking at 89.31% in 2017-18, and then decreasing slightly to 87.78% in 2018-19.

A similar pattern is observed for loans disbursed to women's SHGs. The percentage participation rate starts from 84.46% in 2007-08 and steadily climbs to 94.43% by 2017-18, indicating a positive trend in loan disbursal activities among women's SHGs, except for the year 2018-19. Contrary to the trends observed in savings and loans disbursed, the percentage participation rate for loans outstanding displays a broadly increasing trend. This figure varies from 78.45% in 2007-08 to 90.97% in 2018-19, indicating a consistent upward trajectory over the years.

It is noteworthy that the average participation rate is higher (85.72%) for loans outstanding compared to savings (82.09%) linked with banks for women's SHGs at the national level. This suggests that while women's SHGs may demonstrate fluctuations in savings and loan disbursal activities, they show a relatively consistent and higher level of engagement in repaying outstanding loans.

These observations underscore the dynamic nature of women's participation in microfinance activities, highlighting variations in savings, loan disbursal, and repayment behaviours over time. Understanding these trends is crucial for policymakers and stakeholders to tailor interventions and support mechanisms effectively, ultimately fostering sustainable economic empowerment among women across India.

Henceforth, our analysis unveils that women Self-Help Groups (SHGs) have significantly dominated the microcredit industry in India over the past thirteen years. The remarkable participation rates of women SHGs underscore their outstanding performance in engaging with microfinance programs within the microcredit market. This heightened involvement not only boosts economic activities in their daily lives but also contributes to the reduction of poverty levels.

In practical terms, the economic empowerment of women translates into pivotal decision-making regarding various aspects of family life, including education, healthcare, and other necessities. When a woman holds economic power, she is better positioned to prioritize and invest in the well-being and future prospects of her children and family members. In essence, the robust engagement of women SHGs in microfinance initiatives not only fosters their own economic empowerment but also serves as a catalyst for broader societal progress, ultimately paving the way for enhanced socio-economic development across India.

Table 2 provides an overview of the average and annual growth rates of women Self-Help Groups (SHGs) in India, shedding light on their significant role in financial inclusion and empowerment. From 2006-07 to 2018-19, there has been a notable average growth rate of 8.62% for the number of SHGs and 17.94% for the amount of savings with banks. This underscores the positive aspect of women's participation in financial inclusion efforts, demonstrating their keen interest in saving with banks even with minimal liquid assets. This intentional savings behaviour reflects their forward-thinking approach, aimed at securing the financial well-being of future

generations. In essence, women SHGs aspire to fulfil the slogan 'micro saving to microcredit', highlighting their journey from savings to accessing microcredit facilities.

Similarly, the average growth rates for loan disbursements to SHGs during the same period stand at 9.81% for the number of SHGs and 21.10% for the amount disbursed. This indicates commendable progress in both the physical and financial performance of women SHGs over the years. Notably, while the growth rate for the number of SHGs receiving loans experienced a modest increase, the growth in the amount disbursed exhibited a phenomenal rise, reflecting the increasing confidence of financial institutions in extending credit to women SHGs.

Examining outstanding loans, we find average growth rates of 5.75% for the number of SHGs and 19.06% for the loan amount. Remarkably, the percentage average share of outstanding loans against women SHGs is lower (19.06%) compared to loans disbursed (21.10%), indicating excellent repayment performance among women SHGs in India. This reflects the absence of defaulters in loan repayment within the microfinance industry, further highlighting the responsible financial behaviour of women SHGs.

Considering the demographic composition of India, where approximately 51% of the population comprises women, an increased participation rate in financial inclusion through microfinance programs holds immense potential for the economy. Women SHGs are recognized as earning members of society, and facilitating their access to formal financial services enables them to build assets, increase incomes, and reduce vulnerability to economic stress. Moreover, formal financial services empower poor families to invest in enterprises, nutrition, living conditions, and the education of their children, ultimately contributing to poverty reduction and national development.

A closer look at the year-wise discussion reveals fluctuations in the annual growth rates of both the number and amount of women SHGs' savings with banks. While there was a decreasing trend up to certain years, followed by subsequent increases, similar patterns were observed for loan disbursements to women SHGs. These fluctuations underscore the dynamic nature of financial inclusion initiatives and emphasize the importance of continued monitoring and support to ensure sustained progress in empowering women through microfinance programs.

The fluctuating annual growth rates in both the number of Self-Help Groups (SHGs) and the amount of loans disbursed to them over the specified years suggest a pattern akin to a 'U' shape distribution. Let's delve deeper into the expanded text to explore the reasons behind this trend, particularly in light of the microfinance crisis in the southern region in 2006.

The substantial growth rates (32.04%) observed in 2008-09 signify a period of rapid expansion in microfinance activities. This could be attributed to various factors such as increasing awareness about microfinance, government support initiatives, and favourable economic conditions, which encouraged the formation of SHGs and facilitated higher loan disbursals.

Table 2: The Annual and Average Growth Rate of number and amount of women SHGs , by Savings , Loan Disbrushed and Outstanding in India during 2006-07 to 2018-19 (%)														
Particulars	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	Aver age
	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	
SHG Savings with Banks #	.....	21.85	22.02	9.18	14.8	3.3	-5.7	5.27	6.38	1.68	8.26	0.94	15.44	8.62
Loans Disbursed to SHGs during the year	.....	8.67	32.04	5.8	-21.4	-9.2	12.4	11.02	25.69	12.5	5.34	20.92	13.98	9.81
Loans Outstanding against SHGs #	.....	22.09	12.34	18.9	2.2	-8.4	2.9	-9.34	13.27	4.61	6.14	6.2	-1.93	5.75
	Amt.	Amt.	Amt.	Amt.	Amt.	Amt.	Amt.	Amt.	Amt.	Amt.	Amt.	Amt.	Amt.	Amt
SHG Savings with Banks #	.....	2.77	42.64	1.46	17.8	-3.7	27.6	22.99	15.61	29.92	18.67	22.51	17.01	17.94
Loans Disbursed to SHGs during the year	.....	31.65	40.85	18.1	1.6	12	26.3	17.83	16.07	40.92	4.92	23.42	19.51	21.10
Loans Outstanding against SHGs #	.....	31.55	39.35	23.9	13.4	16.6	7.8	10.08	26.97	12.04	9.75	24.73	12.54	19.06
Note: No. = Number of SHGs, Amt. = Amount # = during the year ended 31 March														
Source:NABARD: Rural Credit Innovations Department														

The negative growth rates (-21.4%) experienced in 2010-11 indicate a downturn in microfinance activities. This could be a consequence of several factors, including the aftermath of the microfinance crisis in the southern region in 2006. The crisis might have led to increased regulatory scrutiny, decreased investor confidence, and a cautious approach towards microfinance lending, resulting in a contraction in the number of SHGs and loan disbursals.

Whereas, the subsequent years, particularly from 2012-13 onwards, show a revival in growth rates (12.4%). This suggests that the microfinance sector gradually recovered from the challenges it faced, possibly due to interventions aimed at addressing the root causes of the crisis. These interventions could include regulatory reforms, improved risk management practices, and efforts to rebuild trust among stakeholders.

The positive growth rates observed towards the end of the period indicate a resurgence in microfinance activities. This could signify a phase of renewed growth and expansion within the sector, driven by factors such as improved regulatory frameworks, increased investor confidence, and continued efforts to enhance financial inclusion, particularly for women through SHGs.

The 'U' shape distribution observed in the growth rates of SHGs and loan disbursals underscores the resilience of the microfinance sector. Despite facing significant challenges, including the crisis in the southern region, the sector demonstrated its ability to bounce back and thrive. This highlights the importance of adaptive strategies, effective governance, and stakeholder collaboration in ensuring the sustainability and impact of microfinance initiatives, particularly those aimed at empowering women through access to financial services.

In conclusion, while the microfinance crisis in the southern region in 2006 may have contributed to the observed fluctuations in growth rates, the subsequent recovery and expansion

of microfinance activities indicate the sector's resilience and adaptability in overcoming challenges and driving inclusive economic development.

The findings from N. K Mandal's (2015) study provide valuable insights into the impact of microfinance programs, particularly on women's participation in income-generating activities. He conducted field-based research in Suti 1 block of the Murshidabad district, focusing on the microfinance program's effects in the region.

N. K Mandal found that the average percentage of women participating in income-generating activities through microfinance stands at an impressive 91.89%, it is shown in following table. This indicates a significant level of engagement and empowerment among women beneficiaries of microfinance initiatives. The survey data also reveals a noteworthy trend: women are directly involved in various economic activities such as poultry farming and paddy processing, enabling them to earn income independently. Prior to joining Self-Help Groups (SHGs), these women were not engaged in any income-generating work.

Table: The Participation Rate in Microfinance Programme of Women BPL, Gen, SC, ST, OBC, and Minority

Name of GP	Total SHGs	Total Members	% Women	% BPL	% Gen	% SC	% ST	% OBC	% Minority
Sadikpur	133	1449	96.27	78.88	66.80	0.69	0.00	0.00	32.51
Nurpur	93	1055	90.71	71.56	51.75	20.85	0.00	0.00	27.39
Harua	128	1359	88.01	52.69	4.86	19.79	9.35	2.94	63.06
Bansabati	84	918	97.71	62.42	92.92	0.00	0.00	0.00	7.08
Bahutali	96	1033	87.71	69.22	69.60	0.00	0.00	0.00	30.40
Ahiron	106	1169	91.19	68.95	81.09	4.96	0.00	0.00	13.94
Total	**640**	**6983**	**91.89**	**67.42**	**58.71**	**7.98**	**1.82**	**0.57**	**30.92**

Source: Field Survey, 2015, GP= Gram Panchayat

One of the key impacts highlighted by N.K Mandal's study is the strengthening of women's bargaining power within their households. By actively contributing to household income through their participation in economic activities facilitated by microfinance, women are better positioned to influence important decisions within their families. This shift in dynamics has led to a tangible transformation in rural areas of West Bengal, where traditional gender roles are being challenged, and women are assuming more active roles in economic decision-making processes.

Importantly, Mandal's research does not solely focus on women members of SHGs. He also examines the participation and impact of microfinance programs on various marginalized categories of people, including those belonging to Below Poverty Line (BPL) households, Scheduled Castes (SC), Scheduled Tribes (ST), Other Backward Classes (OBC), and Minority communities. This comprehensive approach provides a holistic understanding of how microfinance initiatives can empower not only women but also other vulnerable and marginalized groups within society.

In conclusion, Mandal's findings and our findings underscore the transformative potential of microfinance programs in promoting women's empowerment, economic inclusion, and social

change in rural areas. By providing opportunities for women to engage in income-generating activities and enhancing their decision-making authority within households, microfinance initiatives contribute significantly to broader efforts aimed at poverty alleviation and socio-economic development.

The fundamental principle underlying microfinance is the empowerment of women through the provision of capital, enabling them to generate independent income and contribute financially to their households and communities. This economic empowerment is anticipated to foster greater self-esteem, respect, and various other forms of empowerment among women beneficiaries.

Summary and Conclusions:

The historical exclusion of women from the financial sector, fuelled by societal biases favouring men, has prompted initiatives to address this imbalance. Increased involvement in microfinance programs is seen as a means of empowering women, indicating a positive link between participation rates and empowerment. Through engagement in microfinance activities, women become earners in their households, contributing to economic dynamics and nurturing critical thinking skills. Their participation also facilitates collaborative problem-solving, leading to enhancements within microfinance institutions and rural economies.

Analysing national-level data reveals trends in women's participation in savings, loan disbursement, and loan repayment activities over thirteen years. Overall, there has been notable progress in these areas, indicating a positive trend in women's engagement with microfinance programs. Women's dominance in the microfinance sector reflects their pivotal role in driving economic activities and poverty reduction efforts. Economic empowerment through microfinance translates into improved decision-making power, particularly in education, healthcare, and family welfare. Women's active involvement in microfinance not only enhances their own empowerment but also spurs broader societal progress, ultimately contributing to socio-economic development across India.

The analysis highlights the transformative impact of microfinance in empowering women and advancing socio-economic development goals in India. Continued support and enhancement of women's participation in microfinance initiatives are essential for promoting inclusive and equitable economic growth.

This study provides an insightful overview of the average and annual growth rates of women Self-Help Groups (SHGs) in India, shedding light on their significant role in financial inclusion and empowerment. Notable growth rates in the number of SHGs, savings with banks, loan disbursements, and outstanding loans reflect commendable progress in women's participation in microfinance programs over the years. This underscores their growing economic agency and contribution to socio-economic development. Fluctuations in growth rates indicate the dynamic nature of financial inclusion initiatives, with the observed 'U' shape distribution suggesting resilience and adaptability within the microfinance sector. Despite challenges, including the crisis

in the southern region in 2006, the sector has demonstrated its ability to bounce back and drive inclusive economic development.

Selected References:

Bhattacharyya S. & Mandal N. K. (2021), "Transition in the Rural Credit Structure of West Bengal: The Case of Murshidabad District" Agrarian South: Journal of Political Economy- A tri-annual Journal of Agrarian South Network and CARES, First Published February 1, 2021 https://doi.org/10.1177%2F2277976020968319

Cheston, S., and L. Kuhn (2002). *Empowering women through microfinance.In: S. Daley-Harris, comp. & ed. Pathways out of poverty: Innovations in microfinance for the poorest families*, pp. 167-228. Bloomfield, CT, USA: Kumarian Press.

Gutierrez, Lorraine M. (1990). "Working With Women of Color: An Empowerment Perspective". Social Work, vol. 35:2, pp. 149.153

Kabeer, N. (1999). *The conditions and consequences of choice: Reflections on the measurement of women's empowerment*. UNRISD Discussion Paper No. 108. Geneva: United Nations Research Institute for Social Development

Kabeer, N. (2001). *Conflicts over credit: Re-evaluating the empowerment potential of loans to women in rural Bangladesh*. World Development 29 (1): 63-84.

Kaur, B., & Batra, N. (2023). Technology adoption of digital banking and women consumers: An empirical investigation. *Int. J. Exp. Res. Rev.*, *32*, 278-287. https://doi.org/10.52756/ijerr.2023.v32.024

Krishna, A. (2003). *Social capital, community driven development, and empowerment: A short note on concepts and operations*. Working Paper No. 33077. Washington, DC: World Bank.

Malhotra, A., Schuler S.R and Boender C. (2002). *Measuring women's empowerment as a variable in international development*. Background paper for World Bank Workshop on Poverty and Gender: New Perspectives.

Mandal N. K. (2015), "Social Exclusion of Women and Microfinance: A critical analysis in the respect of West Bengal" in Sen (ed.) Social Exclusion and Development Programmes, Rupali Publisher, Kolkata, pp 72-85 ISBN:978-93-81669-9

Mandal N. K. (2018), "Women's Empowerment, Microfinance: A Study of West Bengal in the New Millennium" in Chattopadyay and Kushwaha (eds) Issues in Sustainable Development in India: Present Problems and Future perspective, New Delhi Publisher, New Delhi, pp 167-176, ISBN:978-93-86453-44-0

Mandal N. K. (2020), Financial Inclusion through Microfinance Model in India: SpecialFocus on West Bengal, RAY: International Journal of Multidisciplinary Studies, VolumeV,No. 1, April, 2020, pp.45-58, E-ISSN: 2456-3064.

Maiti, M. (2017). Low birth weight is associated with maternal nutrition of Indian women. *Int. J. Exp. Res. Rev.*, *12*, 24-30. https://doi.org/10.52756/ijerr.2017.v12.003

Mayoux, L. (1998). *Participatory learning for women's empowerment in micro-finance programmes: Negotiating complexity, conflict and change.* IDS Bulletin *29*(4), 39-51.

Moirangleima, K. (2016). Empowering rural women by participating in sustainable environmental management: A case study of Banasthali University, Rajasthan. *Int. J. Exp. Res. Rev.*, *5*, 25-32.

NABARD: Status of Microfinance in India in various years

Nair Tara S (2005). *The Transforming World of Indian Microfinance" Economic and Political Weekly*. pp- 1695-98.

Nair Tara S (2011). *Microfinance: Lessons from a Crisis*. Economic & Political Weekly.

Sen, A.K. (1993). *Capability and well-being. In: Nussbaum and Sen, eds. The quality of life. Helsinki:* World Institute of Development Economics Research.

Sriram M S (2005). *Microfinance and the State Exploring Areas and Structures of Collaboration*" Economic and Political Weekly 1699-1703, xlvi (6), pp- 23-26

Yunus M (1999). *Banker to the Poor*. New York: Public Affairs

HOW TO CITE

Nikhil Kumar Mandal (2024). Women's empowerment and financial inclusion in India: 2006-2019. © International Academic Publishing House (IAPH), Dr. Suman Adhikari, Dr. Manik Bhattacharya and Dr. Ankan Sinha, *A Basic Handbook of Science, Technology and Innovation for Inclusive Development [Volume: 1]*, pp. 104-116. ISBN: 978-81-969828-4-3. DOI: https://doi.org/10.52756/ bhstiid.2024.e01.007

OPEN ACCESS PEER REVIEW
DOI: https://doi.org/10.52756/ bhstiid.2024.e01.008
Chapter- 8

An Insight into the Challenges and Issues of Inclusive Development of Tripura (India): A Study in Perspective of Yearly State Budget

Dr. Bankim Debbarma

Keywords: Development, Challenges, Issues, Policies, Transparency and Reforms.

Abstract:

Development might be achieved by different ways and processes, but there is not any substitute for development for any program and initiative in a public or private sector organization. In the same way, the overall development of the state is not only limited to finance, allocation, distribution and infrastructure etc., where the development of human resources and sustainable development are the primary requirements for ensuring inclusive development of the state. Uplift of the people of all sections of society will never succeed until the challenges and issues with feasible allocation of resources among all the sections of society are removed. Further, the positive planning & decision-making of all the development works, proactive execution of all the related policies can only accelerate the development, where transparency and required administrative reforms in all the wings of the government can only ensure the development of the state.

Introduction:

The issues and challenges for development of any state are prevailed in different types and faced before accomplishment, whether it is a small or big one. These particular issues and challenges provide the scope to re-think about the new dimension and perspective for achieving the ultimate objectives of development. Development in all respects is the basic primary condition for ensuring the progress and development of the peoples of society. These developments can be achieved by only fulfilling all the related measures of development along with proper investment of funds. The finance and financial condition of the state are a very important and significant part of fulfilling the required investment for the development of society. On the question of development - finance, planning, budget, and proper financial management are very important components for achieving ultimate desired goals. From this perspective, the state's economic and financial condition must be explored for taking necessary initiatives for developing the components related to inclusive development.

At present, the economic landscape of Tripura, nestled in the North-Eastern region of India, is undergoing a tumultuous phase characterised by shortages in revenue collection and a financial crisis for development. As a result, has been observed excessive market borrowing and a surge in debt liabilities over the decades. The escalating debt situation has triggered

Dr. Bankim Debbarma
Assistant Professor, Department of Commerce, Maharaja Bir Bikram College, Agartala, Tripura, India
E-mail: bankimdb79@gmail.com; Orcid iD: https://orcid.org/0009-0005-5792-5180
*__Corresponding Author__: bankimdb79@gmail.com

Dr. Suman Adhikari, Dr. Manik Bhattacharya and Dr. Ankan Sinha, A Basic Handbook of Science, Technology and Innovation for Inclusive Development [Volume: 1]. ISBN: 978-81-969828-4-3; pp: 117-128; Published online: 27th May, 2024

concerns about the state's financial health, pushing the state towards a financial crisis which is not only perilously creating an unfavourable situation for development, but also pushing the state towards bankruptcy. In this comprehensive exploration, it is required to delve into the intricate details of Tripura's budgetary dynamics; meticulously analysing the reasons behind its growing reliance on market borrowing, the trajectory of its escalating debts and the profound consequences of this fiscal approach. All the issues and their related challenges are very relevant to ensuring inclusive development of the state. The prevailing shortage of funds has inflicted a severe blow on the timely execution of vital inclusive development plans across Tripura. Historically, the primary source of funding has been the 'State Share of Fund' allocated by the Union Government of India. However, Tripura has increasingly turned to market borrowing, leading to a substantial rise in debt liabilities and annual interest payments for its yearly development requirements. The financial strategy employed by the Government of Tripura for inclusive development programmes involves sourcing funds through market borrowing and loans from a diverse set of institutions, ranging from the banking and insurance sector of the country, including the National Bank for Agriculture and Rural Development, the National Co-operative Development Corporation, National Small Savings Fund of the Central Government, etc.

Review of Literature:

Inclusive growth policy is an important part of the sustainable growth strategies and framework for inclusive economic growth of every country. Productive employment is considered as the main tool for sustainable and inclusive economic growth. Inclusive economic growth is a long-term perspective where it is very important to understand the necessary reforms and the lag between reforms and results (Ianchovichina & Lundstrom, 2009). The leading multilateral institutions in the world, namely, the World Bank, the Asian Development Bank, and the International Monetary Fund has used the term 'inclusive growth' for advocating a pro-poor perspective which is limited to market participation, i.e., creating jobs for the poor (Halder, 2016). But efficiency such as economic processes, policies, and institutions is still based on an economic paradigm that does not value social or environmental sustainability in its growth models (Pouw & Gupta, 2017). Inclusiveness is the key instrument to ensure the development of poor people and the environment by countering the dominance of the neoliberal paradigm (Gupta et al., 2023). If development is focused on local resource management on which most people are directly dependent, then greater emphasis on establishing global eco-centric standards is required to be ensured in the context of the ‘Anthropocene’ by sharing 'Environmental Utilisation Space' or 'Eco-Space' (Gupta & Ros-Tonen, 2015).

Poverty reduction is an important component of inclusive development, at the current pace, which depends on the process of sharing growth benefits and not on the rate of economic growth. Economic growth can ensure the eradication of poverty, but it alone does not guarantee that everyone will benefit equally. Inclusive development and poverty reduction are only

possible through a comprehensive program for social development policies which includes inclusive social development in education, health, gender and ensuring employment for human resources (Rauniyar & Kanbur, 2009). Despite considerable success in global poverty reduction by increasing income, the inequalities in resource sharing and environmental problems are becoming the burning issues in the process of development evaluation. All aspects of the human centred comprehensive development indexes are required to be compared by the Multidimensional Inclusiveness Index (MDI) and its two versions, namely, Human Development Index (HDI) and Inclusive Development Index (IDI) for ensuring achievement and equity in development (Dörffel & Schuhmann, 2020).

Budget and public expenditure are the most powerful instruments to ensure inclusive development, but it is only the right policy choices, proper assessment of the incidence of different population groups, particularly the poor poetising education and health that are the key instruments for ensuring inclusive development. Inclusive infrastructural development with the analysis of the effects of spending measures on inclusive needs, cost-effective package, and a consistent and sustainable fiscal position can help to achieved inclusive growth with improved quality and efficiency (Zouhar et al., 2021). But, in the budgets & public expenditure - inadequate attention to allocative efficiency, absence of long-term expenditure planning, lack of efforts related to developmental planning, absence of effective financial management and economic policy inputs, absence of proper expenditure objectives (Planning, Programming, Performance Budgeting or PPPB Systems), absence of economic classification of expenditures including cost-benefit analysis and forward-multiyear planning, absence of management and stabilisation studies at different levels of administration creates a gap in proper budget utilisation for development (Premchand, 1966).

India a country of infinite potential and incredible opportunity, contributing significantly to global growth can certainly adopt accelerated and environmentally sustainable development, and bringing in numerous socially and economically disadvantaged citizens' programmes for inclusive economic growth (T.G, 2019). Market economics, Empowerment, and Pragmatism are the three pillars of the Indian model of inclusive growth which involved creating inclusive social and economic environment. The growth of entrepreneurship in every community and socio-economic group through the evolution and tremendous changes in trade policy namely, 'Make in India'; 'Atman Nirbhar'; and 'Free Trade Agreements (FTAs)' with developed countries are the examples of these policies (Virmani, 2023). Despite such a development, India is currently facing many internal issues and challenges in the area of financial inclusion, including distribution of banking services to its population coverage especially in the regions namely, North, North-East, East, Central, West and South, which has directly impact on the progress of financial inclusion and poverty rate (Snehlata, 2018). The challenges of providing proper support for perspective plans, studies, investigation, etc. for conservation, development and management of natural resources are the major burden for ensuring inclusive development in India. It is required to review all the implemented schemes/ programmes continuously which

affect land resources for effective control and up-scaling technologies of higher productivity, production, aggregation, branding, packaging and processing, especially different agro products for inclusive development (Devi, 2022). The business of India is expanding in worldwide but, the evidence of shackled in dishonesty, red tape, traditional social hurdles and a bewildering lack of transparency, un-uniform growth across the sectors and sub-sectors of the large group of population creating hurdles in reaching its true potential. Moreover, numerous social, political and economic factors, major issues in society, such as eradication of child labour, women empowerment, removal of caste barriers, and corruption in high places are demanding to frame the right policy for the country (Mubarak, 2016).

Stability in microeconomics, human resources and structural changes are the key determinants of inclusive growth in the emerging market of any country. In terms of structural changes and globalisation, trade openness and foreign direct investment promoting inclusive economic growth, and economic openness can play a positive role in inclusive development of any country. According to the IMF, deepening financing can have a negative effect, although this effect is not statistically significant where stability, competiveness and growth are the key drivers of inclusive growth for inclusive economic development (Anand et al., 2013).

Objectives of the Study:

The objectives of the study may be summarised at different points and angles for the purpose of discussing the issues and challenges of the inclusive development of the state of Tripura. The primary objectives of the study are pointed out as follows:-

(i) To find out the various issues and challenges in achieving inclusive development related to the yearly budget of Tripura (India);

(ii) To explore the scope and possibilities for removing the issues and challenges for ensuring the sustainable, inclusive development of Tripura (India).

Methodology:

This study is a secondary data-based study supplemented by conducting spot visits for getting information and numerical primary data collection from all the offices and departments under the Government of Tripura related to the yearly budget allotted fund for inclusive development program. For collecting the information, a questionnaire were used which is partially structured having direct and open-ended questions. Similarly, separate schedules were used to collect information from selected staff of different offices by applying judgement sampling to find out the application of budget allotted funds and its related constraints and hurdles of proper utilisation in time for arriving at conclusion of the study. However, this study calls for a comprehensive review of all available documents of finance and planning, i.e. Budget of Tripura from 2021-22 FY to 2024-25 FY which helped to get a complete overview of funds, allocation and utilisation of funds related to the study for inclusive development of Tripura in perspective of the yearly total budget, fund condition and allocation as well as utilisation of funds for inclusive development of the state.

Discussion of the Study:

Budget, finance and financial management are the important components for initiating and ensuring inclusive development in each and every sector of developmental activities. It is observed that over the past fiscal years, Tripura's budget has exhibited a concerning trend, peaking at ₹27,804.67 crores in 2024-25. This surge is accompanied by a worrisome almost dependence on Union Government funds, resulting in escalated market borrowing on total budget receipt. This fiscal challenge necessitates a paradigm shift in financial management to address the necessary inclusive development. The effective preparation of yearly budgets, prudent utilisation of funds, and a focused approach to generating additional revenue may be the significant steps towards this transformation. Unfortunately, in many wings of the state government, the emphasis lies on utilising allocated funds with minimal attention to asset creation and revenue generation, so that the government can ensure the required supply of funds. This strategy is making the state even more dependent on market borrowing, which feeds a vicious cycle of debt build-up and presents obstacles to the flow of funding as well as new financial obligations for the government.

Table-01: Market Borrowing/ Loan of the Govt. of Tripura from 2018-19 to 2024-25

Financial Year (FY)	Interest Paid in the Year (₹ In crore)	Estimated Total Principal Loan Amount (₹ In crore)	Market Borrowing & Loan in the Year (₹ In crore)	Total Loan Amount Before Yearly Repayment (₹ In crore)	Repayment of Loan in the Year (₹ In crore)	Net Total Principal Loan Amount (₹ In crore)
N	**I**	**P**	**d**	**P1= (P + d)**	**R**	**D=(P1-R)**
2018-19	1146.82	11468.20	1543.00	13011.20	520.50	12490.70
2019-20	989.81	12490.70	2380.00	14870.70	635.54	14235.16
2020-21	1256.93	14235.16	2546.00	16781.16	729.34	16051.82
2021-22	1124.98	16051.82	3093.98	19145.80	889.07	18256.73
2022-23	1499.18	18256.73	2795.00	21051.73	1023.12	20028.61
2023-24	1501.73	20028.61	2614.00	22642.61	918.25	21724.36
2024-25	2486.07	21724.36	2300.00	24024.36	566.92	23457.44
∑n=7	**∑I=10005.52**	---	**∑d=17271.98**	---	**∑R=5282.74**	---

Source: *Author's Analysis as per the Budget of the Finance Department, Govt. of Tripura*

A significant financial burden is brought to light by the disclosure of an estimated total principal loan amount of ₹11,468.20 crores prior to the 2018-19 budget, which is determined using typical interest rates in another study by the author. After deducting repayments, the net total principal loan amount increased to ₹12,490.70 crores by 2018-19. This noteworthy debt, attributed to both the borrowing and subsequent repayments by the then government, and the total principal loan amount has remained inadequately highlighted and absent in the yearly budget, which is prompting questions not only about transparency but also free flow execution

of inclusive development. The glaring discrepancy between the estimated and actual net total principal loan amount raises serious concerns about transparency in financial reporting. The failure to sufficiently emphasise or disclose this substantial debt burden, including the impact of the then government's borrowing, in the government's budgetary presentations raises doubts about the clarity and openness of the fiscal management process. This situation underscores the critical importance of transparent communication in fiscal matters, and emphasising the urgent need for comprehensive disclosure and accountability to foster trust amongst stakeholders.

A comprehensive overview of the yearly budget and market borrowing & loan amounts spanning from the fiscal year 2018-19 to 2024-25 reveals a consistent and incremental uptrend in these financial transactions, indicating a burgeoning need for capital, which is highlighted in Table-01. Over the specified period, the cumulative figures portray a financial landscape marked by a total interest payment of ₹10,005.52 crores, market borrowing amounting to ₹17,271.98 crores, and loan repayment totalling ₹5,282.74 crores. This foresight underscores the persistence of the upward trend and signifies a continual demand for additional funds in the foreseeable future for inclusive development of the state.

Table-02: Changes of Budget Amount from the Budget Estimate to Budget Actuals in Compare to Market Borrowing & Loan

Financial Year (FY)	Changes of Budget Position (₹ In crore)				Changes of Market Borrowings & Loan as per Budget Position (₹ In crore)		
	Estimates	Revised Estimates	Actuals	Decreased of Budget	Estimates	Revised Estimates	Actuals
1	2	3	4	5=(2-4)	6	7	8
2018-19	16387.21	16380.80	14193.48	-2193.73	1543.00	1695.83	1707.57
2019-20	17530.46	17247.20	14679.94	-2850.52	2380.00	3081.00	3257.77
2020-21	19380.19	18357.83	17612.27	-1767.92	2546.00	2940.95	2322.35
2021-22	21951.07	23707.29	18967.59	-2983.48	3093.98	2065.00	527.18
2022-23	26323.15	25169.11	20864.99	-5458.16	2795.00	1829.62	519.36
2023-24	*(27654.45)*	*(26658.96)*	---	---	*(2614.00)*	*(2472.00)*	---
2024-25	*(27804.67)*	---	---	---	*(2300.00)*	---	---
TOTAL	**101572.08**	**100862.23**	**86318.27**	**-15253.81**	**12357.98**	**11612.40**	**8334.23**

Source: *Author's Analysis as per the Budget of the Finance Department, Govt. of Tripura*

From the analysis in Table-02, it comes to know that the total estimated budget amount from 2018-19 to 2022-23 of ₹1,01,572.08 crores has changed and decreased consecutively up to an actual budget of ₹86,318.27 crores. The budget amount decreased by ₹15,253.81 crores in the five (05) years, whereas in that period the changes in market borrowing and loans in Budget Estimates, Revised Estimates and Actual Budget positions are ₹12,357.98 crores, ₹11,612.40

crores and ₹8,334.23 crores respectively. The revealed trend in budgetary changes from 2018-19 to 2022-23 raises significant concerns that warrant more in-depth exploration of changes in budget and to unveil the discrepancy. The decrease in the total budget amount by ₹15,253.81 crores over this period is also an alarming indicator, where the budget allotted inclusive development funds are not utilised in time in maximum departments, particularly when the market borrowing and loans of the government are increasing. This fiscal dissonance calls for a nuanced analysis to uncover the reasons behind these seemingly contradictory financial dynamics and analyse its impact on inclusive development the programme and its related fund management.

The apparent reduction in the overall inclusive budget demands scrutiny regarding the allocation of resources across different sectors. Understanding which areas or sectors of development experienced cuts and the potential consequences for critical public services is crucial. Additionally, it is essential to assess the government's priorities during this period and how they align with the evolving needs of the populace. The substantial increase in market borrowing and loans amid a shrinking budget prompts fundamental questions about the fiscal strategy employed. ***Why was there a need for heightened borrowing when the overall budget was contracting?*** Unravelling the purpose behind these financial decisions is crucial for evaluating the government's economic stance and its implications on the country's financial health.

Moreover, an in-depth examination should extend to the impact of these budgetary shifts on vital sectors of inclusive development such as healthcare and education. These areas often bear the brunt of budget cuts, and understanding the specific consequences for public welfare is imperative. Assessing the adequacy of allocations in critical sectors may shed light on potential challenges in delivering essential services to citizens. Furthermore, this analysis should involve a review of the consistency in budget revisions. ***Were there unforeseen economic challenges that led to mid-year adjustments, or do these revisions have ensured broader fiscal stability related to inclusive development programmes?*** Addressing these questions is essential for comprehending the government's ability to predict and respond to inclusive development and economic changes effectively. Further scrutiny of the budget components, such as market borrowing, repayment of loans, and interest payments, exposes inconsistencies in budget components and its unravelling priorities. The emphasis on market borrowing in revised estimates compared to actual is evident. The government's focus on borrowing over repaying loans and managing interest payments raises concerns about financial prudence, planning and development. Examining revenue earnings and capital expenditure reveals another layer of fiscal challenges in revenue and capital expenditure. While salaries and wages have seen substantial increases, capital expenditure has lagged behind, growing at a slower pace. This discrepancy raises questions about the allocation of funds and the effectiveness of capital investments in driving economic growth.

Table-03: Changes in Fiscal Surplus (+) or Deficit (-) in the Budget from Budget Estimate to Budget Actuals in Comparison to Market Borrowing & Loan

Financial Year (FY)	Fiscal Surplus (+) or Deficit (-) in the Budget (₹ In crore)			Primary Surplus (+) or Deficit (-) in the Budget (₹ In crore)			Actual Market Borrowings & Loan (₹ In Crore)
	Estimates	Revised Estimates	Actuals	Estimates	Revised Estimates	Actuals	
2018-19	-1851.50	-1232.44	-1339.70	-704.68	-305.96	-320.75	1707.57
2019-20	-1794.45	-3574.51	-3261.56	-804.64	-2432.12	-2136.58	3257.77
2020-21	-2149.07	-4084.96	-1383.14	-892.14	-2744.77	-98.33	2322.35
2021-22	-3680.42	-2663.34	+586.47	-2306.82	-1158.08	+1984.63	527.18
2022-23	*-3841.40*	*-2252.94*	*-1162.94*	*-2342.22*	*-799.33*	*+210.58*	*877.42*
2023-24	*(-3778.62)*	*(2669.67)*	---	*(-2276.89)*	*(-1260.47)*	---	*(2614.00)*
2024-25	*(-3405.21)*	---	---	*(-1919.14)*	---	---	*(2300.00)*
TOTAL	**-13316.84**	**-13808.24**	**-6560.87**	**-7050.50**	**-7440.26**	**-360.45**	**8692.29**

Source: *Author's Analysis as per the Budget of the Finance Department, Govt. of Tripura*

The actual fiscal and primary deficits for the years 2018-19 to 2022-23 present an interesting puzzle in the fiscal deficit enigma. The actual fiscal deficit was ₹6,560.87 crores, significantly lower than the total market borrowing and loan amount of ₹8,692.29 crores. This prompts a critical enquiry into the necessity and justification of borrowing when the fiscal deficit is not aligned with the total borrowing. The intricate details of Tripura's fiscal challenges, emphasising the alarming trend of excessive market borrowing and its repercussions, the discrepancy between budgetary practices and fiscal outcomes, raises questions about not only the state's financial management but also, the inclusive development of the state. The consequences of these kinds of financial practices is demanding exploring potential solutions and advocating for a paradigm shift in Tripura's economic approach to set the stage for reforms in inclusive development programmes.

These fiscal challenges and advocating for a comprehensive pathway to reform and agenda, demand us to consider and think about the viable pathways to steer Tripura towards a stable and sustainable economic future, unravelling complexities and urging a paradigm shift in the state's economic approach. Tripura's overreliance on market borrowing extends beyond immediate fiscal concerns, triggering a crisis with multi-faceted consequences. Chief amongst these is the diversion of a significant budget portion towards debt servicing-especially interest payments. This diversion impedes the execution of crucial inclusive development projects, initiating a detrimental ripple effect on economic growth and perpetuating a cycle of escalating debt. Critical sectors like infrastructure, education, and healthcare bear the brunt of fiscal mismanagement. Untimely fund allocations result in project delays, cost overruns, and, in extreme cases, different inclusive development project abandonments are happening. This not

only compromises the quality of public services but also undermines the government's ability to fulfil the aspirations of its citizens. That's why a strategic shifting is imperative to ensure efficient fund allocation and drive sustainable inclusive development with the introduction of different social welfare schemes.

It may be mentioned here that the social welfare programs of the government which are essential for improving all, including marginalised communities and guaranteeing social fairness, are constrained by such budgetary constraints as mentioned above. Though, like many other states of India, Tripura is facing the issues of balancing social welfare and economic development. But, the state's ability to handle important issues like reducing poverty, providing access to healthcare, ensuring education for all children, construction and repairing of roads especially in the villages and district council areas are interrupted by the current budgetary trend. Moreover, the job and recruitment processes in different departments have either been cancelled or postponed, where offices, schools and colleges are running with insufficient staff and teachers. To ensure inclusive growth of the state and the welfare of the people of Tripura, a new fiscal strategy is required. The government must formulate policies that not only ensure food security, create jobs and guarantee welfare systems, but can also improve the living conditions of ordinary people of the state inclusively.

Findings & Recommendations of the Study:

The interplay between market borrowing, debt accumulation, and interest payments forms a self-perpetuating cycle that Tripura must break free from to secure its economic future. The increasing reliance on borrowing leads to higher debt liabilities, subsequently resulting in elevated interest payments that strain the budget further. Breaking this cycle, a strategic approach is immediately required that would address both the root causes and the immediate consequences, which could help a departure from conventional fiscal practices for ensuring development. For the purpose of proposed reforms and ensuring inclusive development in all respects, a blueprint of possible financial resilience is pointed out as below;

Diversifying Revenue Sources:

Tripura's proactive exploration of alternative revenue sources is paramount to reducing dependence on market borrowing. Encouraging industries, promoting tourism, and enhancing agricultural productivity are avenues for creating a diversified revenue base. Additionally, the successful implementation of the Performance Improvement and Revenue Security Assurance system or Process for Internal Restructuring of Systems of Accounting (PIRSA) in various government departments, namely, Food, Civil Supplies and Consumer Affairs (FCS&CA), Department of Higher Education (DHE), and Tripura Tribal Areas Autonomous District Council (TTAADC) are stands as a testament to its efficacy in ensuring maximum non-tax revenue earning by the proper management of non-treasury fund for leveraging the cost of debt or market borrowing.

Enhancing Fiscal Transparency:

Addressing the critical issue of a lack of transparent information regarding market borrowing and loans is very essential. Establishing a comprehensive, easily accessible database of all financial transactions, including market borrowings, enhances transparency, empowering stakeholders to make informed decisions and holding the government accountable for its financial decisions, which would help easy analysis of the position of inclusive development work.

Prioritizing Capital Expenditure:

A careful reassessment of budgetary allocations is imperative. While controlling revenue expenditures is crucial, strategic emphasis should be placed on capital expenditure by allocating funds to those projects that increase revenue, stimulate economic growth and generate long-term benefits and can contribute to sustainable development and reduce reliance on debt.

Effective Debt Management:

Tripura needs to adopt a proactive debt management strategy. Negotiating favourable terms with lenders, refinancing high-interest loans, and exploring debt restructuring options can help minimise the burden of interest payments. This requires skilled financial management and a forward-looking approach to mitigate the impact of debt on the state's finances.

Strengthening Financial Planning:

A robust and forward-looking financial planning process is essential for Tripura's economic stability. The government should set clear fiscal goals, align budgetary priorities with inclusive development objectives, and continuously monitor and adapt to changing economic conditions. This approach will foster resilience against unforeseen challenges and contribute to sustainable economic growth and development.

Building Consensus - A Collaborative Effort:

The government, policymakers, financial authorities, different organisations and the public have to work together to implement necessary reforms in financial rules for achieving the state's inclusive development goal. It is very important to build consensus on the necessary initiatives of policy reforms for the development of the state, communicate long-term advantages, and build support. The people of the state can create a sense of mutual accountability for Tripura’s economic prosperity and ensure sustainable inclusive development by working together.

Concluding Remarks:

With an expected vision for economic renewal initiatives by the government, it can be said that Tripura stands at a crossroads, necessitating a paradigm shift in its fiscal approach. The consequences of excessive market borrowing are apparent, and the state must chart a new course towards financial resilience. By diversifying revenue sources, enhancing transparency,

prioritising capital expenditure, managing debt effectively, and incorporating different innovative revenue-generating systems like PIRSA - An internal fund management system of the departments, Tripura can pave the way for economic renewal and sustainable inclusive development. The journey towards reform requires commitment, strategic vision, transparency in fund management, knowledge & skill in related fields and a collective effort immediately to secure a prosperous future for the people of Tripura.

References:

Anand, R., Mishra, S., & Peiris, S. J. (2013). Inclusive Growth: Measurement and Determinants. *IMF Working Paper*, 1-24.

Devi, K. A. (2022). A Study of Economic Land Use Pattern Development with Special Context in Manipur. *International Journal of Inclusive Development*, 145-147.

Dörffel, C., & Schuhmann, S. (2020). What is Inclusive Development? Introducing the Multidimensional Inclusiveness Index. *Jena Economic Research Papers*, 1-29.

Gupta, J., & Ros-Tonen, M. A. (2015). *Inclusive development.* Amsterdam: PATTBERG.

Gupta, S., Dubey, C., Weersma, L., Vats, R., Rajesh, D., Oleksand, K., & Ratan, R. (2023). Competencies for the academy and market perspective: an approach to the un-sustainable development goals. *Int. J. Exp. Res. Rev.*, *32*, 70-88. https://doi.org/10.52756/ijerr.2023.v32.005

Halder, R. (2016). Work participation rate and development status of Bongaon, Basirhat and Barasat subdivisions of North 24 Parganas District, West Bengal, India. *Int. J. Exp. Res. Rev.*, 3, 30-40.

Ianchovichina, E., & Lundstrom, S. (2009). Inclusive Growth Analytics: Framework and Application. *World Bank: Policy Research Working Paper*, 1-40.

Mubarak. (2016). Inclusive development and sustainable development Policy in India. *IJCRT*, 332-343.

Oinam, B. (2022). A Study on Social Changes among Indigenous Peoples of Hill and Valley of Manipur. *International Journal of Inclusive Development*, 141-143.

Pouw, N. R., & Gupta, J. (2017). Inclusive Development: A Multi-Disciplinary Issue. *Current Opinion in Environmental Sustainability*, Nil.

Premchand, A. (1966). *Control of Public.* Delhi: Allied Publishers.

Rauniyar, G., & Kanbur, R. (2009). *Inclusive Growth and Inclusive Development: A Review and Synthesis of Asian Development Bank Literature.* Manila: Asian Development Bank.

Snehlata. (2018). A Study of Inclusive Growth in India: Its Challenges and Prospects. *JETIR*, 1548-1553.

T.G, S. (2019). Inclusive Growth in India: Some Realities. *Indian Journal of Economics and Development*, 410-417.

Virmani, A. (2023). *Bharatiya Model of Inclusive Development Sabka Sath, Sabka Vikas, Sabka Vishwas, Sabka Prayas.* New Delhi: NITI Aayog.

Zouhar, Y., Jellema, J., Lustig, N., & Trabelsi, M. (2021). Public Expenditure and Inclusive Growth – A Survey. *IMF Working Paper*, 1-75.

HOW TO CITE

Dr. Bankim Debbarma (2024). An Insight into the Challenges and Issues of Inclusive Development of Tripura (India): A Study in Perspective of Yearly State Budget. © International Academic Publishing House (IAPH), Dr. Suman Adhikari, Dr. Manik Bhattacharya and Dr. Ankan Sinha, *A Basic Handbook of Science, Technology and Innovation for Inclusive Development [Volume: 1]*, pp. 117-128. ISBN: 978-81-969828-4-3 DOI: https://doi.org/10.52756/ bhstiid.2024.e01.008

OPEN ACCESS PEER REVIEW
DOI: https://doi.org/10.52756/ bhstiid.2024.e01.009
Chapter- 9

The Importance of the Three-Tier Panchayat System in Promoting Education in Rural West Bengal

Dr. Iftikar Alam

Keywords: *Three-Tier Panchayat Raj, Gram Panchayat, Panchayat Samiti, Zilla Parishad, Village Education Committees, School Management Committee, Shishu Shiksha Kendras, Madhyamik Shiksha Kendras, Decentralisation.*

Abstract:

Though it took another fifty years, a major breakthrough in the history of India's education took place when the Lok Sabha, on November 28, 2001, passed the 93rd Constitutional Amendment Bill, making education a fundamental right. This bill, while emphasizing quality and accessible education, also calls for the sharing of responsibilities between different levels of government. Education being a basic right of citizens, the need for community participation in ensuring adequate and quality education for all (irrespective of class or caste) cannot be over-emphasized. It is our firm conviction that Panchayati Raj Institutions (PRI) has a major role to play in this regard.

This study examines the role of Panchayati Raj Institutions in overseeing education in collaboration with the Education Department in West Bengal. It is based on a field study of recent trends in educational administration in West Bengal. The aim was to thoroughly analyse the connections and collaboration between the development administration and the Panchayati Raj Department in West Bengal. Additionally, it also seeks to evaluate the obstacles in promoting public participation and democratic governance.

Introduction:

The then Government of India constituted many committees and commissions, etc. for the development of education in post-independent India. These committees or commissions made some recommendations for the development of various aspects of education. Following the recommendation, many schemes were subsequently adopted to improve the overall education system, but despite this, the expansion and improvement in the quality of education have not been as expected. Again, proper supervision of educational institutions has not become possible because the power is centralized; hence, its use at the grassroots level was also difficult.

Decentralisation is considered a strategy to enhance the effectiveness of education systems and the quality of educational services by involving community members in the planning and decision-making processes.

In April 1993, the Lok Sabha of India approved the 73rd constitutional amendment through this amendment, the three-tier Panchayat Raj system got constitutional recognition. Part IX of

Dr. Iftikar Alam
Department of Geography, Assistant Professor, Chakdaha College
E-mail: driftikar7421@gmail.com; Orcid iD: https://orcid.org/0009-0005-2975-947X
*__Corresponding Author__: driftikar7421@gmail.com

Dr. Suman Adhikari, Dr. Manik Bhattacharya and Dr. Ankan Sinha, A Basic Handbook of Science, Technology and Innovation for Inclusive Development [Volume: 1]. ISBN: 978-81-969828-4-3; pp- 129-136; Published online: 27th May, 2024

the constitution includes Article 243, which specifies the constitution of the three-tier panchayat system. Arrangements were made to form ten standing committees at the zilla parishad and panchayat samiti level and sub-committees (upa-samitis) at the gram panchayat level, in which "The education, Culture, Information and Sports Standing Committee" and the "Education and Public Health" sub-committee, respectively were given the proper implementation of the education system. As a result, the local administration has a close relationship with educational institutions. The present paper attempts to examine whether the powers of educational planning and management of education, as mentioned in the 73rd Constitutional Amendment, have devolved to three-tier Panchayati Raj Institutions at district, block, and gram panchayat levels in West Bengal. Further, the paper discusses strengths, and weaknesses in terms of the structures, functions, roles, and responsibilities of PRIs (Panchayati Raj Institutions) for managing education in West Bengal. The paper argues for wider research on these issues and has given the necessary roadmap for future policy and concrete strategy for the development of school education under Panchayati Raj Institutions.

Literature Review

There are different views about the role of Panchayati Raj Institutions in the management of education in India. It is clear from many observations that there is a lack of administrative linkage between educational institutions and local administration. As a result, "the quality of supervision has considerably gone down due to ineffective supervision, haphazard inspection, tardiness of administration and insecurity of teaching staff" (Krishnamacharylu, 1993). Bhargava and Venkata Krishnan (1993) argue that the Panchayati Raj Institutions and the Education system lack a clear definition of their powers and functions, resulting in dual control over education (Srivastava et al., 2016; Malhotra et al., 2023; Mittal & Mittal, 2023). "In the last two decades of the last century, primary education in West Bengal under PRIs has not been at all encouraging" (Acharya, 2002). Panchayats are primarily involved in offering community support, with their role being peripheral, if not negligible, in the management and administration of education. There is poor coordination between the Panchayati Raj Institutions and the schools. PRIs are often unable to achieve the expected outcomes due to their limited authority to take on significant roles in the realm of education. However, Mathew's observation in 2008 emphasized that the empowerment of panchayats is the ultimate solution to all education-related issues at the village level. There is hardly any capacity-building programmeme for PRIs in school management. In spite of provisions in the guidelines that PRIs will be responsible for the recruitment and selection of teachers, they are not included in the selection committees of teachers but are simply assigned the task of posting teachers in schools from the list of selected teachers (Tyagi and Akhtar, 2009).

Objectives

The following are the research objectives:

1. The role of Panchayati Raj Institutions in the management of education in rural West Bengal.
2. To find out if there is any lack of linkage between local administration and educational institutions in rural areas of West Bengal.
3. To study the structure of Panchayati Raj Institutions from the perspectives of educational management and promotion in rural areas of West Bengal.
4. To assess the role of the standing committee of the three-tier Panchayati Raj system in expanding education in rural areas.
5. The linkage between the Right to Education Act 2009 and panchayat
6. To assess the decentralisation of power in education management and its relation to the panchayat

Methodology

The paper critically examines the linkages and coordination between the administration and the Panchayati Raj Department in the development of education and identifies deficiencies in the interface between development administration and PRIs. The study's methodology relied on survey research to gather primary and secondary data from interviews and document analysis pertaining to educational development and interface. Transcriptions of open-ended questions and interviews were made, leading to the drawing of inferences. Interviews were conducted with all the stakeholders, including officers and elected representatives of PRIs and officers of the Education Department.

Major Findings & Discussion

(A) "The Education, Culture, Information and Sports Standing Committee" of Zilla Parishad

In the case of Zilla Parishad, the Sabhadhipati (Chairman) and the assistant chairperson are ex-official members of the standing committee. Also, three to five elected representatives and two opposition representatives are members of this standing committee, depending on the number of elected members. One of the representatives is elected as the executive officer. The officers of the concerned department are also members of the standing committee, and one of them is nominated as the secretary of this standing committee. Various offices related to education, such as the District Inspector of Schools (Primary and Secondary), District project officer (Sarva Shiksha Mission), District Nodal Officer (Child Education Programme and Secondary Education Programme) officer in charge of Madrasa Education, and officer in charge of Mid-Day Meal scheme, are the members of the standing committee. In the meeting of the standing committee, various officers informed the standing committee about the various information of their department. Also, the infrastructure of the educational institution, the quality of education, and any special problems are discovered and discussed in detail in the meeting. Elected public representatives present problems or suggestions related to education in their area in this meeting. The standing committee of various Zilla Parishad can arrange visits

to educational institutions so that they can see the implementation of various decisions on the ground.

(B) "The Education, Culture, Information and Sports Standing Committee" of Panchayat Samiti

Though the same in terms of functioning panchayat samiti, the structure of the "Education, Culture, Information and Sports" standing committee of panchayat samiti differs. At this level, the Sabhapati and Saha Sabhapati (Chairperson and Vice Chairperson) are the members of this standing committee. Similar to Zilla Parishad three to five elected representatives and one elected representative from the opposition party members of this standing committee, depending on the number of elected representatives. A Karmadhyaksha is elected from among the majority party members. Similarly, officers from various education departments, such as sub-inspectors of schools, education officers, and mid-day-meal coordinators, are members of this standing committee.

All the primary schools, upper primary schools, secondary schools, Shishu Shiksha Kendras, Madhyamik Shiksha Kendras madrasa, and Jana Shiksha Kendras under a panchayat samiti are discussed in detail about the infrastructure, quality of education, etc. in this standing committee.

(C) "Education and Public Health" Standing Committee and Gram Panchayat

The "Education and Public Health" subcommittee at the gram panchayat level looks after the local educational institutions and educational matters. Pradhan and Upa-Pradhan (Chairperson and Vice-chairperson) are ex-official members of this subcommittee. In addition, one to three elected representatives are members of the subcommittee, and one of them is elected as a moderator. The gram panchayat secretary and the executive assistant are included as members of the government representatives.

Right To Education Act 2009 And Panchayat

The implementation of the education system has been significantly emphasized by the three-tier panchayat system, as stated in "The Right of Children to Free and Compulsory Education Act 2009," which became effective in August 2009. Section nine of the third chapter of this act states that as a local authority, the three-tier system of the panchayat is to see the set up of schools, admit children of all suitable groups in the concerned panchayat areas, ensure education for all up to the age of 14 years, develop the quality of education, and above all assess how the educational institutions in their areas are functioning.

Village Education Committee (VEC) And Panchayat

The National Policy of Education, 1986 recommended ensuring the participation of local people in the education system. Village Education Committees were formed under the guidelines of the Sarva Shiksha Mission as per the "Right of Children to Free Compulsory Education Act 2009 " to connect the common man, i.e. the rural mass with the education

system at the village level in West Bengal. This committee had the financial power to plan and implement the overall infrastructural improvement of all educational institutions under a village council. In addition, the committee was also tasked with ensuring that all children between the ages of 14 years are enrolled in an educational institution and that they have completed their primary education.

School Managing Committee And Panchayat

Sections 21 and 22 of Chapter 4 of the "Right of Children to Free Compulsory Education Act 2009 " deal with the school management committee. As per Section 22 of the Act, the managing committee shall plan the overall development of the school. The managing committee will include members of the local village panchayat as representatives of the local authority. The school managing committee will oversee the day-to-day activities of the school. Besides, the managing committee with financial capacity will be responsible for the development of school infrastructure, the proper implementation of the mid-day meal system, etc.

Child Education Programme And Secondary Education Programme in West Bengal

As one of the most notable examples of the role of panchayats in the education system of West Bengal, the Child Education Programme and the Secondary Education Programme have already carved their place in the educational history of the state. In the 1993 Supreme Court of India in J. P. Unni Krishnan case recognised education as a fundamental right of children. Earlier, the literacy movement had greatly increased the interest of the common people in education. Although there were primary schools, the state still had many schoolless villages where children had no primary education within their reach.

To bring children from such schoolless settlements and geographically isolated areas into the arena of education, the child education programme was started in 1997- 98 under the panchayats and Rural Development Department of the Government of West Bengal, which provided literacy from class one to four. In 1997, there were only 410 Shishu Shiksha Kendras (Child Education Centre) in the state, but later this number increased to meet the demand of the local people. In the academic year 2018, the number of Child Education Centres in the state is 1,58,004 where 10,59,059 students are studying of which 28.01% belong to the scheduled caste and 11.27% belong to the scheduled tribe.

For much the same reason, in 2002-03, the Panchayat and Rural Development Department expanded the programme vertically so that children in remote areas could ensure their early education.

Then the secondary education programme started in 2003-2004. There were 863 Madhyamik Shiksha Kendras that paved the way for getting an education with classes from five to eight. In the academic year 2018, a total of 1912 Madhyamik Shiksha Kendras (Secondary Education Centre) in the state provided education to 3,01,094 numbers of students, among whom 27.50 percent belonged to the schedule caste and 11.01% belonged to schedule tribe. A notable fact is

that while the ratio of boys to girls is almost equal in the case of Shishu Shiksha Kendras the number of girls is comparatively higher in the case of Madhyamik Shiksha Kendras. It may also be mentioned that 43.58% of children in Shishu Shiksha Kendras and 44.10% of students in Madhyamik Shiksha Kendras belong to the minority community.

Decentralisation of Power In Education And Panchayat

Generally, the administration takes the decision to establish the school, but it was decided by the common people of the villages where the Shishu Shiksha Kendras and Madhyamik Shiksha Kendras were to be set up. It was the people of the village who arranged the required land, identified prospective students, and arranged admission in the centre according to their age. Later on, they were sanctioned through the three-tier panchayat system and started getting government facilities. People over forty years of age with suitable educational qualifications were given the opportunity to teach in these centres. They are named Sahayak/Sahayaki for Shishu Shiksha Kendras and Samprasrak/Samprasrika in the case of Madhyamik Shiksha Kendras .

The three-tier panchayat also played an important role in the recruitment of these education workers. The approval of "The Education, Culture, Information and Sports Standing Committee" and "Education and Public Health" Standing Committee of the Panchayat Samiti was mandatory for the appointment of Sahayak/Sahayaki for Shishu Shiksha Kendras and Samprasrak/Samprasrika in case of Madhyamik Shiksha Kendras. In special cases, the approval of Zilla Parishad and the concerned department was required. In Shishu Shiksha Kendra or Madhyamik Shiksha Kendra, the curriculum, syllabus, and textbooks designed by the education department of West Bengal are fully followed. Also, the students studying in these centres get all the facilities, like free textbooks, mid-day meals, etc.

Initially, managing a committee of nine members for these centres was in the supervision of Shishu Shiksha Kendras and Madhyamik Shiksha Kendras, with one ex-official member from the local Gram Panchayat. After February 2013, administrative committees were created in place of the managing committee for these centres where local panchayat members serve as the chairman of the administrative committee.

Although initially started temporarily, these two programmes gained such popularity that in 2013 Shishu Shiksha Kendras and Madhyamik Shiksha Kendras received the status of ordinary primary and primary school, respectively by the Department of Education, Government of West Bengal.

The transformation of power from central to local government is called decentralization. As a result of this decentralisation of power in the education system, elected representatives of the three-tier panchayat system can directly participate in the management of the education system. Consequently, schools have been able to connect with people today. Day-to-day issues such as what are the infrastructural needs of an institution, how is the quality of education there, which teachers are irregular in the school and what is the quality of the mid-day meal, etc. can only be

monitored by the local people. In this regard, the public representative associated with the three-tier system of panchayats is performing their responsibilities. Apart from this, the panchayat system helps a lot in the celebration of various anniversaries like Independent Day, Republic Day, and Manifestation Day in schools and in organising cultural programmes and sports competitions, etc.

Conclusion And Suggestions

Although the three-tier Panchayat system has a close relationship with the development of educational institutions and the quality of education, its various manifestations are observed in different places. At present, many educational institutions in the state are supported by panchayats, and the desired gold can be achieved through the intensive training of elected public representatives of the three-tier panchayat system on educational needs and panchayat issues.

Panchayats also help in improving physical infrastructure and providing some of the non-academic support for the Sishu Siksha Karmasuchi as well as the formal system of education. However, there has been very little formal devolution to the Panchayats of functions related to formal education in West Bengal, and the Panchayats mostly play facilitating roles.

Every school encounters various challenges. While certain problems were exclusive to particular schools, there existed a set of issues that were shared among all of them. The government mandated that all primary schools accept every child in their vicinity. This led to a high student-teacher ratio and subsequently, a decline in the quality of education provided at the schools.

The current understanding of the field realities strongly contradicts the anticipated outcomes of decentralizing educational administration. According to Noronha, 2003, it is true that the decision-making process has come down to the local level. Nevertheless, the means to implement these decisions have not been provided to the decision-makers at the local level.

The examination of the VEC formation process reveals that, on certain occasions, individuals with limited education are involved in the formation. Despite the potential ethical concerns, it is likely not preferable to appoint such individuals as decision-makers.

It is important to ensure that there is no overlap in functions when empowering the panchayat system across the three tiers. By clearly defining the roles and responsibilities of each tier, we can effectively enhance the impact of this evolution.

References:

Acharya, Promesh (2002): Education: Panchayat and Decentralization—Myths and Realities, *Economic and Political Weekly*, February 23, 2002.

Bhargava, B. S. and V, Venkatakrishnan.(1993): Panchayati Raj in Tamil Nadu—Issue and Problems, *Kurukshetra*, Vol. 40 (9).

George Mathew, Buddhadeb Ghosh and Rajan Soni.(2001): *The Scoping Study on Decentralisation and Convergence Issues in West Bengal*, (Report prepared at the Institute of Social Sciences, New Delhi, for DFID, UK)

Government of India, Ministry of Human Resource Development, Department of Education (1993): Report of the Central Advisory Board of Education (CABE) Committee on Decentralized Management of Education, New Delhi.

Government of India, Ministry of Human Resource Development, Department of Education (1992): National Policy on Education and Programme of Action 1986 & 1992, New Delhi.

Krishnamacharyulu, V. (1993): *Management of Education in Panchayati Raj Institutions in Andhra Pradesh*: An Unpublished Case Study, Hyderabad.

Kumar, Suresh & Tyagi R.S. (2013): *A Study of Block Level Educational Administration in Gujarat—Emerging Challenges and Need for Reforms*, Unpublished Report, NUEPA, New Delhi.

Malhotra, S., Anil, K., & Kaur, A. (2023). Impact of Social Entrepreneurship on Digital Technology and Students' Skill Set in Higher Education Institutions: A Structured Equation Model. *Int. J. Exp. Res. Rev.*, *35*, 54-61. https://doi.org/10.52756/ijerr.2023.v35spl.006

Mathew, George.(2008): *Panchayats and Education, Institute of Social Science*, New Delhi, Unpublished Paper presented in the Workshop of Management of School Education under PRIs in Madhya Pradesh (August 30-31, 2008), Bhopal.

Mittal, P., & Jora, R. (2023). Exploring student community engagement in higher education: A bibliometric analysis on the path to sustainable development. *Int. J. Exp. Res. Rev.*, 32, 166-177. https://doi.org/10.52756/ijerr.2023.v32.014

National University of Educational Planning and Administration (1991-2001): Studies on Educational Administration—Structures, Processes and Systems, New Delhi: Vikas Publishing House

Raghabendra Chattopadhyay, Sudip Chaudhuri, Saila Ghosh, Anup Sen, V N Reddy (1998): The Status of Primary Education in West Bengal, (UNICEF-sponsored study prepared for the Government of West Bengal).

Srivastava, G., Maity, A., & Srivastava, M. (2016). Spatial Analysis of Female Literacy in Religious Minorities of Uttar Pradesh, India. *Int. J. Exp. Res. Rev.*, 8, 39-45.

Tyagi, R. S. & Najma Akhtar (2009): Management of School Education Under Panchayati Raj Institutions in Gujarat and Madhya Pradesh—Participation, Progress and Perspective, NUEPA, New Delhi.

HOW TO CITE

Dr. Iftikar Alam (2024). The Importance of the Three-Tier Panchayat System in Promoting Education in Rural West Bengal. © International Academic Publishing House (IAPH), Dr. Suman Adhikari, Dr. Manik Bhattacharya and Dr. Ankan Sinha, *A Basic Handbook of Science, Technology and Innovation for Inclusive Development [Volume: 1]*, pp. 129-136. ISBN: 978-81-969828-4-3 DOI: https://doi.org/10.52756/ bhstiid.2024.e01.009.

OPEN ACCESS PEER REVIEW
DOI: https://doi.org/10.52756/ bhstiid.2024.e01.010
Chapter- 10

Effect of Different Yogic Practices on Resting Heart Rate Among the Working Men of North Tripura (India)

Meenakshi Saini, Prasanta Kumar Das, Ankan Sinha*

Keywords: *Yoga interventions, Controlled group and Resting Heart Rate*.

Abstract:

The project aims to investigate the physiological outcomes of 6 weeks different yoga practices among working men. One Hundred Twenty (120) men working in educational institutions and offices were purposively chosen as subjects for the study, were randomly distributed evenly among three experimental groups and a control group i.e., (n=30). The individuals' ages ranged from 25 to 45 years old. The experimental groups underwent either Power Yoga, Restorative Yoga, or a combination of both, while the control group received no intervention. Resting Heart Rate were measured before and after the intervention using Automatic Digital Monitor. The analysis of covariance, or "F-ratio," was used at the 0.05 level of significance to observe the impact. Statistical analyses revealed significant reductions in all experimental groups' resting heart rates as compared to the control group. There is no apparent difference between groups B (74.68903) and C (74.72451) when the pairwise difference of adjusted means with the critical difference is compared. This is because the difference in their adjusted means, or 0.03548, is smaller than the critical difference (1.149549). Whereas pair wise difference for all the other groups namely; group A (72.04698) & group B (74.68903), group A (72.04698) & group C (74.72451), group A (72.04698) & group D (76.67282), group B (74.68903) & group D (76.67282), group C (74.72451) & group D (76.67282) in their adjusted means were higher than the critical difference (1.149549). These results suggest that group A should be preferred out of the four training programmes since its adjusted mean (72.04698) is lower than the adjusted means of the other four training groups. For this reason, restorative yoga instruction is advised to lower resting heart rate among the working men of North Tripura.

Introduction:

Yoga is the ideal physical activity for fostering equilibrium in the body, mind, and soul. Asanas are poses in yoga that allow you to hold or move your body in various ways. There are numerous yoga postures and techniques that are beneficial to individual's overall physical and mental well-being. Numerous studies have demonstrated that practicing yoga on a daily basis can truly save lives by lowering stress and inflammatory levels throughout the body and enhancing cardiovascular health.

Meenakshi Saini
Dept. of Physical Education, Kendriya Vidyalaya, Kailashahar, North Tripura
Orcid iD: https://orcid.org/0000-0002-1430-9565
Prasanta Kumar Das
Dept. of Physical Education, Tripura University, Agartala, Tripura (W)
Ankan Sinha*
Department of Physical Education, Government Degree College, Dharmanagar, Tripura (N)
E-mail: ankansinha4770@gmail.com; Orcid iD: https://orcid.org/0009-0009-7203-3059
***Corresponding Author**: ankansinha4770@gmail.com

Dr. Suman Adhikari, Dr. Manik Bhattacharya and Dr. Ankan Sinha, A Basic Handbook of Science, Technology and Innovation for Inclusive Development [Volume: 1]. ISBN: 978-81-969828-4-3; pp- 137-143; Published online: 27th May, 2024

Indians have traditionally valued "yoga" and "physical exercises" highly, employing them to maintain their physical fitness and to either avoid or treat bodily ailments (**Basak & Biswas, 2016; Kaur et al., 2023; Khant et al., 2023**). The ancient Rishis, the Vedas, and the Puranic writings all placed a great importance on physical well-being **(Uppal & Gautam, 2006).**

Although some people claim that yoga and exercise are two different concepts, yoga shares many of the same health advantages as exercise but places more of an emphasis on spirituality and the mind than on physical fitness **(Govindaraj et al, 2016).**

The history of power yoga is closely linked to that of contemporary yoga. Even while power yoga shares the same objectives as conventional systems, it was really one of the first forms of yoga to break away from them. Power yoga proponents claim that the practice improves posture, mental focus, flexibility, and stamina. Sweating releases toxins and eases anxiety, much like any physical activity **(Sullivan et al., 2017).** It can aid in weight loss because it is more strenuous than most traditional types of yoga, burning more calories in the process.

Among the qualities that characterize restorative yoga are gentleness, support, and therapeutic effects. Fundamentally, restorative yoga is a form of non-active healing. This type of yoga, as its name implies, "restores" the body to the function of the parasympathetic nervous system, which aids in the body's ability to heal, rest, and regain equilibrium. Restorative yoga promotes a deeper breathing pattern and lengthier asanas (postures), which assist induce a state of relaxation. This reaction can lower blood pressure, aid moderate breathing, and provide a calmer, more balanced mood. **(Lindberg, 2020)**

Objectives of the study

1. To evaluate the impact on resting heart rate of Power Yoga, Restorative Yoga, and their combination.
2. To investigate which yoga training programme will be more effective to influence the Resting Heart Rate of working men of North Tripura.

Methodology:

The study's subjects were 120 working men from North Tripura who were recruited at random. Individuals who had participated in any additional training programmes were excluded from the training. To ensure they were medically fit to take part in the different training sessions, the subjects had a health examination. The subjects were between the ages of 25 and 45.

Experimental Design

In this study an experimental design called as randomized pre-test/post-test design was used. The subjects were divided into three experimental groups and one control group, each made up of 30 working men. The subjects were randomized to the training programmes at random in each of the four groups. The subjects were selected at random by drawing lots, and the treatment was administered at random.

Collection of Data

The scores regarding functional response, i.e. resting heart rate, among working men in North Tripura were gathered using an Automatic Digital Monitor. Before and after the test administrations, adequate rest was taken in order to collect all of the data. Five days week trainings were scheduled as the experimental programmes, with each group receiving around one hour every day.

Pre- and post-tests were administered to each of the four groups, as needed, both before and after the experimental programme was completed.

Administration of yoga interventions

First, the subjects in group A are given 45 minutes of Power yoga five days every week for six weeks. Each training day's practice includes eight sets of asanas. Whereas, group B subjects receive 45-minute restorative yoga practice five days a week for six weeks. Every training day, there were six sets of asanas in the sessions. Conversely, however, group C subjects receive 45-minute combined yoga practice (Power & Restorative) five days a week for six weeks. Every training day, the workouts comprised four sets of Power yoga poses and four sets of Restorative yoga poses.

Findings:

The mean and standard deviation of working men of North Tripura pertaining to resting heart rate in power yoga training group under various experimental settings are as follows:

Table 1-A DESCRIPTIVE INVESTIGATION OF THE RESTING HEART RATE OF WORKING MEN FOLLOWING POWER YOGA TRAINING

Variables	Experimental Conditions	Mean	S.D	Minimum	Maximum	Range
Resting Heart Rate	**Pre test**	76.6	11.57	58	100	42
	Post test	74.27	10.10	58	92	34

The mean and standard deviation of working men of North Tripura pertaining to resting heart rate in restorative yoga training group under various experimental settings are as follows:

Table 2- A DESCRIPTIVE INVESTIGATION OF THE RESTING HEART RATE OF WORKING MEN FOLLOWING RESTORATIVE YOGA TRAINING

Variables	Experimental Conditions	Mean	S.D	Minimum	Maximum	Range
Resting Heart Rate	**Pre test**	76.27	11.76	58	98	40
	Post test	71.33	9.84	56	90	34

The mean and standard deviation of working men of North Tripura pertaining to resting heart rate in combine yoga interventions (Power & restorative yoga training) for different experimental conditions are as follows:

Table 3- A DESCRIPTIVE INVESTIGATION OF THE RESTING HEART RATE OF WORKING MEN FOLLOWING COMBINE YOGA INTERVENTION GROUP (POWER & RESTORATIVE YOGA TRAINING)

Variables	Experimental Conditions	Mean	S.D	Minimum	Maximum	Range
Resting Heart Rate	**Pre test**	78.47	12.35	56	98	42
	Post test	75.93	11.19	56	92	36

The mean and standard deviation of working men of North Tripura pertaining to resting heart rate under various experimental circumstances in the control group are as follows:

Table 4- A DESCRIPTIVE INVESTIGATION OF RESTING HEART RATE OF WORKING MEN OF CONTROL GROUP

Variables	Experimental Conditions	Mean	S.D	Minimum	Maximum	Range
Resting Heart Rate	**Pre test**	77	10.93	58	94	36
	Post test	76.6	10.52	60	96	36

The following tables present the results of the analysis of covariance and mean difference method applied to the resting heart rates of working men in North Tripura amongst four groups: Control Group (CG), Combination Yoga Training (CYT), Restorative Yoga Training (RYT), and Power Yoga Training (PYT).

Table 5- ANALYSIS OF COVARIANCE OF RESTING HEART RATE OF WORKING MEN

	RYT	**PYT**	**R & P YT**	**CG**	**SOV**	**df**	**SS**	**MSS**	**F-ratio**
Pre means	76.27	76.6	78.47	77	B W	3 116	84.63 16322.53	28.21 140.71	0.20
Post means	71.33	74.27	75.93	76.6	B W	3 116	496.27 13045.6	165.42 112.46	1.47
Adjusted means	72.05	74.69	74.72	76.67	B W	3 115	324.38 581.45	108.12 5.06	**21.37**
***Sig. at .05 levels Tab. F. 05 (3,115) = 2.68**									

Table 5 above demonstrated that the tabulated F (2.68) is smaller than the adjusted calculated F (21.37). Therefore, there were notable differences in the four groups' resting heart rates: the restorative yoga training group, the power yoga training group, the combine (restorative + power yoga) training group, and the control group. It is determined that not every training programme has the same impact on improving or lowering the resting heart rate of North Tripura's working men. On the adjusted mean of the posttest data, pair wise comparison analysis (LSD test) was performed to determine which training programme is more successful. Table 6 displays the outcome in relation to this:

Table 6- FOR RESTING HEART RATE IN DIFFERENT GROUPS THE ADJUSTED MEAN SCORES DURING POST TESTING

Restorative Yora Training (A)	Power Yoga Training (B)	Retotative+Power Yoga Training (C)	Control Group (D)	Adjusted Mean Difference	Cd At 5 % Level
72.04698	74.68903			**2.64205**	
72.04698		74.72451		**2.67753**	**1.149549**
72.04698			76.67282	**4.62584**	
	74.68903	74.72451		0.03548	
	74.68903		76.67282	**1.98379**	
		74.72451	76.67282	**1.94832**	

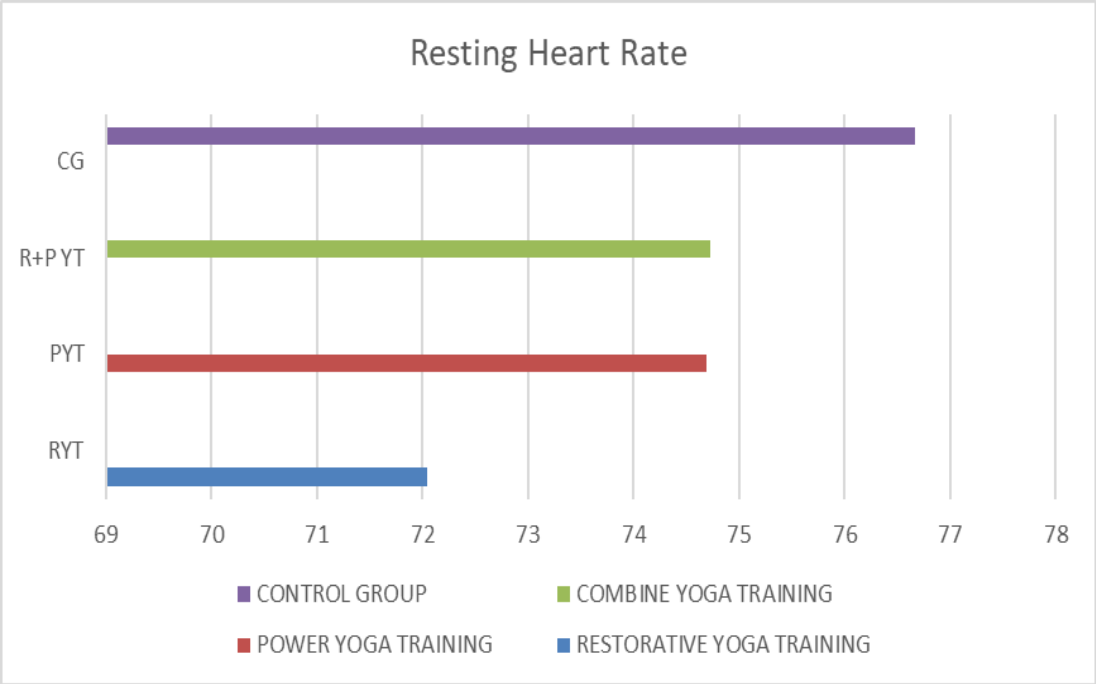


Figure 1. Adjusted Means of Resting Heart Rate in different groups

Discussion:

When the pairwise difference of adjusted means is compared to the critical difference, it is clear that there is no significant difference between groups B (74.68903) and C (74.72451), since the difference in adjusted means, 0.03548, is smaller than the critical difference (1.149549). Whereas pair wise difference for all the other groups namely; group A (72.04698) & group B (74.68903), group A (72.04698) & group C (74.72451), group A (72.04698) & group D (76.67282), group B (74.68903) & group D (76.67282), group C (74.72451) & group D (76.67282) in their adjusted means were higher than the critical difference (1.149549). Thus, out of four training programmes, group A is favoured since its adjusted mean (72.04698) is lower than the adjusted means of the other four training groups. Hence, restorative yoga training is indicated to reduce the resting heart rate among the working men of North Tripura.

Conclusion:

The hypothesis stated earlier that there would be a significant difference in the resting heart rate of working men after giving Power yoga training, Restorative yoga training and their combination training is accepted as the tabulated F (2.68) is smaller than the adjusted calculated F (21.37). Thus, all three yoga training programmes benefited working men in the North Tripura district. The adjusted means of Power Yoga Training (74.68903) and Combination Yoga Training (74.72451) are higher than the adjusted means of Restorative Yoga Training (RYT), indicating that RYT was most effective in lowering and maintaining the resting heart rate of working men.

References:

Basak, S., & Biswas, K. (2016). A study of selective physiological parameters in physical training college students. *Int. J. Exp. Res. Rev., 3,* 1-6.

Bridges, L., & Sharma, M. (2017). The Efficacy of Yoga as a Form of Treatment for Depression. Journal of Evidence-Based Complementary & Alternative Medicine, 22(4), 1017–1028.

Gaskins, R. B., Jennings, E., Thind, H., Becker, B. M., & Bock, B. C. (2014). Acute and Cumulative Effects of Vinyasa Yoga on Affect and Stress among College Students Participating in an Eight-week Yoga Program: A Pilot Study. International Journal of Yoga Therapy, 24, 63–70.

Govindaraj, R., Karmani, S., Varambally, S., & Gangadhar, B. N. (2016). Yoga and physical exercise - a review and comparison. International Review of Psychiatry, *28*(3), 242–253.

Kaur, P., Arora, G., & Aggarwal, A. (2023). Psycho-Social Impact of COVID-2019 on Work-Life Balance of Health Care Workers in India: A Moderation-Mediation Analysis. *Int. J. Exp. Res. Rev., 35*, 62-82. https://doi.org/10.52756/ijerr.2023.v35spl.007

Khant, A., Dave, Y., Tare, H., Udugade, B., Udugade, S., Choudante, S., & Pulate, C. (2023). Effectiveness of respiratory muscle training on pulmonary function and quality of life in

cotton industry workers. *Int. J. Exp. Res. Rev.*, *32*, 160-165. https://doi.org/10.52756/ijerr.2023.v32.013

Lindberg, S. (2020). The Benefits of Restorative Yoga and Poses to Try. Healthline. Retrieved from https://www.healthline.com/health/restorative-yoga-poses

Miyoshi, Y. (2019). Restorative yoga for occupational stress among Japanese female nurses working night shift: Randomized crossover trial. Journal of Occupational Health, 61(6), 508–516.

Nayak, A. K. (2016). Effects of yoga on mental and physical health. International Journal of Physical Education, Sports and Health, 3(5), 268–270.

Rayat, S. (2015). Effect of Yoga on Selected Physical and Physiological Variables of Physical Education Students. IOSR Journal of Sports and Physical Education, 2(4), 18–24.

Saini, M., Das,P.K., & Sinha,A.(2023).A pilot study: Comparative efficacy of power yoga, restorative yoga and their combination on reaction time among the college boys of North Tripura. International Journal of Yogic, Human Movement and Sports Sciences, 8 (1): 239-242.

Sullivan, M., Carberry, A., Evans, E. S., Hall, E. E., & Nepocatych, S. (2017). The effects of power and stretch Yoga on effect and salivary cortisol in Women. Journal of Health Psychology, 24(12), 1658–1667.

Uppal, A. K., & Gautam, G. P. (2006). Physical Education and Health. New Delhi: Friends Publication.

Wergeland, M. (2021). The Healing Powers of Restorative Yoga. Balance Live Well. Retrieved from https://balance.media/restorative-yoga/.

HOW TO CITE

Meenakshi Saini, Prasanta Kumar Das, Ankan Sinha (2024). Effect of Different Yogic Practices on Resting Heart Rate Among the Working Men of North Tripura (India). © International Academic Publishing House (IAPH), Dr. Suman Adhikari, Dr. Manik Bhattacharya and Dr. Ankan Sinha, *A Basic Handbook of Science, Technology and Innovation for Inclusive Development [Volume: 1]*, pp. 137-143. ISBN: 978-81-969828-4-3 DOI: https://doi.org/10.52756/ bhstiid.2024.e01.010

OPEN ACCESS PEER REVIEW
DOI: https://doi.org/10.52756/ bhstiid.2024.e01.011
Chapter- 11

Innovative Approaches to Enhance Education and Healthcare in Tribal Regions Through Science & Technology

Sukanta Chandra Nath*, Rahul Dev Choudhury, Debraj Nath

Keywords: Tribal region, Policy frameworks, Socio-economic inequalities, Indigenous populations, Digital learning platforms, Telemedicine services.

Abstract:

Recent advancements in science and technology present promising prospects to confront enduring difficulties faced by the people in tribal regions of India, especially accessing fundamental services like education and healthcare. This article explores the transformative potential of technological interventions in enhancing indigenous population's socio-economic landscape and well-being. By analyzing successful case reports, policy frameworks, and execution techniques, the investigator explores the benefits and obstacles of employing science and technology to elevate tribal communities. The examination underscores the importance of digital learning platforms and telemedicine services in promoting inclusiveness and sustainable progress in indigenous areas. Through thematic examination of multiple case reports, the paper reveals how technology can bridge educational & medical disparities, decrease health inequities, and increase access to quality medical care. Moreover, it outlines strategic approaches such as community participation, capability development, and policy support for successfully integrating science & technology in tribal education and healthcare policies. Adopting innovation and fostering collaborative initiatives that can promote inclusive growth and empower tribal communities throughout India.

Introduction:

Tribal regions in India have had persistent challenges in accessing crucial services like education and healthcare, contributing to socio-economic inequalities and delaying overall progress (Malhotra et al., 2023; Mittal & Jora, 2023). Recent advancements in science and technology provide exciting opportunities to tackle these difficulties and improve the conditions of tribal populations. New methods utilizing technological progress have become vital factors in improving education and healthcare in indigenous areas around the country. Digital learning platforms and telemedicine services are transforming tribal development, boosting inclusivity, and encouraging sustainable advancement (Srivastava et al., 2016; Donath et al., 2020). The

Sukanta Chandra Nath*
Dept. of Physical Education, Govt. Degree College, Dharmanahgar, Tripura, India
Orcid iD: https://orcid.org/0009- 0005- 1990 -6800
Rahul Dev Choudhury
Dept. of Physical Education, Regional College of Physical Education, Panisagar, Tripura, India
E-mail: devrahul09@gmail.com; Orcid iD: https://orcid.org/0000- 0002- 8570 -532X
Debraj Nath
Dept. of Physical Education, Regional College of Physical Education, Panisagar, Tripura, India
Orcid iD: https://orcid.org/0009- 0001- 0555 -6476
***Corresponding Author**: sukantarst1430@gmail.com

Dr. Suman Adhikari, Dr. Manik Bhattacharya and Dr. Ankan Sinha, A Basic Handbook of Science, Technology and Innovation for Inclusive Development [Volume: 1]. ISBN: 978-81-969828-4-3; pp- 144-154; Published online: 27th May, 2024

research paper explores how science and technology interventions might bring about significant changes in tribal communities in India. This study explores the potential benefits and obstacles of using science and technology to improve education and healthcare outcomes for indigenous populations by analyzing successful case studies, policy frameworks, and implementation techniques. Understanding these novel methods is crucial for creating successful interventions and promoting comprehensive growth in India's tribal areas.

Objectives:

1. To Explore the pros and cons of using science and technology interventions to improve indigenous education outcomes in India's tribal areas.
2. To explore how science and technology can improve tribal healthcare to reduce tribal health disparities and increase quality medical care.
3. To overcome tribal education barriers, examine digital learning toolsto promote tribal learning.

Methodology:

The research aims to investigate the effects of science and technology on tribal education and healthcare in India. The study focuses on analyzing the comprehensive literature, and case studies analysis offers fundamental knowledge and insights by reviewing existing literature on technological interventions and workplace productivity, providing a foundational understanding of the subject matter. Multiple case studies are analysed thematically to extract recurring themes and patterns. These case studies provide rich contextual insights into the real-world implications of technology adoption on the effects of science and technology on tribal education and healthcare in India. The study aims to provide actionable insights for organizations seeking to leverage technology effectively to enhance productivity and competitiveness in the digital age.

Innovative Approaches to Enhance Education in Tribal Regions

While limited access to education and healthcare hasintensified socioeconomic disparities historically confronting indigenous communities in India, new technologies now offer hope. Digital learning platforms and telehealth services have spawned revolutionary changes for tribal development, fostering greater inclusiveness and sustainability(Nagarajan et al., 2013). This analysis delves deeply into how technology can dramatically transform tribal regions across India, examining closely case studies of successes achieved, beneficial policy frameworks designed, and strategies implemented effectively. Understanding fully these methods is vital for interventions that promote comprehensive and equitable growth while narrowing gaps in indigenous populations' education and healthcare. Collaboration involving government, nonprofit groups, universities, and local communities is undoubtedly crucial to leveraging technology to enhance conditions for tribal populations nationwide.

Bridging Healthcare Gaps in Tribal Communities with Science & Technology

Tribal communities in India have a substantially sized population lacking quality education and medical care due to geographic seclusion, financial restrictions, and cultural diversity, retaining indigenous health progress despite scholarly evolution(Patel, 2021). The inventive scientific and engineering solutions revolutionizing pedagogy can revolutionize health in deprived regions through support from technology, neighbourhood participation, and administration. Remote areas have scientific advances within reach through coordinated community outreach, government subsidies, and telemedicine; however, respect for tradition is crucial to connecting with people.

Utilizing Mobile Health Camps and Clinics

Mobile health camps and clinics can improve tribal healthcare with mobility and allow remote tribes access to basic and sophisticated medical examinations by qualified medical staff using portable equipment. Besides providing curative care, these mobile units can increase health education, vaccination access, and sickness screenings to underserved populations(Chakravorti, 2018).

Digital Health Records and Data Analytics

Collecting and administrating tribal patient healthcare data is crucial to serve these communities better. Digital health records streamline the management of tribal medical histories, allowing quicker access for providers and more comprehensive tracking of illnesses and treatment outcomes. Data analytics can reveal tribal health patterns and outbreaks, informing resource allocation and interventions. This systematic approach improves care and informs culturally appropriate local policies and services(Mishra et al., 2015).

Community Participation and Traditional Health Practices

Incorporating community participation into healthcare initiatives ensures that the solutions are culturally sensitive and community-approved, leading to higher acceptance and effectiveness. Engaging tribal communities in the planning and implementing health projects allows for a better understanding of their specific needs and cultural nuances. Additionally, integrating traditional health practices with modern medical science can provide a holistic approach to healthcare in tribal regions. Recognizing and validating traditional medicine within the framework of healthcare services can foster trust and encourage more tribal individuals to seek medical care when needed.

Training and Capacity Building

Involving the community in developing and implementing tribal healthcare projects makes them more culturally fitting. When members of indigenous people get involved in developing medical projects, everyone learns about needs and traditions. A combination of both Western and traditional medicine can help there. The trust of Indigenous people in the public medical system dictates that they should put themselves in care anyway(George et al., 2020).

Policy Support and Infrastructure Development

To implement science- and technology-based healthcare innovations effectively in tribal regions, supportive policies and infrastructure are crucial. Both governmental and non-governmental organizations are key players in crafting policies that promote technology in healthcare delivery and in funding infrastructure projects that facilitate these initiatives. Investments in telecommunication infrastructure, power supply, and transportation networks are vital for the success of technology-driven healthcare solutions in remote tribal areas.

Empowering Educational Technology:

In tribal regions of India, limited access to quality education poses a significant challenge due to inadequate infrastructure and trained teachers. Science and technology-based innovations like digital learning platforms and virtual classrooms offer promising solutions to address these barriers, providing interactive educational resources and overcoming geographical constraints to empower tribal communities with improved learning opportunities (Sai, 2023)

Integration of Local Culture and Traditional Knowledge

Incorporating local tribal culture, traditions, and traditional knowledge into the curriculum can help make education more relevant and engaging for tribal children. This approach preserves and promotes indigenous knowledge and encourages a sense of identity and pride among tribal students.

Vocational and skill based virtual development programs

By incorporating online platforms for skill development and vocational training, tribal children can have access to a variety of training packages that are catered to their particular needs and interests.

Community Engagement

Engaging the tribal community members in the educational process can enhance the effectiveness and relevance of education. Incorporating their perspectives, knowledge, and skills can help create a more inclusive and community-centered educational environment.

Telemedicine

Utilizing telecommunication technology to provide healthcare services remotely in tribal regions. This can include virtual doctor consultations, remote monitoring of patients, and telemedicine-based training programs for healthcare providers in tribal areas(Boro & Saikia, 2020).

Mobile Health (mHealth)

Utilizing mobile devices such as smartphones to deliver healthcare services, health education, and health promotion programs in tribal regions. These programs can include mobile applications for health monitoring, appointment scheduling, and access to medical information.

Integration of Traditional Medicine

Incorporating traditional healing practices and traditional medicine into the healthcare system can provide a holistic approach to healthcare in tribal regions. This can involve training traditional healers and integrating their knowledge with modern healthcare practices(Kumar &Jain, 2023).

Incorporating Community Health Workers

Training and empowering local community members as community health workers can help bridge the gap between healthcare providers and the tribal population and improve access to healthcare services.

Public-Private Partnerships

Collaborating with private organizations and corporations can help bring in resources, expertise, and funding to support innovative approaches to education and healthcare in tribal regions.

Enhancing Healthcare Delivery in Tribal Areas via Technological Interventions

Digital tools and technology advancements offer enhanced healthcare delivery in tribal areas, where traditional barriers such as geographical isolation, limited resources, and cultural differences often hinder access to quality healthcare. The following tactical measures have the potential to provide in various areas significantly:

Mobile Health Units Equipped with Telehealth Capabilities

Mobile health units equipped with state-of-the-art telehealth technologies can bring healthcare services directly to remote tribal communities. These units can serve as moving clinics, offering primary healthcare services and enabling virtual consultations with specialists. This approach can dramatically reduce the travel time and expenses for tribal people seeking medical care, making healthcare more accessible to everyone(Kumar. V., & Jain. S., 2023).

AI-Powered Diagnostic Tools

Artificial intelligence can play a pivotal role in diagnosing diseases efficiently in areas where medical professionals are scarce. AI-powered diagnostic tools can analyze symptoms, medical images, and test results quickly, providing preliminary diagnoses that help healthcare workers in decision-making and treatment planning(“Artificial Intelligence-Powered Diagnostic Tools, Networked Medical Devices, and Cyber-Physical Healthcare Systems in Assessing and Treating Patients with COVID-19 Symptoms,” 2021). This can be particularly beneficial for identifying and managing chronic diseases and conditions that require specialized knowledge.

Wearable Health Monitoring Devices

Wearable technology can be used to monitor the health conditions of individuals in tribal areas continuously. These devices can track vital signs, physical activity, and other health metrics,

transmitting the data to healthcare providers for monitoring and analysis. This ongoing health data collection can help detect potential health issues early, prevent complications, and enable timely interventions(Pozdin & Dieffenderfer, 2022).

Digital Platforms for Health Education

Creating digital platforms tailored to the languages and cultures of tribal communities can provide vital health education and promote healthy lifestyles. These platforms can host videos, interactive modules, and other engaging content on nutrition, hygiene, and disease prevention topics. By making this information accessible and understandable, it is possible to foster a culture of health awareness and empowerment among tribal populations.

Enhance Supply Chain in Pharmaceutical Delivery

Implementing blockchain technology in the pharmaceutical supply chain can ensure the integrity and transparency of drug delivery to tribal areas. This technology can help track the distribution of medications, verify their authenticity, and reduce the incidence of counterfeit drugs. By ensuring that tribal communities receive genuine medications, the overall effectiveness of healthcare delivery can be improved(Elarbi et al., 2021).

Successful Case Studies: Science & Technology Initiatives in Tribal Areas

Eklavya Model Residential Schools

The Eklavya Model Residential Schools initiative is a successful example of promoting science and technology education in tribal areas of India. These residential schools aim to provide quality and promote STEM education for tribal students. They offer specialized science and technology programs, well-equipped laboratories, and highly trained teachers to ensure a holistic learning experience. Evaluation studies have shown that students from Eklavya Model Residential Schools have demonstrated significant improvements in academic performance, critical thinking skills, and scientific knowledge(Jain, 2020).

Initiative: DICE Program

The DICE program has emphasized Science & Technology as another vital intervention in the tribal regions to enhance education. Focusing on bridging the digital divide, the program has been instrumental in providing digital literacy and educational resources through technology. The program has seen the establishment of digital libraries, the provision of tablet PCs to students & teachers, and online and Wi-Fi-enabled study centers in remote and complex areas. The program has largely improved the learning outcomes and the digital literacy rate among the tribal population, providing better access to learning content and resources(Dhianawaty et al., 2023).

Solar Microgrids in Odisha's

In partnership with local NGOs and government agencies, solar microgrids were installed in several tribal villages in Odisha. These microgrids provided reliable electricity for lighting,

household appliances, and small-scale enterprises. There have been improvements in living standards, enhanced educational opportunities through extended study hours, increased economic activities, and reduced dependency on kerosene lamps and diesel generators(Tayade et al., 2015).

Digital Literacy and Internet Access in Madhya Pradesh

An initiative to provide digital literacy training and Internet access in remote tribal villages of Madhya Pradesh. Community centers were created, each with a PeoplePC – a general-purpose computer powered by a solar power system and connected with 4G LTE Internet. The community centers empower tribal residents to access digital literacy training, online educational resources, and government services, support local artisans and farmers in accessing e-commerce for their crafts produce and organic farm produce, and foster communication and information sharing within the community(Yadav, 2021).

Biogas Plants in Chhattisgarh

Implementation of biogas plants in tribal households of Chhattisgarh using locally available organic waste materials. These plants provided clean cooking fuel, reduced indoor air pollution, and generated organic fertilizer for agriculture. The initiative has improved health outcomes by mitigating respiratory illnesses, minimizing deforestation, thereby alleviating pressure on natural resources for fuelwood, enhancing agricultural productivity through adopting organic farming practices, and facilitating additional income generation through the sale of surplus biogas and fertilizer(Einfalt & Kazda, 2016).

Telemedicine Services in Jharkhand

As per the “Strengthening eSanjeevani Telemedicine Services in Jharkhand" from Intelehealth, the introduction of telemedicine services in remote tribal health centers of Jharkhand will address the shortage of healthcare professionals and specialist doctors. Telemedicine kiosks with video conferencing facilities allowed patients to consult with doctors in urban hospitals. The expansion of healthcare service accessibility accelerated diagnosis and treatment of illnesses, mitigation of travel duration and expenses for patients, enhancement of maternal and child health outcomes, and elevation of the general quality of healthcare delivery in tribal areas.

Rainwater Harvesting and Water Management in Rajasthan

Implement rainwater harvesting and water management projects in tribal regions of Rajasthan to address water scarcity and improve agricultural productivity. Techniques like rooftop rainwater harvesting, check dams, and watershed management were employed. The increased availability of water for drinking and irrigation purposes, the reduction in dependency on erratic rainfall patterns, the improvement in crop yields and agricultural incomes, the rejuvenation of groundwater resources, and the enhancement of resilience to droughts and climate change are notable outcomes(Singh et al., 2013).

Skill Development and Entrepreneurship in Maharashtra

As per Government of Maharashtra, India in their about skill development section mentioned that training programs in skill development and entrepreneurship for tribal youth in Maharashtra enable economic self-reliance and employment generation. Training modules included tailoring, carpentry, agriculture, and digital marketing, among other trades. Empowerment of tribal youth with marketable skills and entrepreneurial knowledge has resulted in increased employment opportunities, promotion of self-employment ventures and the establishment of small-scale enterprises, by which migration to urban areas in search of livelihood has been reduced and tribal communities' socio-economically empowered.

Future Directions in Tribal Education and Healthcare Policies

Integrating science and technology in tribal education and healthcare policies is crucial for the long-term development and empowerment of tribal communities in India. This integration should involve several key aspects:

Infrastructure Development

Infrastructure development is crucial for leveraging science and technology in tribal regions. Providing reliable internet, computer labs, digital learning centers, computers, tablets, and mobile devices allows tribal communities access to educational and healthcare resources.

Capacity Building and Training

Capacity building and training programs are vital for integrating science and technology effectively into tribal education and healthcare. Promoting digital literacy, technological proficiency, and using technology for learning and wellness is key. Collaborations between government, educators, healthcare workers, non-profits, and local groups enable sharing resources and expertise and adopting best practices to maximize the impact of interventions in tribal communities.

Digital Content Creation and Localization

Digital content creation and localization can revolutionize education and healthcare in tribal regions by providing culturally relevant resources. Tailoring content to local languages and customs ensures better engagement and understanding among tribal communities. This approach facilitates access to vital information, bridging gaps and improving education and healthcare services outcomes (Panda & Subudhi, 2020).

Sustainability and Scalability

Focusing on sustainability and scalability ensures long-term benefits and widespread impact. Strategies include developing partnerships with local leadership and organizations, empowering community members, and integrating initiatives into existing systems and structures.

Policy Support and Funding

Strong policy support and adequate funding are essential to strengthen education and healthcare through science and technology in tribal regions. Policies facilitating collaboration, digital content creation guidelines, resource allocation for monitoring, and sustainability prioritization are crucial(Soni, 2017). Research emphasizes innovative approaches like online learning and telemedicine to overcome barriers and improve service access. Addressing the unique challenges of tribal communities is vital for successful implementation.

Conclusion

To summarise, harnessing community-based digital solutions driven by developments in science and technology can serve as a critical next step in facilitating equitable education and healthcare access for indigenous people. Even if there are still issues with sustainability and infrastructure, digital technology have the ability to drastically alter society.

To ensure their scalable and sustained impact, it is vital to move forward with developing alliances, supportive policies, and integration methods.

It will also be crucial to evaluate and modify these projects in an iterative manner as they start and grow. The potential and future it can enable—empowered tribal communities, equal access to healthcare and education—are too great to ignore, despite the journey's inevitable difficulty. Focusing this work on innovation originating from tribal contexts is both possible and necessary in order to achieve a more fair end and future for everybody.

References:

Artificial Intelligence-Powered Diagnostic Tools, Networked Medical Devices, and Cyber-Physical Healthcare Systems in Assessing and Treating Patients with COVID-19 Symptoms. (2021). American Journal of Medical Research, 8(2), 91. https://doi.org/10.22381/AJMR8220217

Boro, B., & Saikia, N. (2020). A qualitative study of the barriers to utilizing healthcare services among the tribal population in Assam. PLOS ONE, 15(10), e0240096. https://doi.org/10.1371/JOURNAL.PONE.0240096

Chakravorti, B. (2018). Patient-centric healthcare industry: Pharmaceutical companies can do more to put patients first. Primary Health Care: Open Access, 08. https://doi.org/10.4172/2167-1079-C4-026

Dhianawaty, D., Dwiwina, R. G., &Achadiyani. (2023). Efforts and Support of Digital Literacy Program Development by Student Real Work Lecture Program to Improve the Quality of Human Resources of Digital Technology Use. Innovare Journal of Education, 8–10. https://doi.org/10.22159/IJOE.2023V11I5.48562

Donath, L., Mircea, G., & Rozman, T. (2020). E-Learning Platforms as Leverage for Education for Sustainable Development. European Journal of Sustainable Development, 9(2), 1–1. https://doi.org/10.14207/EJSD.2020.V9N2P1

Einfalt, D., & Kazda, M. (2016). Characterisation of biogas plants on organic farms and potentials for improvement. Organic Agriculture, 6(4), 243–254. https://doi.org/10.1007/S13165-015-0133-3/METRICS

Elarbi, M., Ayadi, O., Masmoudi, M., & Masmoudi, F. (2021). Drug-inventory-management-model for a multi-echelon pharmaceutical supply-chain: case study of the Tunisian pharmaceutical supply-chain. Supply Chain Forum: An International Journal, 22(1), 44–56. https://doi.org/10.1080/16258312.2020.1824532

George, M. S., Davey, R., Mohanty, I., & Upton, P. (2020). "everything is provided free, but they are still hesitant to access healthcare services": Why does the indigenous community in Attapadi, Kerala continue to experience poor access to healthcare? International Journal for Equity in Health, 19(1), 1–15. https://doi.org/10.1186/S12939-020-01216-1/TABLES/6

Jain, S. (2020). Vocational Interest of Tribal Adolescents of Eklavya ModelResidential Schools of Madhya Pradesh Boys and Girls. JOURNAL OF TEACHER EDUCATION AND RESEARCH, 15(02), 11–14. https://doi.org/10.36268/JTER/15204

Kumar, V., & Jain, S. (2023). Landscape Analysis of Traditional Tribal Healers and Their Healing Practices in the Tribal-dominated States of India. IJFMR - International Journal For Multidisciplinary Research, 5(5). https://doi.org/10.36948/IJFMR.2023.V05I05.7284

Malhotra, S., Anil, K., & Kaur, A. (2023). Impact of Social Entrepreneurship on Digital Technology and Students' Skill Set in Higher Education Institutions: A Structured Equation Model. *Int. J. Exp. Res. Rev.*, 35, 54-61. https://doi.org/10.52756/ijerr.2023.v35spl.006

Mishra, S., Kusuma, Y. S., & Babu, B. V. (2014). Migration and health-care access: Barriers to access government health services by migrant tribal community living in an eastern Indian city. International Journal of Medical Science and Public Health 4(1), 101-108.

Mittal, P., & Jora, R. (2023). Exploring student community engagement in higher education: A bibliometric analysis on the path to sustainable development. *Int. J. Exp. Res. Rev.*, *32*, 166-177. https://doi.org/10.52756/ijerr.2023.v32.014

Nagarajan, R., Velmanirajan, K., & Kanna, K. S. (2013). Integrating Digital Technologies in Teaching Learning Process. I-Manager's Journal of Educational Technology, 10(3), 1–5. https://doi.org/10.26634/JET.10.3.2499

Panda, P. K., & Subudhi, C. (2020). Pattern and Determinants of Maternal and Child Healthcare Services Among Tribals: With a Special Reference to Tribal Regions of Odisha. Https://Doi.Org/10.1177/2455133320935536, 5(2), 167–183. https://doi.org/10.1177/2455133320935536

Patel, S. P. (2021). Medical pluralism: Health care system among the indigenous tribal communities (with special reference to mirdha tribe of rural Western Odisha). Asian Man

(The) - An International Journal, 15(2), 184–196. https://doi.org/10.5958/0975-6884.2021.00020.7

Pozdin, V. A., & Dieffenderfer, J. (2022). Towards Wearable Health Monitoring Devices. Biosensors 2022, Vol. 12, Page 322, 12(5), 322. https://doi.org/10.3390/BIOS12050322

Sai V.R.N.(2023). Education for Tribal Communities in India: Challenges and Solutions. Medium Partner Program: Content writing on Sept. 6th.

Singh, G., Mishra, D., Singh, K., & Parmar, R. (2013). Effects of rainwater harvesting on plant growth, soil water dynamics and herbaceous biomass during rehabilitation of degraded hills in Rajasthan, India. Forest Ecology and Management, 310, 612–622. https://doi.org/10.1016/J.FORECO.2013.09.002

Soni, A. (2017). Tribal Needs and Expectations: National Policy for Education. Indian Journal of Research in Anthropology, 3(2), 115–119. https://doi.org/10.21088/IJRA.2454.9118.3217.7

Srivastava, G., Maity, A., & Srivastava, M. (2016). Spatial Analysis of Female Literacy in Religious Minorities of Uttar Pradesh, India. *Int. J. Exp. Res. Rev.*, 8, 39-45.

Tayade, M. G., Thombre, R. E., & Dutt, S. (2015). Performance Evaluation of Solar Parabolic Trough. International Journal of Scientific and Research Publications, 5(1), 1–5. www.ijsrp.org

Yadav, P. P. (2021). Smart Classroom: Need of the hour for Madhya Pradesh Government Schools. Research Ambition an International Multidisciplinary E-Journal, 5(IV), 01–05. https://doi.org/10.53724/ambition/v5n4.02

HOW TO CITE

Sukanta Chandra Nath, Rahul Dev Choudhury, Debraj Nath (2024). Innovative Approaches to Enhance Education and Healthcare in Tribal Regions through Science & Technology © International Academic Publishing House (IAPH), Dr. Suman Adhikari, Dr. Manik Bhattacharya and Dr. Ankan Sinha, *A Basic Handbook of Science, Technology and Innovation for Inclusive Development [Volume: 1]*, pp. 144-154. ISBN: 978-81-969828-4-3 DOI: https://doi.org/10.52756/ bhstiid.2024.e01.011

OPEN ACCESS PEER REVIEW
DOI:https://doi.org/10.52756/ bhstiid.2024.e01.012
Chapter- 12

The Evolution of Tribal Communities in Post Independence India

Debajyoti Gupta

Keywords: Evolution, Tribal Communities, Tribal Sub-Plan (TSP), Tribal Development.

Abstract:

Since its independence, India has actively focused on addressing the challenges faced by its scheduled tribes, making significant strides towards their resolution. Unlike the British colonial regime, which largely limited its interaction with these communities to discussion without action, often isolating tribal peoples to keep them apart from 'civilized' society under the guise of protection through indirect governance, post-independence India has taken a markedly different approach. The British period is noted for keeping tribal communities segregated from the broader societal developments, effectively sidelining them from the nation's evolving narrative.

In contrast, the period following independence has seen a concerted effort by both the Central and State Governments to enhance the socio-economic status of tribal populations and to ensure the preservation of their constitutional rights. This has been part of a broader policy aimed at integrating tribal communities into the national mainstream, fostering a harmonious adjustment between tribal and non-tribal populations. Such a policy of integration, or progressive acculturation, seeks not only to safeguard tribal interests and heritage but also to involve these communities actively in the national development process. The government's initiatives in this direction have laid a solid foundation for the tribes' seamless progression towards a future marked by inclusive growth and equal opportunity.

Introduction:

India is a vibrant tapestry of cultures, with a remarkable diversity that includes 573 scheduled tribes scattered across its vast landscape (Rao & Ramu, 2014). These communities, each with its unique identity, communicate in over 270 languages, highlighting the country's rich multicultural heritage (Sindhi, 2012). Recognizing the importance of safeguarding and promoting the welfare of these tribal populations, the Indian Constitution mandates the government to take active steps towards their development (Sethi et al., 2019). Key constitutional provisions, such as Article 275, prioritize financial assistance for the upliftment of tribal areas, while Article 244 and the Fifth Schedule outline the governance of Scheduled and Tribal Areas (Sengupta, 2018).

In a concerted effort to promote the welfare and development of tribal communities across India, the government has instituted the Tribal Sub-Plan (TSP) as a mechanism of Special Central Assistance (Nayak et al., 2020). This initiative is a cornerstone of India's approach to addressing the unique needs and challenges faced by its tribal populations, aiming to elevate

Debajyoti Gupta*
Research Scholar, Department of Philosophy, Tripura University
E-mail: debajyoti111.gupta@gmail.com; OrcidiD: https://orcid.org/0009-0002-2726-5992
***Corresponding Author**: debajyoti.philosophy@tripura.univ.ac.in

Dr. Suman Adhikari, Dr. Manik Bhattacharya and Dr. Ankan Sinha, A Basic Handbook of Science, Technology and Innovation for Inclusive Development [Volume: 1]. ISBN: 978-81-969828-4-3; pp- 155-166; Published online: 27th May, 2024

their socio-economic status through targeted financial support. The TSP is designed to funnel resources directly into projects that have a tangible impact on the lives of tribal families, encouraging self-sufficiency and sustainable growth within these communities (Dilip, 2016).

The scope of funding under the TSP is extensive, covering a wide array of sectors that are crucial for the holistic development of tribal areas. This includes investments in agriculture and horticulture, which empower tribal families to leverage their traditional knowledge and resources for commercial farming practices (Dungdung& Pattanaik, 2020). Similarly, support for minor irrigation and soil conservation projects ensures the sustainable use of natural resources, vital for the long-term viability of tribal agriculture. In the realm of animal husbandry and forestry, the emphasis is on promoting practices that align with the environmental and cultural ethos of tribal communities, while also opening up new avenues for income generation (Rowkith& Bhagwan, 2020).

The TSP also underscores the importance of education, cooperatives, and the fisheries sector as pillars of community development, enabling tribal populations to diversify their skills and economic activities. Support for village and small-scale industries underlines the government's commitment to nurturing entrepreneurship and local craftsmanship, providing tribal communities with the means to flourish in a modern economy while preserving their heritage (Chowdhury et al., 2022).

Moreover, the inclusion of basic needs programs within the TSP framework ensures that the fundamental requirements of tribal populations, such as access to clean water, healthcare, and sanitation, are met (Kujur et al., 2021). This comprehensive approach not only addresses immediate economic needs but also lays the foundation for sustained improvement in the quality of life for these communities.

The dual strategy for tribal development, which combines protective measures with developmental initiatives, represents a balanced approach to integrating India's tribal populations into the national development agenda. Legal and administrative safeguards are in place to protect tribal lands, cultures, and rights, preventing exploitation and disenfranchisement. Concurrently, planned development schemes under the TSP aim to empower tribal communities through education, infrastructure development, and economic opportunities (Rashmi & Paul, 2022).

This multifaceted strategy is reflective of a broader vision for India's development, one that values diversity and seeks to ensure that progress is inclusive and equitable. By acknowledging the unique contributions of tribal communities to India's cultural mosaic and economic fabric, the government aims to foster a sense of unity and shared destiny, ensuring that the nation's growth benefits all its citizens, regardless of their geographic or cultural origins(Chouhan, 2022; Yadav, 2021).

Methodology:

The methodology section of a research study provides a detailed account of how the research was conducted, including the data collection methods and sources. For a study focusing on the upliftment of the tribal population in India post-independence, the utilization of secondary

sources plays a pivotal role. Below is a detailed description of the methodology employed in this study:

Research Design

The study adopts a descriptive research design, leveraging secondary data to analyze the socio-economic development of India's tribal population post-independence. This approach allows for a comprehensive examination of governmental policies, the influence of colonial legacies, the contributions of non-governmental organizations (NGOs), and advancements in health and education sectors affecting tribal communities.

Data Collection

Secondary data collection is the primary method used in this research, drawing on a variety of sources to ensure a broad and nuanced understanding of the subject matter. The following sources were meticulously selected and analyzed:

Books

Academic books and historical texts provided in-depth insights into the historical context of tribal communities in India, governmental policies over the years, and the evolution of tribal rights and welfare measures. Books written by subject matter experts offered theoretical frameworks and historical narratives essential for understanding the complexities of tribal development.

Websites

Official websites of government departments, such as the Ministry of Tribal Affairs, were crucial for accessing up-to-date policy documents, reports, and statistical data related to tribal welfare programs. Additionally, websites of international organizations and research institutes offered comparative analyses and global perspectives on indigenous and tribal welfare strategies.

Articles

Peer-reviewed journal articles served as a primary source for current research findings, scholarly debates, and case studies focusing on tribal development. Articles from reputed journals in the fields of sociology, anthropology, and development studies provided empirical data, theoretical analyses, and critiques of existing policies and programs.

Reports and Publications

Reports from NGOs, voluntary organizations, and international bodies like the United Nations were instrumental in gathering data on ground-level initiatives, success stories, and challenges in implementing development projects. These reports also offered insights into the health and education status of tribal populations, highlighting areas of progress and concern.

Data Analysis

The collected data underwent a thematic analysis to identify recurrent themes and patterns relevant to the study's objectives. This involved categorizing the data according to key topics such as policy initiatives, the role of British colonialism, NGO contributions, and advancements in health and education sectors. The analysis aimed to trace the trajectory of tribal development post-independence, evaluate the effectiveness of various interventions, and understand the socio-political dynamics influencing tribal welfare.

Ethical Considerations

Given the study's reliance on secondary sources, ethical considerations primarily revolved around ensuring the credibility and reliability of the sources used. This entailed a critical evaluation of the authors, publication venues, and the data's relevance and accuracy. Additionally, proper citation and acknowledgment of all sources were maintained to uphold academic integrity and respect intellectual property rights.

Through this detailed methodology, the study endeavours to provide a comprehensive analysis of the upliftment of India's tribal population post-independence, highlighting the multifaceted efforts of the government, NGOs, and other stakeholders in promoting tribal welfare and development.

Role of the Government:

The Government of India's approach to tribal welfare and development is anchored in a vision of integration, aiming to weave the country's tribal populations into the national fabric without eroding their distinctive cultural identities (harishankarBanothu, 2016). This policy, often referred to as progressive acculturation, seeks to foster a harmonious blend of tradition and modernity, enabling tribal communities to enjoy the benefits of economic and social progress while preserving their unique ways of life (Mosse et al., 2002). The ultimate goal is to create a responsible partnership between tribal and non-tribal citizens, characterized by mutual respect and shared values.

Foundations of the Integration Policy

The policy of integration is not about assimilation, where tribal cultures would be absorbed into a dominant culture, losing their distinctiveness. Instead, it is about creating spaces within the national mainstream that respect and nurture tribal identities, ensuring that tribal communities can thrive on an equal footing with the rest of the country(Mondal, 2020). This approach is predicated on the belief that India's diversity is a strength and that the full participation of tribal communities in national life enriches the entire country(Kumar_Behera, 1991).

Constitutional Commitments

India's constitution lays down a dual mandate that forms the bedrock of the government's tribal policy:

1. Protection of Distinctive Ways of Life: The constitution recognizes the importance of protecting the unique cultures, languages, and traditions of India's tribal communities. This includes safeguarding their lands, forests, and resources, which are not only vital for their economic sustenance but also for the continuation of their cultural and spiritual practices (Shriraam et al., 2021). By securing these rights, the constitution aims to ensure that tribal communities can continue to live in accordance with their ancestral traditions while adapting to the changes of the 21st century.
2. Protection from Social Injustice and Exploitation: The constitution is unequivocal in its commitment to protect tribal populations from social injustice, exploitation, and discrimination. This entails a range of legal and policy measures designed to prevent the dispossession of tribal lands, protect tribal populations from economic exploitation, and ensure their access to justice (Lal, 2019). Moreover, the constitution seeks to uplift tribal communities by providing them with equal opportunities in education, employment, and political representation, thus enabling their integration into the national mainstream on their own terms.

The government's policy of progressive acculturation involves several strategic interventions:

Economic Development: Initiatives aimed at improving the economic viability of tribal communities through access to land, capital, education, and markets. This includes the promotion of sustainable agriculture, forestry, and other traditional livelihoods, alongside opportunities in the modern economy (Malhotra et al., 2021).

Education and Healthcare: Enhancing access to quality education and healthcare services for tribal communities, with a focus on inclusivity and sensitivity to cultural nuances. This is crucial for building capacities within tribal societies and ensuring their well-being(Bori, 2023).

Political Empowerment: Ensuring representation of tribal communities in political processes and decision-making bodies at various levels, thus giving them a voice in the governance and development of their regions (Priyadarshini & Abhilash, 2019).

Cultural Preservation: Supporting initiatives that preserve and promote tribal languages, arts, crafts, festivals, and rituals, acknowledging these as integral to India's cultural heritage.

By adopting this multifaceted approach, the Government of India aims to ensure that tribal communities do not merely survive but thrive, contributing to and benefiting from the country's development. The integration policy, thus, is a testament to India's commitment to its pluralistic ethos, seeking to build a nation that celebrates diversity and fosters equality and justice for all its citizens, including its most marginalized communities (Arun Sapre & Gori, 2023; Bagavandas, 2021).

Role of NGOs and Voluntary Organisations:

The synergy between governmental efforts and the work of NGOs is underpinned by the understanding that the task of developing Scheduled Tribes cannot be accomplished through government efforts alone. The grassroots connections, dedication, and service orientation of voluntary and non-governmental organizations make them vital partners in this endeavor. They are often better positioned to implement government schemes in tribal areas more efficiently and effectively, thanks to their local insights and flexible operational methodologies. Their ability to connect on a personal level and adapt to the unique needs of different tribal communities enables a more tailored and impactful delivery of services(Singh, 2018).

To support and leverage the potential of voluntary organizations in the realm of tribal development, four key schemes have been designed:

1. Grant-in-aid for Voluntary Organizations Working for Scheduled Tribes: This scheme provides financial support to NGOs working on the welfare of Scheduled Tribes. It includes initiatives such as coaching for tribal students and awards for the special incentive to improve infrastructure. By enhancing educational and infrastructural support, this scheme aims to uplift tribal communities and offer them better opportunities for growth (Negi & Azeez, 2022).
2. Strengthening Education among ST Girls in Low Literacy Districts: Recognizing the double disadvantage faced by tribal girls, this scheme focuses on boosting literacy and educational attainment among them, particularly in districts where literacy rates are alarmingly low (Patra et al., 2021). Through targeted educational programs, scholarships, and support mechanisms, it aims to empower tribal girls with education, paving the way for their socio-economic upliftment.
3. Vocational Training in Tribal Areas: With an emphasis on skill development, this scheme introduces vocational training programs in tribal areas. By equipping tribal youths with marketable skills, it opens up new avenues for employment and entrepreneurship, thus contributing to the economic advancement of tribal communities.
4. Development of Particularly Vulnerable Tribal Groups: Previously known as the scheme for the development of primitive tribal groups, this initiative focuses on the most marginalized segments within tribal societies. By providing comprehensive support in terms of health, education, housing, and livelihood opportunities, it seeks to safeguard these groups from exploitation and enhance their overall well-being (Pradeep Kumar, 2022).

These schemes underscore the multifaceted approach required to address the challenges faced by tribal communities. Through collaborative efforts between the government, NGOs, and voluntary organizations, there is a concerted push towards not just economic development but also the preservation of tribal cultures and identities, ensuring that progress is inclusive and respectful of diversity (Kapoor et al., 2021).

Educational Facilities

The Post-Matric Scholarship Scheme offers financial support to ST students for post-matriculation studies at recognized institutions across India. This program ensures 100% funding from the Ministry to the State Governments and UT Administrations that administer the scheme, in addition to their existing financial commitments. Furthermore, the Ministry extends financial aid for the establishment of Book-Banks in institutions offering professional courses such as Medicine, Engineering, Law, Agriculture, Veterinary Science, Chartered Accountancy, Business Management, and Bio-Sciences (Patil, 2022). Every year, the Ministry selects 9 outstanding ST students to receive financial assistance for pursuing Post-graduate, Doctoral, and Post-Doctoral studies at foreign universities and institutions. Additionally, the merit-upgradation scheme organizes coaching classes at reputed colleges to enhance the competency of ST students, improving their performance in competitive exams for admission to Medical and Engineering courses. The coaching scheme supports Pre-Examination Coaching for tribal students preparing for various examinations conducted by the UPSC, SSC, Banking Services Recruitment Boards, and more(Dr. Basavaraj Bheemaraya, 2022).

Special Pre-Examination Training Centres have been established for ST and SC candidates, preparing them for UPSC exams, including those for the I.A.S and I.P.S.

Initiated during the Third Plan, the Girls' Hostels scheme plays a crucial role in promoting education among ST girls by providing Central assistance to States/UTs for constructing new hostel buildings or extending existing ones.

The Boys' Hostels scheme, which mirrors the objectives, terms, conditions, and assistance pattern of the Girls' Hostels scheme, has been operational since 1989-90 and was integrated with the Girls' Hostels scheme during the Tenth Plan.

Ashrama schools have been established to offer basic education and vocational training to tribal students. These schools provide education and training in fields such as agriculture, forestry, animal husbandry, farming, beekeeping, and handicrafts, among others.

Various Programme for Tribal Development:

The Constitution of India, established in 1950, articulates under Article 343 the recognition of certain races and ethnic groups as distinct national entities. Over the years, this categorization has evolved, though the foundational attributes outlined by the British have endured (Minz, 2020). Central to the vision of India's founding leaders was the imperative to propel the nation towards development, with a keen emphasis on safeguarding the tribal regions from exploitation. In 1958, Prime Minister Jawaharlal Nehru championed the nation's advancement, advocating for the cultivation of indigenous culture over foreign influences, and for the preservation of national rights in rural and forested lands. The fiscal support for these tribal areas was encapsulated within five Indian initiatives, transitioning in their fifth phase from separate national grants to inclusion within standard budgetary allocations(Darmawan, 2019).

Nehru proposed the oversight of amakhosi districts by a dedicated minister, tasked with executing special programs across distinct sectors within these regions. The initial plan concentrated on bolstering education, healthcare, economic development, and the establishment of communication infrastructures. Subsequent plans prioritized economic upliftment through agriculture, small-scale industries, forestry, cooperatives, and specialized development zones. The strategy remained unchanged through the Third Plan, while the Fourth and Fifth Plans introduced Area Development Plans, targeting specific regions for comprehensive development (Vidyarthi, 1972).

Government efforts in social welfare span five primary areas: economic, educational, health and sanitation, housing, and social and political services. At the state level, Special National Development Blocks and Government Economic Development Boards have been established to harmonize national policies with local initiatives, including livestock improvement and small-scale irrigation projects suited to hilly terrains. Support for traditional crafts through grants and loans, as well as initiatives for educational and healthcare expansion, highlight the government's commitment to holistic tribal development (Vandana & Bhattacharya, 2023).

To date, 184 Integrated Tribal Development Projects (ITDP), 277 Modified Area Development Plans (MADA) for tribal regions, along with 73 sub-projects for National Organized Groups, have been initiated, providing financial aid to tribal communities. The Sixth Plan assisted 39.67 lakh tribal families, with the Seventh aiming to support 40 lakh individuals. Literacy rates among Scheduled Tribes have seen a significant rise, from 8.54% in 1961 to 16.35% by 1981. Healthcare expansion is evident in the establishment of 1542 Primary Health Centre’s and 10489 sub-centres in tribal districts.

Technological interventions, such as radio and television broadcasting, have been leveraged to connect and inform tribal districts, with substantial coverage expansions during the Sixth and Seventh Plans. To combat exploitation, the Tribal Cooperative Marketing Development Federation of India (TRIFED) was founded in August 1987, facilitating the sale of forest products by tribal people. Special provisions by the Seventh and Eighth Finance Commissions for forest area improvement, alongside the New Forest Policy of 1988, underscore a shift in perspective towards tribal communities, recognizing them as stewards rather than exploiters of forest resources, and involving them actively in forest conservation and development efforts.
Despite these initiatives, the legacy of division and infrastructural deficits necessitates continued and enhanced efforts to elevate tribal areas to national development standards.

Medical facilities

Various medical facilities have been provided for the tribal’s in the tribal areas. In some places, hospitals are established and in many places mobile hospitals facilities have been provided. Many preventive and curative measures to combat the diseases like malaria, leprosy, forest fever, monkey fever, typhoid, small pox, skin diseases etc are undertaken. Medical camps are organized in the tribal areas to enable the tribal’s to realize the importance of modern medical facilities.

Conclusion

In conclusion, the multifaceted approach adopted by the Indian government to foster the development of tribal areas reflects a deep-seated commitment to inclusive growth and the preservation of indigenous cultures. Through constitutional recognitions, targeted schemes, and the establishment of specialized agencies like TRIFED, India has laid down a robust framework aimed at addressing the unique challenges faced by its tribal populations. The strategic emphasis on education, healthcare, economic empowerment, and the preservation of traditional crafts underscores a holistic approach to uplifting these communities, recognizing their pivotal role in the nation's socio-cultural fabric.

Moreover, the incorporation of technological interventions to bridge informational gaps, alongside legislative reforms such as the New Forest Policy, signifies a progressive shift towards recognizing tribal communities as integral stakeholders in the nation's developmental narrative. The notable improvements in literacy rates and healthcare accessibility in tribal areas highlight the positive impact of these concerted efforts.

However, the journey towards achieving equitable development for tribal areas is ongoing. The historical context of division and infrastructural inadequacies presents a complex challenge that demands continuous, focused, and adaptive strategies. As India moves forward, it is imperative that these initiatives not only continue but are also expanded and refined, ensuring that the tribal communities can fully partake in the benefits of national development, thereby enriching the entire nation with their diverse heritage.

References:

Arun Sapre, A., & Gori, S. (2023). Development-Induced Displacement in India and the Tribal Rights: A Quest for Social Justice. Journal of Asian and African Studies. https://doi.org/10.1177/00219096231168064

Bagavandas, M. (2021). Development of multifactor index for assessing quality of life of a tribal population of India: multilevel analysis approach. BMC Public Health, 21(1). https://doi.org/10.1186/s12889-021-10338-2

Bori, J. P. (2023). (Re) conceptualizing and Contextualizing ‘Community’ in Tribal/Indigenous Cultures and Development in India. International Journal of Community and Social Development, 5(1). https://doi.org/10.1177/25166026221142696

Chouhan, V. (2022). Developing a sustainable tribal tourism model vis-a-vis the tribal region of Rajasthan. Journal of Tourism, Heritage and Services Marketing, 8(1). https://doi.org/10.5281/zenodo.6594696

Chowdhury, A., Roul, S. K., & Mete, J. K. (2022). A Review on Tribal Literature Focus on Tribal Education With Special Reference to Tribal Women. Journal of Higher Education Theory and Practice, 22(4). https://doi.org/10.33423/JHETP.V22I4.5163

Darmawan, D. (2019). Tribal Development In India. Journal of Chemical Information and Modeling, 53(9).

Dilip, M. (2016). Tribal Development Policies in India-An Overview. International Journal of Humanity and Social Sciences, 5(1).

Dr. Basavaraj Bheemaraya. (2022). INDIAN TRIBAL WELFARE SCHEMES AND THEIR IMPLEMENTATION: A STUDY. EPRA International Journal of Economic and Business Review. https://doi.org/10.36713/epra10579

Dungdung, K., & Pattanaik, B. K. (2020). Tribal Development Disparities in Odisha: An Empirical Analysis. South Asia Research, 40(1). https://doi.org/10.1177/0262728019894129

harishankarBanothu. (2016). Tribal Economic Development in India. International Journal of Multidisciplinary Advanced Research Trends, III(3).

Kapoor, N., Ahmad, N., Nayak, S. K., Singh, S. P., Ilavarasan, P. V., & Ramamoorthy, P. (2021). Identifying infrastructural gap areas for smart and sustainable tribal village development: A data science approach from India. International Journal of Information Management Data Insights, 1(2). https://doi.org/10.1016/j.jjimei.2021.100041

Kujur, A., Kumar, D., Kumar, C., Rana, R. K., & Kashyap, V. (2021). Socio-demographic differentials of cognitive development and nutrition among school children: Evidence from the tribal areas of Jharkhand, India. International Journal of Adolescent Medicine and Health, 33(4). https://doi.org/10.1515/ijamh-2018-0219

Kumar_Behera, J. (1991). Policies and programmes for tribal development in India. VanyajatiQJ1 Vanyajati, 59(1).

Lal, B. S. (2019). Tribal Development In India: Some Observation. Journal of Chemical Information and Modeling, 53(9).

Malhotra, A., Nandigama, S., & Bhattacharya, K. S. (2021). Food, fields and forage: A socio-ecological account of cultural transitions among the Gaddis of Himachal Pradesh in India. Heliyon, 7(7). https://doi.org/10.1016/j.heliyon.2021.e07569

Minz, S. K. (2020). Tribal Development Policies in India : Its Implications and Prospects. Mukt Shabd Journal, IX(V).

Mondal, S. (2020). TRIBAL MOVEMENTS IN INDIA: STRUCTURAL AND METHODOLOGICAL APPROACHES. GLOBAL JOURNAL FOR RESEARCH ANALYSIS. https://doi.org/10.36106/gjra/7212570

Mosse, D., Gupta, S., Mehta, M., Shah, V., & Rees, J. (2002). Brokered livelihoods: Debt, labour migration and development in Tribal Western India. Journal of Development Studies, 38(5). https://doi.org/10.1080/00220380412331322511

Nayak, S. R., Kant, N., & Anjali, K. (2020). Strategy of using ICT in ODL to disseminate higher education in tribal communities: a case of MP, India. Asian Association of Open Universities Journal, 15(2). https://doi.org/10.1108/AAOUJ-05-2020-0029

Negi, D. P., & Azeez, E. P. A. (2022). Impacts of Development Induced Displacement on the Tribal Communities of India: An Integrative Review. In Asia-Pacific Social Science Review (Vol. 22, Issue 2).

Patil, R. R. (2022). Tribal Development in India: Challenges and Prospects in Tribal Education. In Tribal Development in India: Challenges and Prospects in Tribal Education. https://doi.org/10.4135/9789354791710

Patra, U., Gayak, J., Karim, S., Halder, S., Sen, A., & Paul, G. (2021). A COMPARATIVE STUDY OF TRIBAL EDUCATION DEVELOPMENT IN INDIA: WITH SPECIAL REFERENCES TO PURULIA DISTRICT, WEST BENGAL. Journal of Critical Reviews, 8.

Pradeep Kumar, B. (2022). Revisiting Major Approaches to Tribal Development in India: A Brief Review of Isolationist, Integrationist and Assimilative Approaches. Contemporary Voice of Dalit. https://doi.org/10.1177/2455328X221122600

Priyadarshini, P., & Abhilash, P. C. (2019). Promoting tribal communities and indigenous knowledge as potential solutions for the sustainable development of India. In Environmental Development (Vol. 32). https://doi.org/10.1016/j.envdev.2019.100459

Rao, M. S., & Ramu, P. (2014). An Overview of the Tribal Development Policy of India. International Journal of Academic Research ,1(1).

Rashmi, R., & Paul, R. (2022). Early childhood circumstances and educational wellbeing inequality among tribal and non-tribal children in India: evidence from a panel study. Scientific Reports, 12(1). https://doi.org/10.1038/s41598-022-13889-5

Rowkith, S., & Bhagwan, R. (2020). Honoring tribal spirituality in India: An exploratory study of their beliefs, rituals and healing practices. Religions, 11(11). https://doi.org/10.3390/rel11110549

Sengupta, M. (2018). Gender, tribe and development: a case study of the Reang tribal community in Tripura (Northeast India). Asian Ethnicity, 19(1). https://doi.org/10.1080/14631369.2017.1301777

Sethi, V., Bhattacharjee, S., Sinha, S., Daniel, A., Lumba, A., Sharma, D., & Bhanot, A. (2019). Delivering essential nutrition: Interventions for women in tribal pockets of eastern India. Economic and Political Weekly, 54(4).

Shriraam, V., Mahadevan, S., & Arumugam, P. (2021). Prevalence and risk factors of diabetes, hypertension and other non-communicable diseases in a tribal population in South India. Indian Journal of Endocrinology and Metabolism, 25(4). https://doi.org/10.4103/ijem.ijem_298_21

Sindhi, Ms. S. (2012). Prospects and Challenges in Empowerment of Tribal Women. IOSR Journal of Humanities and Social Science, 6(1). https://doi.org/10.9790/0837-0614654

Singh, R. (2018). “TRIBAL AREA DEVELOPMENT PROGRAMMES IN INDIA: ISSUES AND CHALLENGES.” Journal Homepage: International Journal of Research in Social Sciences, 8.

Vandana, & Bhattacharya, R. (2023). Contested food, conflicting policies: health and development in tribal communities in India. Third World Quarterly, 44(1). https://doi.org/10.1080/01436597.2022.2141222

Vidyarthi, L. P. (1972). Problems and Prospects of Tribal Development in India. Indian Anthropologist, 2(2).

Viswanadha Gupta, P. (2018). Tribal Development in India-Status and Strategies. International Journal of African and Asian Studies Www.Iiste.Org ISSN, 48(March 2018).

Yadav, K. K. (2021). Rajakishor Mahana, Negotiating Marginality: Conflicts Over Tribal Development in India. Journal of the Anthropological Survey of India, 70(1). https://doi.org/10.1177/2277436x20970293

HOW TO CITE

Debajyoti Gupta (2024). The Evolution of Tribal Communities in Post Independence India© International Academic Publishing House (IAPH), Dr. Suman Adhikari, Dr. Manik Bhattacharya and Dr. Ankan Sinha, *A Basic Handbook of Science, Technology and Innovation for Inclusive Development [Volume: 1]*,pp. 155-166. ISBN: 978-81-969828-4-3 DOI:https://doi.org/10.52756/ bhstiid.2024.e01.012